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Évaluation des stocks canadien
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Proceedings of the Workshop on Cod Stock Components
March 3-5, 1997
St. John's Newfoundland

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Fisheries and Oceans
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INTRODUCTION

Atlantic cod (*Gadus morhua*) are widespread on both the eastern and western sides of the North Atlantic. In the Northwest Atlantic, specific cod stock boundaries were adopted by ICNAF in 1953 (ICNAF, 1953). Since that time assessment and management of Canadian cod stocks has been conducted within that framework of stock structure. Recent concerns over causes of the depressed state of many of these stocks, and the corresponding need for effective rebuilding and subsequent sustainable management programs, has given new importance to an accurate understanding of the relationships among cod stock components. From March 3-5, DFO sponsored a workshop in St. John's, Newfoundland.

The objectives of the Workshop were to :

1. Evaluate our ability to distinguish cod stock components, particularly between nearshore and offshore areas, using historic knowledge and current scientific data and techniques.
2. To the fullest extent possible, evaluate the hypotheses that there are separate "bay" or "fjord" stock components of Atlantic cod, as well migratory stock components which spawn offshore.
3. Evaluate the implications of the existence of inshore and offshore stock components for assessment and management of Atlantic cod stocks.
4. Identify areas of research which would advance our ability to achieve Objectives 1-3.

There has been a long debate about the possible existence of resident inshore, or "bay", stocks, the affinities of possible inshore and known offshore spawning components, and the relationships among different major stock components (reviewed in Pinhorn and Halliday, 1996). Until the early 1990s, the weight of evidence and requirements of management continued to support the use of the ICNAF stock delineations, treating inshore and offshore components together (Lear *et al.,* 1986; Pinhorn and Halliday, 1996).

With the collapse of numerous Northwest Atlantic groundfish stocks in the early 1990s, many cod fisheries were placed under moratoria. Despite these moratoria, rebuilding of offshore cod spawning components has been slow on the Newfoundland Shelf, Gulf of St. Lawrence, and northeastern Scotian Shelf (CSAS, 1996). Offshore cod remain scarce, and individuals tend to be small at age and in below average condition (CSAS, 1996). However, there are numerous anecdotal reports and some systematic observations of large aggregations of cod in inshore bays at some times and places along coastal Newfoundland and the Gulf of St. Lawrence (FRCC, 1996). Also, research and fisheries samples suggest the stock affinities of cod in some areas, particularly Cabot Strait and the south-eastern Gulf of St. Lawrence, may no longer be consistent with the stock structure used in present assessments and management approaches (DFO Science - Campana ed.).

The severely depressed state of at least the offshore stock components add new importance to the questions about the relationships among stock components. Clarifying the relationships among cod stock components in Atlantic Canada is fundamental to sound and scientific assessment and management of cod, and conservation of biodiversity. Accurate assessment of the status of cod in Atlantic Canada, and sustainable management of fisheries on any stock components, requires not just an evaluation of the abundance of cod in the inshore and offshore areas, but an understanding of how each stock component may contribute to rebuilding.

The Workshop on Inshore - Offshore Cod Stock Components was called to review all evidence available on the affinities of cod stock components in Atlantic Canada. The Workshop was mandated to consider what stock structures are most consistent with the body of evidence, and implications of the possible interpretations of stock structure for assessment and management of cod. International experts from Iceland and Norway were invited to join Canadian scientists from Government and academia, experienced fishers, and members of the Fisheries Resource Conservation Council, to conduct the review and discussions.

PRESENTATIONS

Papers or oral reports were presented on a variety of topics, including tagging studies, meristics and morphometrics, life history characteristics, parasite burdens, fishers' knowledge and historical catch records, trawl surveys, hydroacoustic surveys, fisheries statistics, sentinel surveys and food fisheries, pre-recruit surveys, oceanographic information, biochemical and genetics studies, and multi-component studies in restricted areas. Dr. Tore Jakobson also provided a major integrated overview of inshore and offshore cod stock relationships, biology, and fisheries in Norway. All presentations made at the Workshop are found in Table 1, followed by brief summaries of the major points covered by each set of presentations. Full summaries of each presentation are included in the Annex to this report.

Table 1. Presentations made at the Cod Components Workshop
(* denotes no abstract appended)

Type of Information	Stock / Area	Authors	Title
Tagging	2J3KL & 3Ps	J. Brattey	Inshore/offshore cod stock components in Divisions 2J-3KL: the evidence from tagging studies
	2J3KL	R. Myers	Estimation of exploitation rates*
	3Pn4Rs	D. Gascon	Homing in Cod (*Gadus morhua* L.): Tagging in the Gulf of St.

			Lawrence 1983-1996
	3Pn4Rs	A. Fréchet	Tagging of 3Pn4RS cod from the sentinel fishery
	4X & 5Z	J.J. Hunt	Results of cod tagging in the 4X/5Z
	4VsW	P. Fanning	Research and sentinel program*
Morphometrics	3Pn4RS	A. Fréchet	Condition and feeding of 3Pn4Rs cod stock
	3Pn4Rs	D. Chabot	Condition and feeding of 3Pn4Rs cod stock
	4RSTV	S. Goddard	Diversity in the pattern of antifreeze production in juvenile Atlantic cod
	4X & 5Z	D. Clark	Growth rates*
Parasites	2J3KL & 3Ps	J. Brattey	Some comments on the usefulness of parasites as indicators of cod stock structure
	3KL	C. Taggart	Distribution of gill parasite (*Lernaeocera branchialis*) infection in NW Atlantic cod
Pre-recruit surveys	3KL	D. Schneider J. Anderson E. Dalley R. Gregory D. Methven	Post-moratorium distribution of 0+ demersal juvenile cod *Gadus morhua* east of Newfoundland (3KL)
	2J3KLNO	J. Anderson E. Dalley	Spawning and stock structure of Atlantic cod (*Gadus morhua*) in NAFO Divisions 2J3KLNO inferred from pelagic 0-group surveys
	2J3KL	J. Brattey	Tracking the 1990 year class in the inshore of NAFO Divisions 3K and 3L
	2J3KL	J. Anderson E. Dalley	A brief overview on the distribution of dermersal juvenile northern cod (ages 0-3)
Genetics	2J3KL	T. Beacham	An overview of current genetic methods and prospects for use in inshore-offshore stock differentiation
	General	S. Carr	Contrasting patterns of mitochondrial DNA population genetic structure in Atlantic cod (*Gadus morhua*) from the western and eastern Atlantic and Barrents Sea
	General	C. Taggart D. Ruzzante	Genetic structure of NW Atlantic cod using nuclear DNA

			microsatellites
Surveys and catches rates	3Ps	P. Shelton	Treatment of inshore-offshore data in the 1996 Div. 3Ps cod assessment
	2J3KL	E. Murphy	Fixed gear catches and catch rates
	2J3KL	D. Stansbury	Update of recent RV data for 2J3KL cod
	2J3KL	D. Stansbury P. Shelton G. Stenson	Including harp seal removals in the SPA for 2J3KL cod
	2J3KL	B. Davis	The 1996 sentinel survey for cod in NAFO divisions 2J3KL with comparisons to 1995
	3Pn4RS	A. Fréchet	Case studies from sentinel fishery in the northern Gulf of St. Lawrence (3Pn4Rs)
	4VsW	P. Fanning	Sentinel and research surveys*
	3Pn4RS	M. Castonguay	What can acoustic, trawl, and egg surveys conducted in the northern Gulf of St. Lawrence tell us about cod structure?
	3KL & 3Ps	J.P. Wheeler and D.S. Miller	Distribution of Atlantic cod detected in an acoustic survey of Bonavista Bay - Trinity Bay during the fall of 1996
	3KL	J. Brattey	A hydroacoustic survey of cod in western Trinity Bay during April 1996
User knowledge and historical records	2J3KL	G. Lilly	An overview of pre-1990 analysis and speculation regarding inshore cod in Divisions 2J3KL
	2J3KL	B. Neis D. Schneider	Fishers'ecological knowledge and cod stock components in Trinity and Bonavista Bays
	2J3KL	T. Taylor R. Dumphy	Fishers' knowledge*
Approaches to integrate information	General	G. Evans	Mixing rate modelling*
	2J3KL	R.K. Smedbol D. Schneider J. Wroblewski D. Methven D. Pinsent	The population consequences of inshore spawning by northern Atlantic cod (*Gadus morhua*) at low stock levels
	GSL	C. Taggart	An integrated approach to stock

		D. Ruzzante	identification: preliminary results of the High Priority Project on cod stock mixing in the Gulf of St. Lawrence
Case studies	Labrador	J. Wroblewski	Observations of northern cod overwintering in Trinity Bay, Newfoundland and in Gilbert's Bay, southern Labrador
	Norway	T. Jakobson	Research on coastal cod in Norway
	Newfoundland	C. Taggart D. Ruzzante	Random island region and the inshore/offshore stock question
	Newfoundland	J. Brattey	Observations on cod in western Trinity Bay during April 1996

Six presentations covered tagging results, for cod on the eastern and southern Newfoundland Shelves, the northern and eastern Gulf, the Scotian Shelf, and the Bay of Fundy. For Northern cod, many tagging experiments on offshore spawning or prespawning aggregations demonstrated extensive inshore migrations during summer, and substantial fidelity to spawning sites from year to year. However, dispersion of recoveries both offshore and inshore increased with years after tagging, indicating spawning site fidelity is not absolute. Many cod tagged inshore during summer were recaptured on offshore banks in other seasons. Again there were substantial returns to the same bays in subsequent summers. but also dispersion along the coast, which increased over time.

Many fewer cod have been tagged inshore in winter. The small number of recoveries indicated a high proportion of recoveries from near the area of tagging, with some dispersion along the coast and out of the bays beyond headlands. Using the tagging data to estimate exploitation rates indicates that inshore and offshore aggregations have experienced different patterns and intensities of exploitation, possibly over a noteworthy period.

There were fewer tagging experiments in the Gulf of St. Lawrence. Research tagging offshore indicates both movements within the Gulf , inshore-offshore migrations, and some seasonal movement out of the Strait of Belle Isle and Cabot Strait. Recent tagging in the sentinel fisheries programs indicate cod tagged in bays in summer move north along the west coast of Newfoundland through the fall and winter, returning south the next spring and summer, often to the same bays.

Tagging on offshore spawning aggregations on the eastern Scotian Shelf sites indicate cod migrate inshore after spawning, and return often to the same bank in subsequent years. As off Newfoundland, dispersion among inshore locations and exchange among offshore aggregations increases over time. Inshore tagging in summer is consistent with results of tagging offshore during spawning. Recent tagging inshore on aggregations which may have spawned inshore indicate substantial movement along the coast, but little movement to offshore sites.

Tagging experiments on the western Scotian Shelf suggest low or partial mixing of aggregations from Browns Bank with ones further west. Because of the shallow coastal topography, it has been difficult to use tagging to study annual inshore - offshore movements in 4X, if such migrations occur.

A few morphometric analyses were presented. Studies of vertebral counts of cod from the Cabot Strait, eastern Gulf of St. Lawrence, and southern Newfoundland indicate very complex stock affinities, with substantial changes throughout the year. Interpretation of the results is complicated, because this trait has both a genetic and an environmental component. Otolith elemental composition data from the same area showed similarly complex patterns of stock mixing. Again interpretation is complicated, but major research programs are underway to provide a foundation for relating elemental composition to recent historic temperature fields.

Studies of diet and condition factor of cod in the Gulf of St. Lawrence are providing important information about the recent ecological conditions experienced by cod, but were felt to have little information on stock structure and affinities. Length at age data from the southwest Scotian Shelf strongly suggest some differentiation of cod components within that area.

Parasite studies of cod off Newfoundland were generally consistent with the delineation of major stock boundaries. A naso-pharengeal parasite demonstrates that cod undertake return migrations between offshore spawning sites and inshore sites. Weak information about the distribution of inshore hosts hampers using these parasites for more fine scale studies of local affinities of stock components. Data on nematodes show large changes in prevalence over the recent decades. Interpretation of the pattern of codworm parasites is complicated by the large increases in abundance of seals, an intermediate host, in the past decade.

Several studies of distribution of eggs, larvae, and juvenile cod were reviewed. In the northern Gulf, patterns of egg distribution indicate substantial mixing of spawning products, with little evidence of persistent, discrete sub-components of spawners. However, even the number and location of usual spawning sites has not been documented fully. On the other hand, major research programs, including the Scotian Shelf Ichthyoplankton Program, have provided extensive information and understanding about the spawning sites of cod on the Scotian Shelf, and the fates of spawning products. In southwest Nova Scotia several major programs have shown that spawning products are retained on Browns and on Georges Bank, and even the distributions of age 1 and 2 cod suggest substantial differentiation of stock components within 4X and 5Z.

On the Newfoundland Shelf, surveys of various pre-recruit age groups provide diverse results. There is evidence for extensive mixing of pelagic 0-group cod from offshore spawning banks, but also some evidence of retention of pelagic 0-group cod from spawning within the major bays. Data from a Russian study in the 1960's may be particularly informative both regarding overall distribution of eggs, larvae and young 0-group cod on the Newfoundland Banks, and as a frame of reference for interpreting changes to the present .

The degree of mixing of demersal juvenile cod between inshore and offshore areas and among offshore sites seems be low at age 1, but increases with age, so offshore mixing is high by age 3. Recently the beach surveys begun by Fleming several decades ago have been reinstituted, and are finding young cod to be abundant very near shore, with distributions reflecting strong habitat affinities. These habitat relationships must be considered when interpreting what the patterns of pre-recruit distribution imply regarding stock component structure.

Results of several studies of biochemical genetic were tabled, using information nuclear DNA (i.e. microsatellites and MHC complex) and mitochondrial DNA. Mitochondrial DNA indicates that there is no differentiation below the level of the major stocks, in particular that there is no differentiation between inshore and offshore components of Division 3L, and only samples from the Flemish Cap were markedly differentiated from the sets of samples from the Newfoundland Banks and Scotian Shelf. It was also suggested that all northwest Atlantic cod stocks were descended from a common ancestral population, probably in the Scandinavian portion of the northeast Atlantic, with a genetic bottleneck that may have occurred as long as 150,000 years ago, or as recently as 12,000 years ago.

Microsatellite DNA studies reported evidence for differentiation of some of the major recognized stocks in the Northwest Atlantic There was also evidence of a complex stock structure on the eastern Scotian Shelf - Cabot Strait area, with the stock mixture in that area varying seasonally and probably inter-annually. There was also evidence for genetic differentiation of inshore and offshore components on the Newfoundland Shelf, as well as identifiable stock components on the various spawning banks along the Newfoundland Shelf. Preliminary MHC DNA studies also indicated some differences between onshore and offshore components off eastern Newfoundland.

Research trawl survey data were reviewed briefly. Results prior to the 1990s showed generally continuous patterns of distribution along the Newfoundland, Labrador, and Scotian Shelves, and within the Gulf of St. Lawrence. Notwithstanding the lack of marked discontinuities, there were fairly consistent centers of concentration over sequences of years. The research trawl surveys rarely extended close enough to coastal areas to provide direct information about the existence and possible patterns of coastal stock components, particularly in southwest Nova Scotia, where the offshore banks seemed to support reliable aggregations, with cod less evenly distributed in the deeper waters separating the banks. In the 1990s, with stocks at much lower levels, offshore aggregations are rare anywhere. The present pattern of catches suggests a fragmenting of the previously widespread stocks into smaller pockets of occurrence. The fragmentation is most extensive off Newfoundland, somewhat less in the Gulf, and less yet on the Scotian Shelf. This pattern could have several causes acting separately or in concert, including major biological processes and simply sampling zeros due to extremely low abundance.

The weak information from nearshore trawl surveys was augmented by records from the sentinel surveys, and by hydroacousitic surveys nearshore and several score km offshore. The sentinel surveys often found cod to be much more abundant nearshore than the research surveys found cod to be offshore. The sentinel survey results also indicate there may be noteworthy stock structure among the inshore bays of eastern, southern, and northern Newfoundland, with progressively more continuous distributions along the eastern coast of the Gulf of St. Lawrence and the eastern Scotian Shelf. Again this pattern could have biological causes or be a consequence of low abundance.

Hydroacoustic surveys have generally been focused on finding and mapping specific aggregations or studying ecological or behavioral processes, rather than conducting large-scale surveys. Many hydroacoustic studies have found discontinuous dense aggregations in nearshore areas, but these have not been tracked over a long enough period to be confident of their relationships to other cod stock components.

Historic perspectives from early journals, older scientific papers and fisheries reports, and users' experience were also contributed. Much traditional knowledge was interpreted as indicating that historically cod had overwintered and spawned at the heads of deep fjord-like bays of Newfoundland, and these cod could be differentiated by appearance and distribution at particular times and in particular fisheries from cod which had migrated into the inshore in late Spring or Summer. Historic fishery records are consistent with these reports, and some fishers propose that morphologically distinct types of cod still are present within the large stock complexes.

A couple of contributions outlined the implications of more complex stock structures for rebuilding and management of cod stocks, and modelling approaches which may provide initial limits on the degree to which mixing of stock components can affect parameters important in assessment and management. These contributions provided a starting point for the integrative discussions at the end of the workshop.

GROUP DISCUSSION

Following all presentations and discussion of their factual content, the group considered the following proposition:

- **Canada has practiced "science-based management" of cod stocks since the 1950's using stock delimitations set by ICNAF. The status quo is that we continue to assessment and manage cod stocks on the same spatial scales. Based on all the information presented at the Workshop, is it precautionary and best use of science information to continue the status quo?**

- **There was full agreement that, to different degrees in different Regions, there is substantial structural heterogeneity in all the stocks as presently defined. Presently defined stock boundaries mixing and discontinuities among cod stock components.**

More specifically, the status quo is inappropriate at several levels:

- However carefully the boundaries among the major stocks were determined when they were established, distribution of major stocks appear to have changed in recent years, so geographical structures are not captured well in current assessment and management practices. This is a particularly acute problem in the entrance to the Gulf of St. Lawrence.
- Within the major stock boundaries adjustments are also justified. These adjustments will be very difficult to implement. The relationships among stock components cannot be viewed as constant even within a year, for there are important intra-annual dynamics. Moreover, to assess or manage on finer scales will require collection of fisheries data on much smaller scales.
- The results of successfully adjusting the boundaries among stock components would include greater flexibility for management of the fisheries.

Rejecting the initial proposition that the existing stock boundaries are the best possible given all current evidence, did not clarify what alternative structure was preferred. The discussions suggested several possible models which were consistent with various portions of the data. The correctness of the various models hinges in large part on the dynamic relationship between abundance and area occupied by a stock. These relationships are poorly understood for (at least) cod, although this issue had been dealt with several times in ecological theory (MacCall 1990), and specifically with regard to cod (Methven *et al.*, 1997).

- It is possible that the current observations arise solely because of the very low stock levels.

    In this scenario the large stock complexes are real. When the stock is at high abundance, all the suitable area is occupied and there are no discontinuities among stock components. We only perceive discontinuities where abundances are very low and aggregations have withdrawn to discontinuous pockets of preferred habitat. As the stocks rebuild these isolated aggregations will blend together.

    In this scenario, we observe a gradient of perceived discontinuities, paralleling the extremities of collapse of the stocks. For Northeast Newfoundland and Labrador stocks the collapse is so extreme that cod are essentially absent on the entire Shelf, and there are only isolated pockets in the deep inshore bays. In the Northern Gulf the collapse is not quite as extreme. Although cod are essentially absent offshore, their distribution is fairly continuous along the western coast of Newfoundland and the Quebec North Shore. On the Northeastern Scotian Shelf the declines are less extreme. Cod are distributed continuously both along the coastal zone and along the offshore slopes of the major banks. They are only absent on the tops of the banks comprising the Northeastern Scotian Shelf. Finally, in Southwest Nova Scotia and the Gulf of Maine, where the declines were modest and reversed quickly, most of the traditional range remains occupied.

- It is also possible that the current observations arise because there have always been small inshore stock components as well as large offshore stock components.

  In this conceptual model, the increase in biomass and abundance inshore would have an ecological basis. The inshore components would not have to be completely sedentary, but movements would be restricted largely along the coast. The offshore components are highly migratory between offshore spawning areas and nearshore feeding areas, with additional mixing of fish among proximate spawning aggregations from year to year. The offshore stocks on the Newfoundland Shelf and in the Gulf of St. Lawrence have collapsed nearly completely. This has resulted in the inshore stocks being released from competition during the summer, when feeding conditions are often best, and temperatures most conducive to growth. Individual growth and recruitment both may be high compared to historic levels.

  In this scenario, strong growth and increases in abundance of inshore stock components may contribute little to rebuilding of the offshore stock components. Only if the inshore stock components began to migrate to offshore banks when densities were high, would offshore stock components gain recruits. This would be a new and complex set of behaviours for the traditional inshore stock components, and Rose (1993, 1994) suggests several reasons why such migrations are not assured, even when inshore abundances reach high levels.

The Workshop discussed these two scenarios, and various intermediates. **It was concluded that extreme scenarios could be defined which bracketed the true stock component structures for Canadian Atlantic cod stocks.** One extreme model is straightforward:

> **Model I: There is a single interbreeding stock. There is some degree of site fidelity, but adults are strongly migratory. Mixing among spawning aggregations is "high" and there are no breeding discontinuities among stock components. The range occupied by the stock complex may vary with changes in abundance or environmental conditions. However apparent discontinuities in distribution will be eliminated when the environment ameliorates or abundance rebuilds.**

The alternative model has a number of variants.

> **Model II: There have been AT LEAST inshore and offshore breeding stock components. Mixing between these components has been "low" during breeding, due to separation of spawners in space and possibly in time. Because of migration, there may be extensive mixing in catches, in at least some places and seasons.**

Important variants address:

- Substructure of the offshore component - Over several years, is mixing among proximate components during spawning "high" of "low"?
- Substructure of the inshore component - Over several years is exchange among proximate spawning aggregations along the coast great enough for "high" mixing, or do effective discontinuities among spawning aggregations result in "low" mixing among bays?.

No one Model or variant was thought to fit all the types of evidence presented at the Workshop. It was agreed that five separate subgroups would tabulate every type of data or study presented during the workshop with the framework of Models I and II (four variants). The tabulation would assess whether each of the observations was Likely or Unlikely to have been observed, were each of the models or variants actually true. This tabulation is presented as Table 2.

In light of the tabulated information, the Workshop concurred that a precautionary approach to assessment would have to recognize the complex stock component structure explicitly. More importantly, a precautionary approach to management would have to ensure that any harvesting should be carefully distributed among spawning components, so that none of the components would be consistently over-exploited. These approaches would require both assessments and management approaches which are much more complex than have been implemented in the past.

ACTION PLAN FOR COMING ASSESSMENTS

Following review of the tabulation in plenary, each lead assessment biologist outlined the approach planned for the 1997 or 1998 assessments of the major cod stocks, in light of the Workshop discussions and presentations.

- 4VsW - A three compartment model is being developed as a collaboration of Fanning and Mohn. The compartments reflect inshore, bank, and offshore areas. Migration among compartments will be estimated within the model, using tagging data among other sources of information. This model is not expected to be tested and ready for use for 18 months, however. There are also difficulties disaggregting historic catch data into the spatial compartments.

- 2J3KL - The next full assessment will attempt to estimate the absolute biomass of the stock inshore. Methods are still under discussion. Hydroacoustic survey methods are likely to be important, but there are several problems to overcome in making hydroacousitcs a core tool in assessing inshore cod biomass. There are shortages of staff experienced in hydroacoustics, a very large area would have to be surveyed, and the timing of the inshore surveys would have to be coordinated with the offshore surveys.. Also, to conduct ongoing assessments on the inshore stock components would require catch and effort data of very high quality from any inshore fisheries. There are several sources of information on pre-recruit abundance, and these wil have to be integrated and reconciled.

- 3Pn4RS - For the northern Gulf there are very few historic research studies to work with, nor are data from past fisheries on sufficiently fine spatial scales. The fine-scale overlap between the fixed-gear and mobile-gear components of the sentinel fisheries program mean that this data source is likely to be extremely influential in the coming assessments.

- 4X - Assessments have been moving towards conducting separate assessments for the Browns Bank and Bay of Fundy stock components. This has been recognized as a reasonable objective for some time. Again it has required significant investment of time to disaggregate the fisheries data and develop new code for the assessment models.

Two members of the FRCC were also asked to comment on the information presented at the workshop. They stressed that it has been very difficult for the FRCC to deal with single global assessments of stocks which are presently under moratoria, such as 3Ps in 1996. More spatial information in the assessments would be of great value to them. More generally, useful assessment results should balance "best science" with sufficient precaution. They should highlight the assumptions in the assessment which may be wrong, and the risks associated with the alternatives. It was also stressed that it is essential that the assessments provide hard numbers for the FRCC, with associated uncertainties.

FILLING THE INFORMATION GAP

The information presented at the Workshop documented that significant insight has been gained about the structure and affinities of cod stock components in Atlantic Canada. The Workshop itself made important strides in integrating the diverse studies which have been undertaken into a new framework for assessment and management of those stocks. Nonetheless, the Workshop also identified some important information gaps, opportunities for more fully integrated analyses of some data sets, and, especially, a need to develop strategies and tools to use the emerging new view of cod stock structure in future assessments, rebuilding plans, and management of fisheries. The final discussion of the Workshop was planning the work needed to complete the integration of present knowledge, fill in the important knowledge gaps, and build the analytical framework for future assessment and management. Only when this work is completed will it be possible to fulfill the core objectives of the Workshop.

Tagging experiments:

Many past tagging experiments were designed, conducted, and analyzed largely to study migration routes and mixing rates among spawning or fished aggregations. Tagging experiments can be used to estimate many other things, including population size and exploitation rate, if they are designed and carried out with those applications in mind. Future tagging studies should be designed with full attention to the properties needed to estimate these additional parameters.

Cod have been under moratoria for several years, but fisheries will reopen in the future. This presents an unique opportunity to estimate some important things about population dynamics and cod life histories through application of tags over several successive years during closures, and monitor recaptures closely in space and time when the fisheries reopen.

There is an opportunity to apply tags with much greater coverage in space and time, by working in association with fishers participating in the sentinel fisheries programme. Participants have great enthusiasm for tagging studies. This opportunity needs to be balanced against studies showing that tag loss rate can vary substantially among taggers. Using many different individuals, particularly if they have differing levels of training and experience, can introduce high level if variability in the results of tagging experiments. This source of variance is very hard to estimate unless double-tagging included in the experimental design.

Modelling and data analysis:

There is an urgent need to develop assessment software for spatially disaggregated stock assessments. Work of this nature is underway in several laboratories, but opportunities for coordinated progress should be sought.
Many questions can be explored through good modelling studies of spatially complex population dynamics. A preeminent question is how low may mixing rates fall among components of meta-populations without making a difference to population dynamics parameters of the population as a whole.

Modelling of spatially structured metapopulations is also needed to evaluate possible consequences of various types of fisheries on the populations, and to identify appropriate target and limit reference points for such populations.

The existing data base on past tagging experiments has not been analyzed fully. An integrated analysis of population distribution, overlaps, mixing rates, and exploitation would be complex to conduct, but is possible, and should be a priority.

Genetics and reproduction:

It would be extremely informative to implement a programme for obtaining tissue samples from ALL major spawning aggregations in a single year. A programme which samples a few spawning aggregations each year, or samples different aggregations at different points in their reproductive cycles, is much more likely to allow multiple interpretations about stock component relationships.

Even a one-year sampling of all spawning aggregations would be highly informative. However, the value of the study would be increased greatly if there were programmes to sample spawning products "down-stream" from the spawning sites, to track where the spawning products were distributed. A replicate sampling of a selection of the spawning aggregations in a second year would also increase the value of the initial study.
Knowledge of the locations of cod spawning in the Gulf of St. Lawrence is incomplete. Before all spawning aggregations in the Gulf of St. Lawrence can be sampled for genetic studies, they need to be located and inventoried.

There are reports of spawning very near the shore in parts of Newfoundland and possibly the Gulf. These spawnings are thought by fishers and scientists to be anomalous, compared to historic patterns. The genetic affinities of these anomalous spawnings should be determined. However the anomalous aggregations should be differentiated in interpretations of population structure from samples of the traditional spawning aggregations.

Some of the inshore wintering aggregations of cod have been found to have highly skewed sex ratios, even when very close to spawning. To understand the contribution these inshore spawning aggregations can make to rebuilding cod populations, some aggregations need to be followed through the spawning period to determine whether spawning is successful.
No single method of genetic analysis of stock affinities was identified as superior to all others. Different methods provide different types of insight. A combination of methods should be used, and each interpreted in the context of its major strengths and weaknesses.

Abundance estimation:

A significant portion of the bottom in the inshore bays of Newfoundland and Labrador in not trawlable. To assess the biomass of cod in these inshore areas, it will be nearly essential to rely on hydroacoustics as a major survey tool, although some survey sampling can be done with gears other than bottom trawls. To avoid the possibility of double counting of fish, it is important that the timing of the hydroacoustic survey be coordinated with the timing of the trawl survey. For successful application of hydroacoustics, it is also important that the hydroacoustic survey be conducted at times and conditions when most of the cod inshore can be expected to be off the bottom, and, if possible, aggregated rather than dispersed. It is technically feasible to detect and integrate concentrations of cod in close proximity to the bottom in most inshore Newfoundland waters, but the potential to quantify thses estimates will depend upon many factors, one of the most important being the minimization of the bottom exclusion zone.

The sentinel programme is producing many useful results, and has the support of many fishers. It is essential that programmes be implemented to calibrate the relative indices being generated from sentinel programmes to some measure of absolute biomass or numbers.

As noted under "Tagging experiments" tagging should be used to a greater extent to estimate abundance and exploitation rates.

Assessment and management of cod on finer spatial scales will require reliable and complete catch and effort data on comparable spatial scales. There are no conceptual impediments to obtaining such data, but past attempts to improve catch and effort recording have had almost no success. The entire existing logbook programme for inshore (and possibly offshore) fishers needs to be scrapped, and a new one designed with Science needs having an equal role with the needs of other Branches. Fishers also should be part of the group designing the logbooks.

Recruitment studies:

Even the relative monitoring of cohorts from age 0 until they appear in the sentinel fisheries would be of value. Use of the Campellan trawl in groundfish surveys helps achieve this objective, but still misses fish inshore and many age 0 and 1 cod. The "Fleming surveys" appear to be one cost effective tool for sampling close inshore, especially now that they are conducted jointly with fishers. The potential contribution of dedicated young fish surveys also should be considered carefully in developing an approach to the assessment and management of the more complexly defined cod stocks, particularly during moratoria and the years immediately after re-opening of fisheries.

Other issues:

Historic records and users knowledge are proving valuable in gaining understanding of present conditions relative to the past stock structures. Work to obtain users knowledge in systematic ways needs to continue, with close interactions between assessment scientists and those assembling the body of information on users and historic knowledge.

Accepting that the structure of cod stocks is much more complex than assumed by past management practices, marine protect areas may be a useful tool in conservation and management of the stock components. Work should be initiated to explore how this tool would complement other fisheries management tools for cod stock components.

Why are surveys for juvenile and 0 group cod finding reasonable numbers inshore in at least times and places; yet these fish are not showing up offshore at ages 4 or 5, when, traditionally, they would have begun their annual migrations?

Until the past few years, most cod stock assessments used commercial offshore CPUE and offshore trawl survey minimum trawlable biomass as the two most influential indices of abundance. Both of these time series have been interrupted; the commercial CPUE by moratoria on fishing, and the research vessel indices by extremely low catches in much of the area surveyed and changes in survey gear. Empirical tools will be needed to calibrate the indices obtained as the stocks rebuild to the indices used prior to 1993.

FINALE

The Workshop underscored several points. Although the Regions have not undertaken major programs specifically to redefine cod stock structure, the types of research done in the past years has been of sufficiently broad vision and focus to provide much relevant information on this problem. The excellence of the work undertaken has allowed substantial progress to be made on developing a new framework for the structure and affinities of cod components in Atlantic Canada. An zonal and an international perspective have been extremely helpful in taking these initial steps. Much important work remains to be done, and the planning and conduct of this work should retain these larger perspectives.

Even though much important research remains to be completed, the information already available is sufficient to justify Regional adjustments, where feasible, to the assessment and management approaches to the cod components. Two areas of key priority are inshore - offshore components and affinities of cod stocks on the Newfoundland and Labrador Shelves, and determining the mixture of stocks which would be harvested by fisheries in 4Vn and how that mixture varies in space and time. Highlighting those two priority issues does not mean that other matters, such as the proper delineation of cod components in 4X, the documentation of spawning components in the Gulf of St. Lawrence, or understanding the inshore - offshore pattern of cod distribution in 4VsW are either simpler or less important to sustainable stewardship of those stocks. In all areas it is important to both increase our knowledge of cod stock components and use that knowledge effectively.

Table 2 - Summary table of all the data sets or types of knowledge included in the presentations at the cod components workshop. Model I (homogeneous stocks) and Model II (various more complex stock structures) are explained in the text. Each column entry reflects a peer judgment of whether the data presented were LIKELY (L) or UNLIKELY (U) to have been observed, if the specific variant of the model were correct. Many types of data / evidence would have been likely to have been observed under more than one of the models and variants. This simply means those specific data have low information content about some parts or all of the underlying structure of the stock and relationships among components. Some types of data have no information at all about some variants of model II. These are denoted with a - .

TYPE OF EVIDENCE	**STOCK / AREA**	**MODEL I**	**MODEL II - HIGH MIXING OFFSHORE**	**MODEL II - LOW MIXING OFFSHORE**	**MODEL II - HIGH MIXING INSHORE**	**MODEL II LOW MIXING INSHORE**
TAGGING (MOVEMENTS)	NE NFLD SHELF	L	L	U	L	U
"	N. GRAND BANK	L	U	L	L	U
	2J3KL	U	U	L	L	U
	3Ps	U	U	L	L	U
	SW ARM - INSHORE	U	-	-	L	L
	E. SCOTIAN SHELF - OFFSHORE	U	L	L	-	-
	E. SCOTIAN SHELF - INSHORE	U	-	-	L	U
	W. SCOTIAN SHELF - OFFSHORE	U	L	L	-	-
	W. SCOTIAN SHELF - INSHORE	U	-	-	L	U
	NE GULF - INSHORE	L	-	-	L	L
TAGGING - EXPLOITATION RATES	2J3KL	U	-	-	U	L
EGG MOVEMENT	3Pn4RS	L	L	L	-	-
DEMERSAL JUV. SURVEY - AGE 1	2J3KL	U	U	L	U	L
DEMERSAL JUV. SURVEY - AGE 2	2J3KL	U	U	L	U	L
DEMERSAL JUV. SURVEY - AGE 3	2J3KL	L	L	U	L	U
PELAGIC 0-GROUP SURVEY	2J3KL	L	L	U	U	L
EGGS & LARVAL SURVEY	4X	U	U	L	U	L
PELAGIC 0-GROUP SURVEY	4X	U	U	L	U	L

DEMERSAL AGE 1&2 SURVEY	4X	U	U	L	U	L
FALL '96 INSHORE HYDROACOUSTICS	3KL	-	-	-	U	L
RUSSIAN JUVENILE SURVEYS	2GHJ3KLMNO	U	L	L	L	L
EGGS & JUVENILE - LOCAL STUDY	3L	U	-	-	U	L
mtDNA	NFLD BANKS	L	L	U	L	U
"	SCOTIAN SHELF	L	L	U	-	-
"	FLEMISH CAP	U	U	L	-	-
MICROSATELLITE DNA	NFLD SHELF (WINTER)	U	U	L	U	L
"	SCOTIAN SHELF	U	L	U	-	-
"	SCOTIAN - GEORGES - FUNDY	U	U	L	-	-
"	NW GULF - BANQUER.	U	U	L	-	-
MHC DNA	NFLD SHELF	U	U	L	-	-
ALLOZYMES	NFLD - SCOTIAN - FLEMISH	U	U	L	L	L
RV SURVEY	2J3KL	L	L	L	U	U
"	3Ps	L	L	L	U	U
"	4X	U	L	L	L	L
"	3Pn4RS - PRE 1990'S	L	L	U	-	-
"	3Pn4RS - POST 1990	U?	U?	L	L	L
SENTINEL SURVEY	NFLD	U	-	-	L	L
	4VsW	U	L	L	L	L
	3Pn4RS	U	U	L	L	L
USER'S KNOWL. SURVEY	2J3KL	U	U	L	U	L
WINTER FISHERIES 1950S	2J3K	U	-	-	U	L
CATCHES IN 1700S & 1800S	2J3KL3Ps	U	U	L	U	L
CATCH TRENDS - 1960S	2J3K	L	L	U	-	-
CATCH TRENDS - RECENT	2J3KL	L	L	L	L	L

HISTORIC INSHORE CATCH TRENDS	3Ps	U	-	-	L	L
DISTRIBUTION OF 1990 YEARCLASS	3Ps	U	L	U	L	U
HISTORIC GROWTH PATTERNS	2J3KL	U	L	L	L	L
"CAPELIN FISH" , "HERRING FISH" ETC	2J3KL 3Pn4RS	U	U	L	U	L
LENGTH AT AGE	4X	U	L	L	L	L
JUVENILE LENGTH AT AGE	2J3KL	L	U	U	U	U
CONDITION FACTOR	3Pn4RS	-	-	-	-	-
DIET STUDIES	3Pn4RS	-	-	-	-	-
PARASITES	2J3KLNO	L	L	U	L	U
PARASITES	3Ps	U	L	U	-	-
GILL PARASITE	2J-3Ps	U	U	U	U	L
VERTRBRAL COUNT	3Ps3Pn4RTVn - WINTER	L	L	U	U	U
OTOLITH COMPOSITION	"	L	L	U	-	-

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Appendix I

Abstracts of presentations made at:

The Cod Component Workshop

March 3-5, 1997

St. John's, Newfoundland

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Summary of presentations given at inshore/offshore cod components workshop held at the Delta Hotel, St. John's, Nfld (March 3-5th, 1997).

Title: Inshore/offshore cod stock components in Divisions 2J-3KL: the evidence from tagging studies - J. Brattey

Recaptures of cod tagged in NAFO Divisions 2J-3KL on offshore banks (Hamilton Bank, Belle Isle Bank, Funk Isle Bank) and on the North Cape of Grand Bank during winter indicates that these cod migrate inshore during fall and mix extensively along the northeast coast of Newfoundland during summer, typically arriving inshore in June. In fall they migrate back offshore generally to the same offshore banks but with some straying. Recaptures of cod tagged in Southwest Arm, Trinity Bay, during winter on three separate occasions indicated that the majority of these cod remained inshore throughout the year and were recaptured within 60 nm of the tagging area irrespective of season; a small number were subsequently recaptured offshore during winter in subsequent years; however, the results are consistent with the concept of regional (inshore or bay scale) fidelity with some straying. Recaptures of cod tagged off Cape Bonavista in June indicate that a mixture of inshore and offshore stock components were tagged, which is consistent with the results of inshore and offshore winter taggings. More inshore winter taggings in other bays around Newfoundland are needed to investigate the extent to which cod overwinter in the inshore areas.

Homing in Cod (*Gadus morhua* L.): Tagging in the Gulf of St. Lawrence 1983-1996

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In collaboration with the «Ministère de l'agriculture, des pêches et de l'alimentation du Québec», tagging experiments were conducted in the Northern Gulf of St-Lawrence between 1983 and 1986, to assess mixing and summer incursions of 2J3KL cod in the Northern Gulf. Fish were tagged on summer grounds and the winter returns were used to assess the stock of origin. Four successive tagging experiments were conducted in Western Newfoundland and on the Québec North Shore from trawl (1983-1984) and traps (1983-1986). Gascon *et al* (1990) concluded from these experiments that the mixing rates were usually low (>10%) except in the Northeast Belle-Isle Strait. There were very few returns from 3Ps and 4TVn.

These results were re-examined to test the hypothesis that cod showed homing or site fidelity to their summer feeding grounds following their annual migration cycle between the Gulf interior in the summer and Cabot Strait in the winter. We present here preliminary analyses of these results.

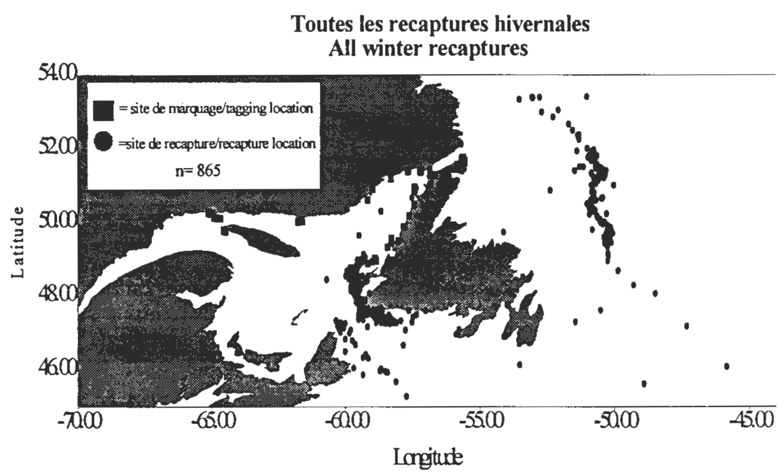

Figure 1. Winter returns (January-December) from tagging experiments conducted between 1983-1986. No returns (red circles) were made on the tagging grounds (blue squares) indicating that all fish had left their summer grounds in winter.

We examined the returns on the onshore/offshore and the along shore axes. Only returns with adequate information on position and date of recapture, from the months of June to September were included in the analysis. Only returns from the years subsequent to the tagging experiments were retained, thus only including cod that had returned from their wintering grounds. Fish in the months immediately following tagging were not included as they would be expected to be recaptured near the tagging sites. Almost all fish do migrate outside the Gulf (Figure 1), so the fish recaptured in the following summers were not sedentary, year round residents of the grounds they had been tagged on.

Inshore/Offshore axis

The database did not contain any information on the distance between shore and the position of recapture. We used the gear of recapture as a proxy of the relative position of fish from shore at recapture, with the assumption that fixed gears were usually deployed closer to shore than otter trawls. We then compared these returns by gears to the gear used for tagging: trawls representing "offshore" tagging and traps, inshore tagging. The results (Table 1) indicate that there is a moderate tendency for fish tagged "offshore" to be recaptured "offshore" and for fish tagged inshore to be recaptured inshore.

Table 1. Gear of recapture of tagged fish classified asccording to the gear used for tagging.

Tagging Gear	Recapture Gear: Fixed	Mobile	Σ
Trap	224 64,0%	126 36,0%	350
Trawl	161 54,9%	132 45,1%	293
Σ	385	258	643

Along Shore Axis

Returns from summers subsequent to tagging(Figure 2) clearly indicate that cod returned to, or near the site they had been tagged on previous summers. After one year at sea, the median distance between tagging and recapture sites was 74 Km, compared to the 500 Km of coastline on the West Coast of Newfoundland or the 1000 km on the Québec North shore (Figure 3). There is also a slow dispersal over the years, the median increasing in years 2, 3 , and 4 at 110 km, 127 km, and 182 km. There is also a tendency for fish tagged in traps to show tighter homing than for those tagged from otter trawls (median 54 *vs.* 81 km in year 1, 105 *vs.* 123 km in year 2 etc.)

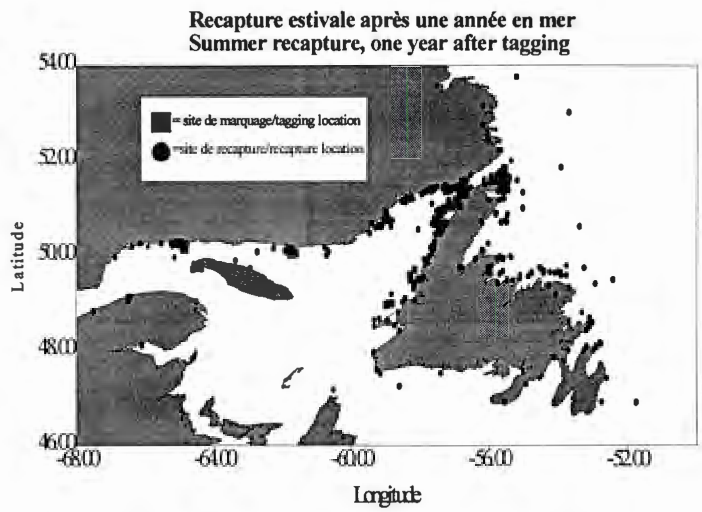

Figure 2 Summer recaptures of cod (red circles) during the months of June to September in the year following the tagging

Conclusions

Cod do clearly show homing to their summer grounds in the sense used by Harden-Jones (1968) "*The return to a place formally occupied instead to going to other equally probable places*". However, this homing is not strict, and there is a tendency to disperse over the years. Under this pattern, it is unlikely that discrete summer components will be able to maintain themselves. Because, most fish tend to spread initially within a restricted radius (≈75 Km), it will be usually impossible to resolve structures smaller than 75 or 100 Km. However, the because of homing, sites distant of 1.5 to 2×radius or more, will appear separate, regardless of the underlying structure. The results presented here do not allow to resolve the question whether there are or not separate spawning components in the northern Gulf (see Castonguay, this workshop).

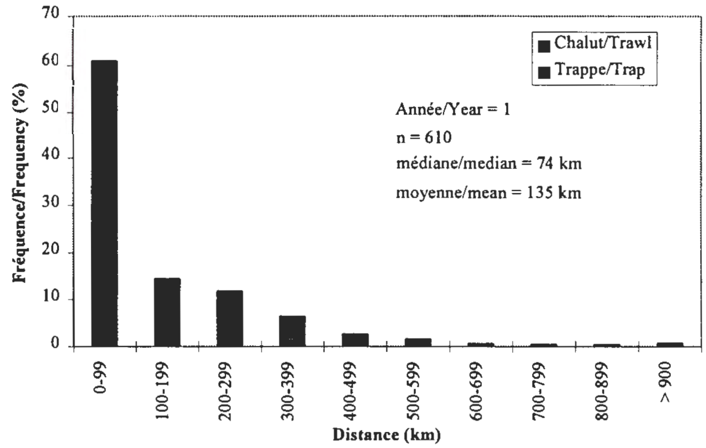

Figure 3 Frequency distribution of the distances between tagging and recapture sites classified by the tagging gear in the year following tagging.

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Summary of the presentations made at the workshop on inshore - offshore cod stock components.

St. John's March 3 - 5 1997.

Alain Fréchet, Denis Chabot.

1- TAGGING OF 3Pn,4RS COD FROM THE SENTINEL FISHERY

Sentinel fisheries programs were initiated in 1994 in the northern part of the Gulf of St. Lawrence in order to provide to science pertinent information of the cod stock status through the implication of fishermen from the area. In the 1996 assessment of the 3Pn,4RS cod stock, differences in condition and feeding were noticed between inshore fish caught by fixed gear and offshore fish caught by mobile gear (see later in this report) and as a result a intensive tagging program was initiated in 1996.

A total of 50,000 external T-bar tags were purchased and deployed throughout all gear sectors and fishing areas of the 3Pn,4RS cod stock. This was done in order to verify if any inshore - offshore stock components were present in the northern par of the Gulf of St. Lawrence. A summary of the deployment is shown below:

	No. of sites (boats)	No. of tags delivered[1]	No. of tags placed[2]	No. of tags recaptured[2]
Quebec Fixed (4S)	17	12,000	1,691	0
Quebec Mobile (4S)	4	8,000	16	0
Newfoundland Fixed (4R, 3Pn)	29	20,000	13,695	67
Newfoundland Mobile (4R, 3Pn)	5	10,000	496	1
TOTAL	55	50,000	15,898	68

The information detailed above concerns tags that were placed and subsequent recaptures on cod between August and December 1996. The reamaining tags should be placed on cod in 1997. Survival of cod subsequent to the taggings was investigated by returning fish to traps after being tagged and were released weeks latter. No mortality was observed. The effect of inter-fishermen tagging efficiency and tag loss can be measured through multiple tagging. Finaly, some sentinel fishermen have recaptured tagged fish, took note of the fish length, and returned the live fish in the water for follow-up.

Recaptures to date are very limited (N=68) given that there is no directed fishery for cod. It is expected that in the absence of fishing activity, multi-year tagging effort could provide estimates of natural mortality. Most recaptures to date come from sentinel fisermen and through reports from the food fishery which was conducted during two weekends in 1997. Recaptures from the first year (N=45) are indicative of fish dispersal whereas recaptures from the subsequent years (N=17) in the same quarter than the tagging are indicative of fidelity to the tagging site itself. A noticeable recapturing event was observed from a particular inshore site along the west coast of Newfoundland. A hook and line fisherman from the Bay of Islands area recaptured seven fish he had tagged in the previous year (N=550), another seven individuals were also recaptured in proximity in the next year. It is assumed that the fish that had been tagged in the previous year had undertaken an annual migration out of the Gulf (4R) into 3Pn during the winter. This very interesting result would support the hypothesis of fidelity to a particular summer feeding area. As more tags are being placed and recoveries occur, this particular phenomenon should appear more clearly.

2- <u>CONDITION AND FEEDING OF 3PN,4RS COD STOCK.</u>

Along with the decline of the abundance of the 3Pn,4RS cod stock, observations were made from fishermen and fish plant owners to the effect that the condition of cod had decreased substantially. Laboratory studies at the Maurice Lamontagne Institute have shown that the fish in the wild had conditions as low as those that were starving and dying in laboratory conditions. The monitoring of the feeding and condition was thus established as part of the regular sampling done both on the DFO research vessel *Alfred Needler* as well as from the various components of the sentinel fisheries.

Given that cod displays an important annual cycle in condition and feeding which is size dependant, the sampling targetted fish from 30 to 60 cm sampled in the fall where conditions should be at their highest in the year.

The condition of cod from the 3Pn,4RS cod stock has improved significantly since the closure of the fishery for all gear sectors. However significant differences have been observed between cod caught inshore with fixed gear and offshore cod caught by mo bile gear.

Combining cod stomachs collected on the Needler and those collected by Sentinel Fisheries in 3Pn4RS provided us with a good coverage of cod diet and stomach fullness for the period July through October in both 1995 and 1996. To avoid biases due to differences in cod size, only cod measuring 40-59 cm were retained for this analysis. Two major trends were observed in both years. Firstly, cod sampled by fixed gear inshore by the Sentinel Fisheries contained much more food in their stomach (usually more than 20 g, often more than 40 g) than cod caught by mobile gear (usually 10-20 g, Figure 1). Secondly, cod captured by fixed gear had a diet made mostly of fish (in particular, capelin, cod and sand lance), whereas cod captured by trawls offshore had a diet made almost exclusively of invertebrates (especially hyperidean amphipods and shrimps, Figure 1). Our data show that in general invertebrate prey provide less energy per unit weight than fish prey. It is clear that cod inhabiting deeper waters in the Gulf of St. Lawrence acquire less energy through their food than cod inhabiting coastal waters. There could be segregation by habitat, with some cod prefering coastal waters and others prefering deeper waters. But cod could also move between these two habitats. For instance, cod could feed in shallower waters but migrate through deep waters. These strategies would have very different implications for the condition of cod. It is important to obtain information on movement of cod in 3Pn4RS in Summer and Fall to better understand variations in feeding such as observed in this study.

3- **CASE STUDIES FROM SENTINEL FISHERY IN THE NORTHERN GULF OF ST. LAWRENCE (3Pn,4RS).**

Two specific cases drawn from sentinel fisheries in the northern Gulf relevant to inshore - offshore stock components were presented. The first detailled fishing activities from LaPoile fjord in southwestern Newfoundland (3Pn). Fishing activities were conducted since 1994 in the fjord itself and in adjacent waters. Although catch rates in the fjord were lower than outside, the local population was available throughout the year whereas cod caught outside the fjord had a more migratory nature with stronger seasonnal variations in catch rates. These catches are interpreted as being conducted in the migratory Gulf cod stock (3Pn,4RS) and not of local resident stock.

The second case study described a particular collaboration with a fixed gear sentinel fishermen from southwestern Newfoundland (3Pn). The purpose of this collaboration was to investigate any large scale oceanographic process that could be the cause of the dispersion of fish into greater depths in winter which would halt the fixed gear hook and line fishery in that area. CTD casts were done over a period of one month at five fixed sites betweeen 22 and 177 meters. A strong thermal gradiant was observed in the depest stations for a period of three weeks. The whole thermal structure was changed after a severe winter storm that occured early in 1997. The cold intermediate layer (CIL) was completly disrupted and a continuous thermal gradient was observed from the surface to as deep as 177 meters. Catch rates had declined over that period indicating that cod had moved into deeper waters.

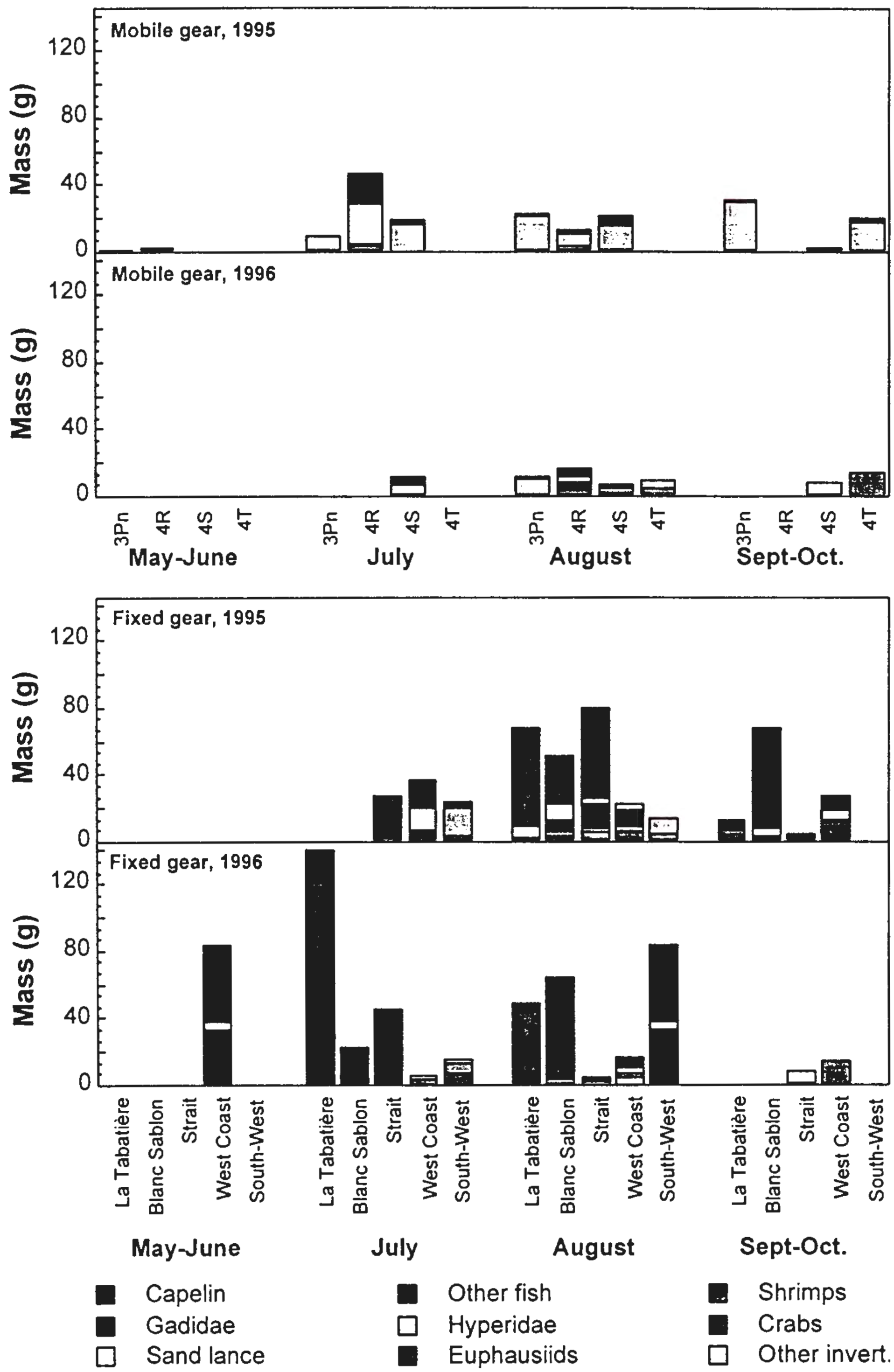


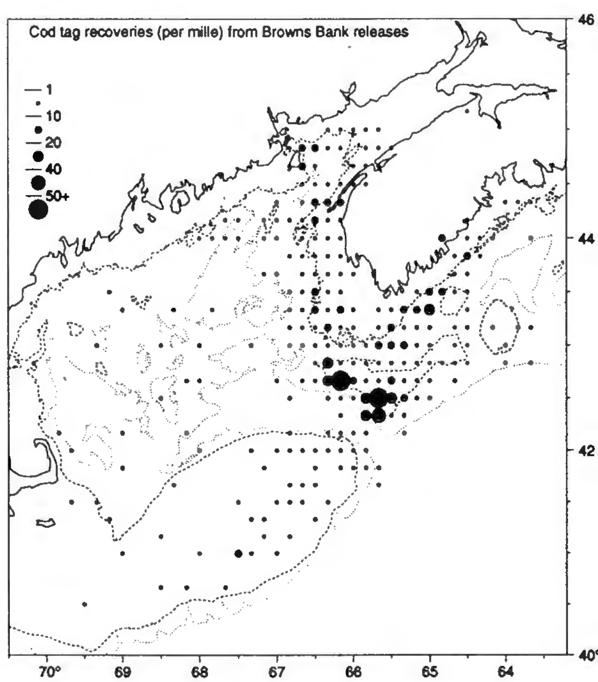
Figure 1. Mass of stomach content and of major prey items found in 40-59 cm cod for each of 4 time periods: May-June (few samples), July, August and Sept-Oct. Upper two panels: Mobile gear, 1995 and 1996. Lower two panels: Fixed gear, 1995 and 1996. Mobile gear surveys were subdivided in 3Pn, 4R, 4S and 4T (with very small sample sizes in 4T). Fixed gear surveys were subdivided in two regions for the Lower Northern Shore (La Tabatière and Blanc Sablon) and three regions for Western Newfoundland (Strait of Belle Isle, most of the West Coast, and the South-West corner). The absence of a bar indicates that no stomachs were sampled, not that all stomachs were empty.

Draft report for cod components workshop

1a. Results of cod tagging in the 4X/5Z (J.J. Hunt, Scotia-Fundy Region)

Results of cod tagging studies in the 1984-1995 time period were presented to the workshop. Based on about 2,500 tag recoveries, it was evident that movement of tagged cod between unitareas within NAFO Divisions was substantial. However, exchange at the larger geographic scale of Divisions (management units) occurred at a much lower rate. In most cases it appeared that movement between areas was bi-directional. Weighting of recaptures to account for fisheries effort did not substantially alter the spatial pattern of distribution. Results of a 1984/85 tagging study on Georges Bank were compared to results from a 1994 study and showed similar distribution patterns suggesting temporal stability in cod movements in the 4X/5Z area.

Inshore-offshore exchange of cod was not specifically addressed in the analysis. However, there was strong evidence that cod tagged while aggregated on offshore banks during the winter spawning season disperse after spawning and may be found in inshore waters later in the year. Results for cod tagged on Browns Bank during the spawning season are shown in the following figure:



Summary of Short Presentation given by Sally V. Goddard at the Workshop on Cod Population Structure (Gulf, Scotian Shelf, Newfoundland Regions) at the Delta Hotel, St. John's, Newfoundland, March 3-5 1997

Diversity in the pattern of antifreeze production in juvenile Atlantic cod from the Newfoundland region suggests that certain populations are better adapted to inhabit the more northerly areas of the distribution range.

During the summer of 1992, juvenile cod were collected from 4 experimental traps set by D.F.O. in 4 locations along the NE Newfoundland coastline - namely Conception Bay, Trinity Bay, Notre Dame Bay, and from the tip of the Great Northern Peninsula (St. Lunaire).
These cod (approximately 50 from each site, approximate mean length 30cm) were transported to the Ocean Sciences Centre of Memorial University, tagged with very small electronic internal tags (PIT Tags), and all held together in one large tank over the winter of 1992-1993. The tank was supplied with running sea water at ambient temperature pumped directly from Logy Bay throughout the winter. During this period, small blood samples were taken at monthly intervals from each fish and these were examined for the presence of antifreeze, a glycoprotein produced by the Atlantic cod in response to low temperatures. Antifreeze proteins confer freeze resistance and cold tolerance to individuals possessing them, the degree of protection being directly related to the concentration of antifreeze in the blood and extracellular fluids.
The results of this experiment showed quite clearly that the juveniles from the tip of the GNP (the most northerly location) began producing antifreeze earlier in the winter, and also produced considerably higher levels of antifreeze than cod from the three other areas. Thus, they appear to have developed a quicker and more pronounced response to cold than the groups collected from the more southerly locations.
These results provide evidence of diversity in cold tolerance between cod living in the 2J3KL region, and suggest that more northerly populations of Atlantic cod may be particularly well fitted to cope with the temperature/ice regimes of those regions.

Sally V. Goddard and Garth L. Fletcher

Title: **Some comments on the usefulness of parasites as indicators of cod stock structure**

- J. Brattey

The traditional approach to investigating whether parasites are useful for investigating host stock structure involves conducting a preliminary parasite survey from a few widely separated areas, cataloguing and characterizing the parasites as potentially useful or not, then conducting an extensive survey that focusses on parasite species with suitable characteristics. These include longevity in the host, ease of detectability, stability over time, little heterogeneity in the infection level within an area (seldom evaluated), but wide differences between areas, and no severe effects on host behaviour or survival. Most studies of Atlantic cod parasites have not been aimed at stock discrimination questions and have revealed only broad scale trends in the infection level that are consistent with ideas about stock structure obtained from other methods. The most pertinent studies include those by Postolaky (1962) on larvae of the cestode Pyramicocephalus in cod off Labrador, Templeman et al. (1976) on the parasitic copepod Lernaeocera branchialis, Templeman et al. (1957) and Brattey et al. (1991) on larvae of the parasitic nematode Pseudoterranova decipiens (sealworm), Khan et al. (1980) on the blood protozoan Trypanosoma sp, and Khan and Tuck (1995) on various parasite species in cod around Newfoundland. Most studies have lacked samples from inshore localities during winter to address the inshore/offshore cod stock components question and detailed quantitative analyses using more rigorous statistical approaches (such as discriminant function analyses) have not yet been attempted on cod parasite data. Parasite studies have been very useful in addressing stock structure questions, but are best used in conjunction with other techniques.

Distribution of gill parasite (*Lernaeocera branchialis*) infection in NW Atlantic cod.
Presented by C.T. Taggart.

- The geographic and host size-related trends in the prevalence of the gill parasite *Lernaeocera branchialis* (Copepoda) infecting Atlantic cod (*Gadus morhua*) in coastal Newfoundland and Labrador was described. Using cod-tagging studies conducted between 1962 and 1989 (Taggart et al. 1995), three null hypotheses were tested: 1) parasite prevalence in the northwest Atlantic is latitudinally invariant; 2) infected cod have the same survival probability as parasite-free cod; and 3) parasite prevalence is independent of fish length. Prevalence varied among tagging studies from 0 % along the Labrador coast to a maximum of ~20 % along the south coast of Newfoundland. The first null hypothesis was rejected given a significantly negative relationship between prevalence and latitude across a gradient of ~1200 km. The second null hypothesis was rejected in one geographic region when it was determined that ~8 % fewer infected and tagged cod from northeast Newfoundland were reported recaptured relative to uninfected cod similarly tagged and released. This implies that infected cod suffer an 8 % differentially higher mortality relative to non-parasitized cod in this region. The final null hypothesis was rejected when it was determined that the proportion of cod infected was generally greatest in the 43 to 49 cm length-class and then decreased significantly with increasing length. However, differential survival between infected and uninfected cod within length-classes was not observed. As infected cod appear subject to parasite-induced mortality, the magnitude of which varies geographically, the parasite's use as a population marker warrants caution. *L. branchialis* also has the potential to affect the recovery of depleted northwest Atlantic cod stocks in a geographically differential manner. *For more information see: Jones, M. and C.T. Taggart. 1997. Distribution of gill parasite (Lernaeocera branchialis) infection in NW Atlantic cod (Gadus morhua) and parasite-induced host mortality: inferences from tagging data. Can. J. Fish. Aquat. Sci. in press; Taggart, C.T., P. Penney, N. Barrowman, and C. George. 1995. The 1954-1993 Newfoundland cod-tagging database: statistical summaries and spatial-temporal distributions. Can. Tech. Rep. Fish. Aquat. Sci. 2042; or contact <chris.taggart@dal.ca>*

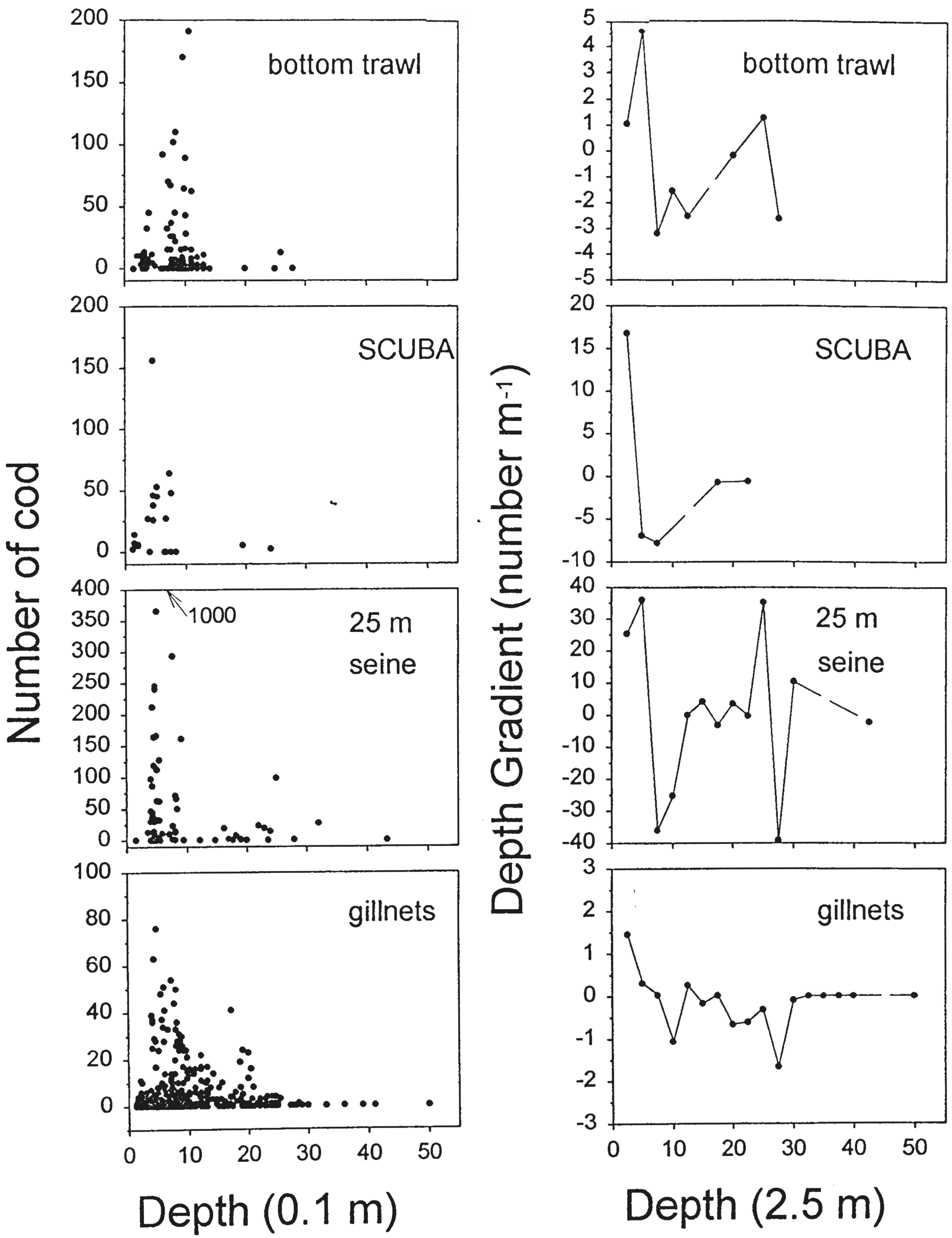
Post-moratorium distribution of 0+ demersal juvenile cod
Gadus morhua east of Newfoundland (3KL).

David Schneider (MUN), John Anderson (DFO), Edgar Dalley (DFO), Robert Gregory (DFO), David Methven (MUN).

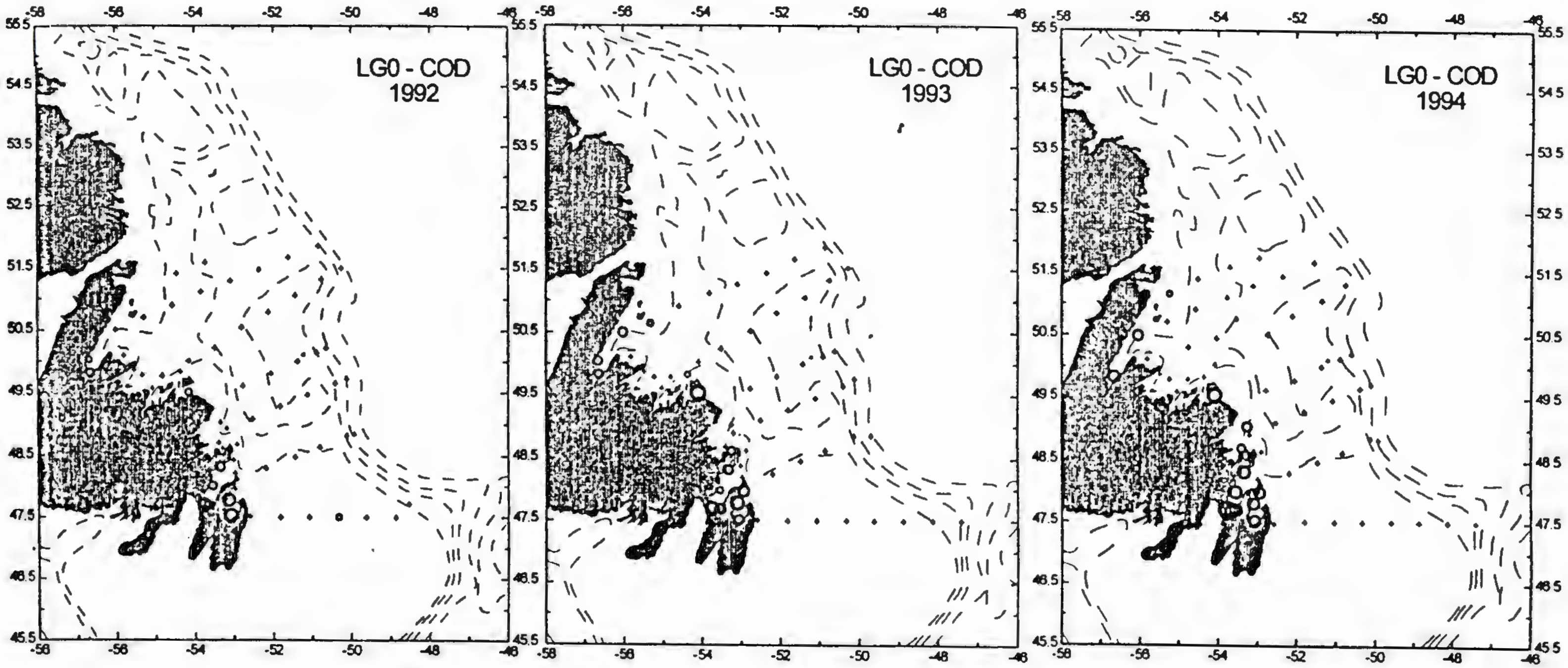
Presentation for workshop on inshore-offshore cod stock components, held 3-4 March 1997 in St. John's, Canada.

Abstract: The distribution of 0+ cod immediately after settlement in 3KL is currently restricted both vertically and horizontally, relative to younger (pelagic) and older stages in the life history. Juveniles settle preferentially in shallow (<10 m) water benthic habitats, based on transects by divers and submarines, and on catch rates by a variety of gears made from 1992 to the present (Figure 1). Densities in well-lit (<7 m) water greatly exceed those in deeper water. From 1992 onward recruitment to the demersal stage has been confined almost entirely to the coastal zone (Figure 2). Within the coastal zone recruitment to the benthos occurs in at least two predictable pulses, a weak pulse in May-June, and a stronger pulse after August (Figure 3). A recruitment signal was detected in the coastal zone in the early 1960s; a similar recruitment signal has yet to be identified, for the period from 1992 onward (Figure 4). There is no evidence of stock recovery after the 1992 moratorium, based on distribution and recruitment of 0+ fish to the demersal stage in 3KL.

Figure 1.



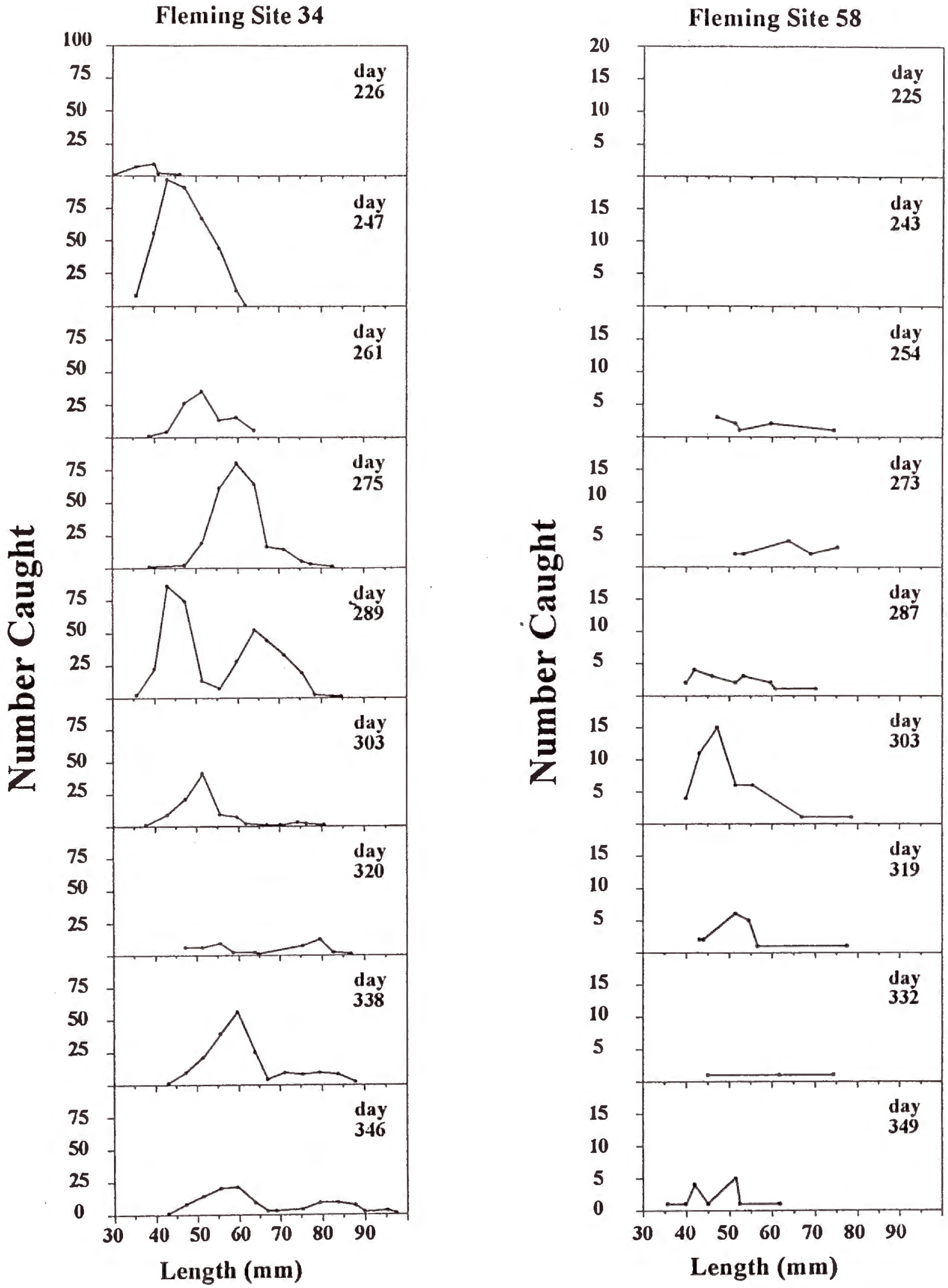
bottom trawl
SCUBA
25 m
seine
1000
gillnets
Number of cod
Depth (0.1 m)
Depth Gradient (number m-1)
Depth (2.5 m)



Dalley and Anderson 1997
in press

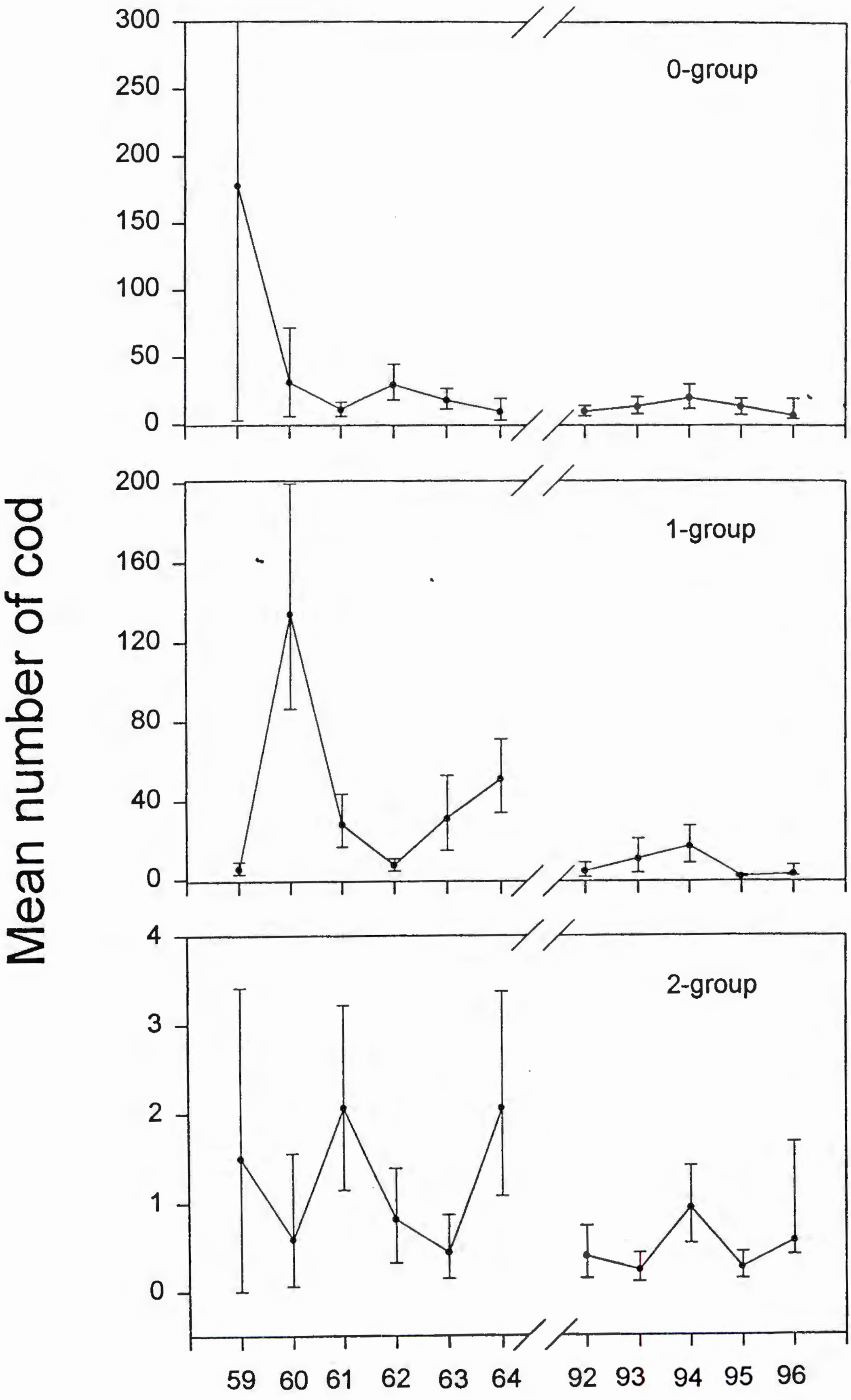
Figure 2.

Figure 3.



Fleming Site 34
day 226
day 247
day 261
day 275
day 289
day 303
day 320
day 338
day 346
100
75
50
25
0
30 40 50 60 70 80 90
Number Caught
Length (mm)
Fleming Site 58
day 225
day 243
day 254
day 273
day 287
day 303
day 319
day 332
day 349
20
15
10
5
0
30 40 50 60 70 80 90
Number Caught
Length (mm)

Figure 4.


0-group
1-group
2-group
Mean number of cod
300
250
200
150
100
50
0
200
160
120
80
40
0
4
3
2
1
0
59
60
61
62
63
64
92
93
94
95
96

WORKSHOP ON INSHORE – OFFSHORE COD STOCK COMPONENTS[1]

Department of Fisheries and Oceans
Delta Hotel
St. John's, NF

March 3-6, 1997

Chair: Dr. J. Rice

Spawning and Stock Structure of Atlantic Cod (*Gadus morhua*) in NAFO Divisions 2J3KLNO Inferred from Pelagic 0-Group Surveys

by

John T. Anderson and Edgar L. Dalley

Northwest Atlantic Fisheries Centre
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P. O. Box 5667
St. John's, NF
A1C 5X1

Summary

The geographic distributions of fish eggs, larvae and pelagic juveniles, combined with knowledge of physical circulation, can be used to determine the origins of spawning. Typical drift times for cod eggs and larvae in the Newfoundland region range from 80 days for March spawning, to 40 days for June spawning (J. Anderson, unpubl. data). We describe predictions of fish egg and larval dispersal based on physical circulation models, and compare these predictions with biological data for capelin and cod. Based on pelagic juvenile cod distributions, we draw conclusions on the proportions of inshore and offshore spawning for the northern cod stock (2J3KL), both historically and recently.

The Labrador Current dominates the ocean waters off Labrador and Newfoundland (Petrie and Anderson 1983). It is a strong Arctic current with inshore and offshore branches, peak velocities of 0.5 m s^{-1} and average surface (0-50 m) velocities of 0.2 m s^{-1} (op. cit.). Physical circulation models predict that cod eggs and larvae spawned offshore will largely remain offshore, downstream of their spawning locations (Helbig et al. 1989, Davidson and deYoung 1996, Pepin and Helbig 1997). Relatively small proportions of eggs and larvae spawned offshore are advected off the shelf to deep waters and inshore into the bays along the northeast coast of Newfoundland. Conversely, eggs and larvae

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[1] C:/words/papers/0-group/abstract in-off workshop.doc

spawned inshore are dispersed relatively rapidly to the offshore (deYoung et al. 1994). Only near the heads of deep bays, such as Conception Bay, is there any indication of entrainment (op. cit.). These predictions largely agree with the Lagrangian drift of satellite tracked buoys (Figure 1) and are supported by biological data.

Capelin spawn on beaches throughout the inshore areas along the northeast coast of Newfoundland. Recent surveys have demonstrated that capelin larvae, once released from beach sediments, are dispersed throughout the inshore and are also advected relatively quickly to the offshore, as predicted by the models (Figure 2). These larvae ranged in length primarily from 5-15 mm, corresponding to ages of 1 to 40 days since release (at 0.34 mm d^{-1}; Frank and Carscadden 1989; J. Anderson, unpubl. data).

Historically, cod spawned throughout the inshore and offshore areas, with major spawning concentrations occurring on the outer shelf (Hutchings et al. 1994). In 1981, pelagic juvenile cod were distributed widely offshore, following the period of egg and larval drift (Anderson et al. 1995). This offshore distribution is consistent with major spawning occurring off southern Labrador, followed by downstream drift as predicted by the models. Comparison of inshore and offshore areas indicated that the inshore area may have contributed <10% of all eggs spawned annually (op. cit.).

Recently, in 1994, pelagic juvenile cod have been observed both offshore and inshore (Figure 3). This distribution is consistent with a known spawning concentration offshore near Hamilton Bank in the spring of 1994 (G. Rose, Chair of Fisheries Conservation, Memorial University of Newfoundland, per. comm.). Inshore spawning is also known to have occurred in recent years, consistent with the distribution of pelagic juvenile cod throughout the inshore in 1994. In 1995, pelagic juvenile cod occurred only sporadically offshore, although they occurred throughout the inshore (Figure 4). Again, this distribution is consistent with a low number of spawners occurring offshore in the spring of 1995 (G. Rose, per. comm.) and the presence of inshore spawning. Most recently, in 1996, pelagic juvenile cod were not found offshore and occurred only sporadically inshore (Figure 5). This distribution is consistent with a total absence of spawners offshore in 1996 (G. Rose, per. comm.) but conflicts with reports of spawning fish occurring inshore.

Recent observations on the distributions of pelagic juvenile cod, 1994-1996, indicate a significant contraction in the spawning distribution of northern cod. Spawning occurred both inshore and offshore in 1994, was primarily inshore in 1995 and was almost non-existent in 1996. This apparent collapse in the spawning distribution of northern cod may be related to both the distribution of spawners as well as their spawning condition. Inshore cod in 1996 were observed to have a low proportion of spawning cod at lengths > 60 cm (J. Brattey, per. comm.). Direct observations on both the distribution of spawning cod and their spawning condition should be carried out.

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List of Figures

Figure 4: Distribution of pelagic juvenile cod in September 1995. Dots represent sampling locations while the contours are based on $\log_{10}$ numbers 10^3m^{-3}.

Figure 5: Distribution of pelagic juvenile cod in August-September 1996. Dots represent sampling locations while the contours are based on $\log_{10}$ numbers 10^3m^{-3}.

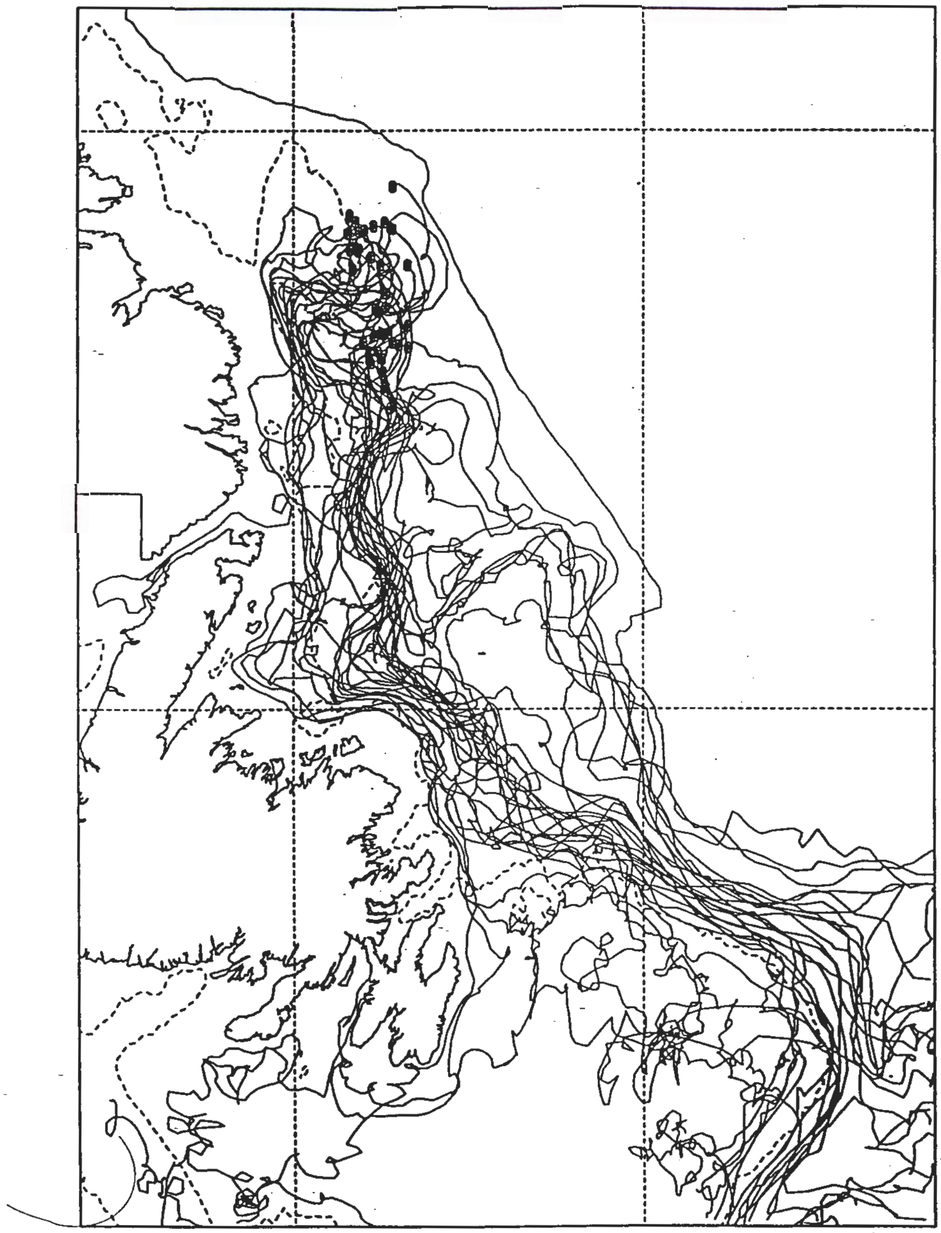
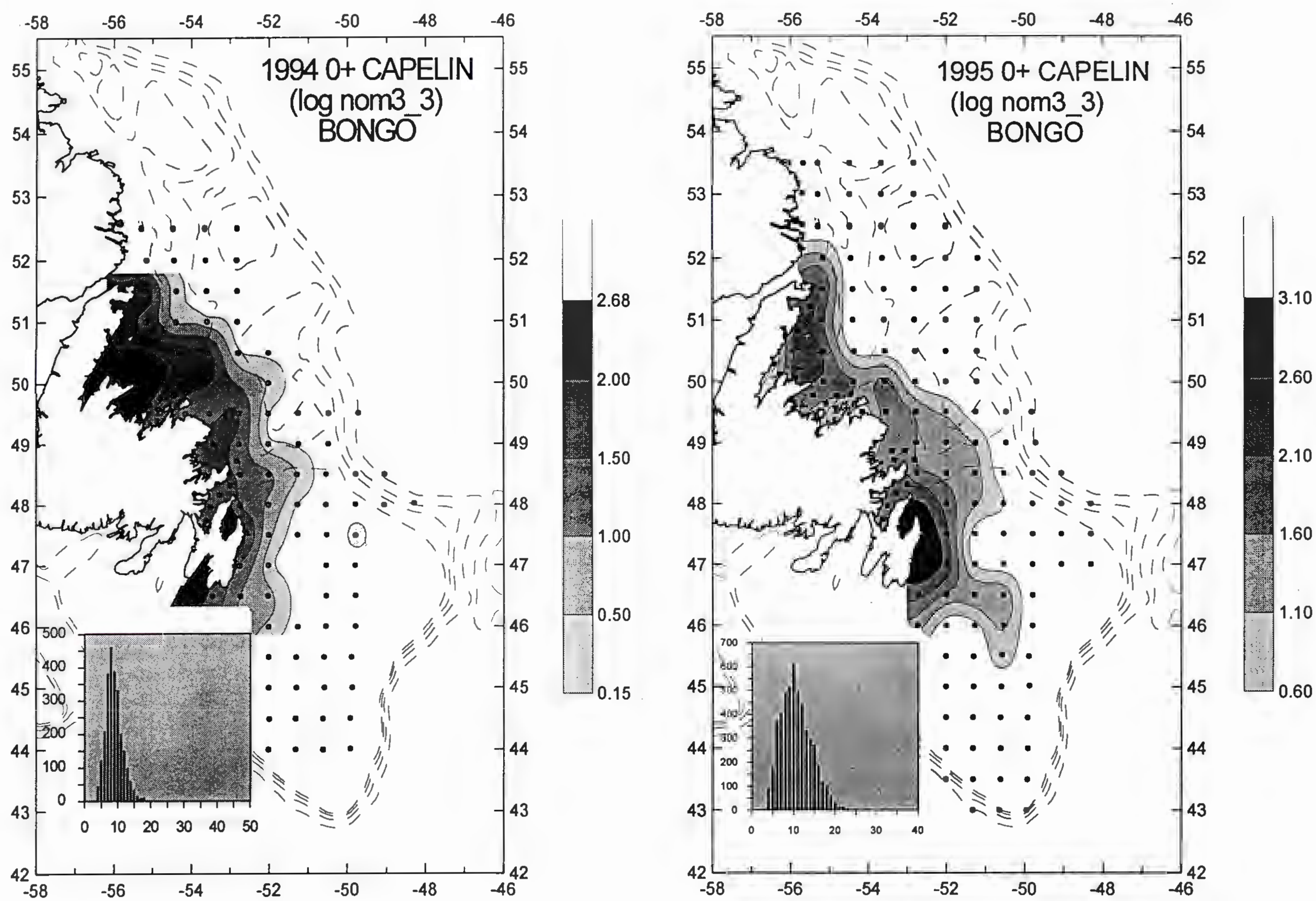


Figure 1.



1994 0+ CAPELIN
(log nom3_3)
BONGO
2.68
2.00
1.50
1.00
0.50
0.15
1995 0+ CAPELIN
(log nom3_3)
BONGO
3.10
2.60
2.10
1.60
1.10
0.60

Figure 2.

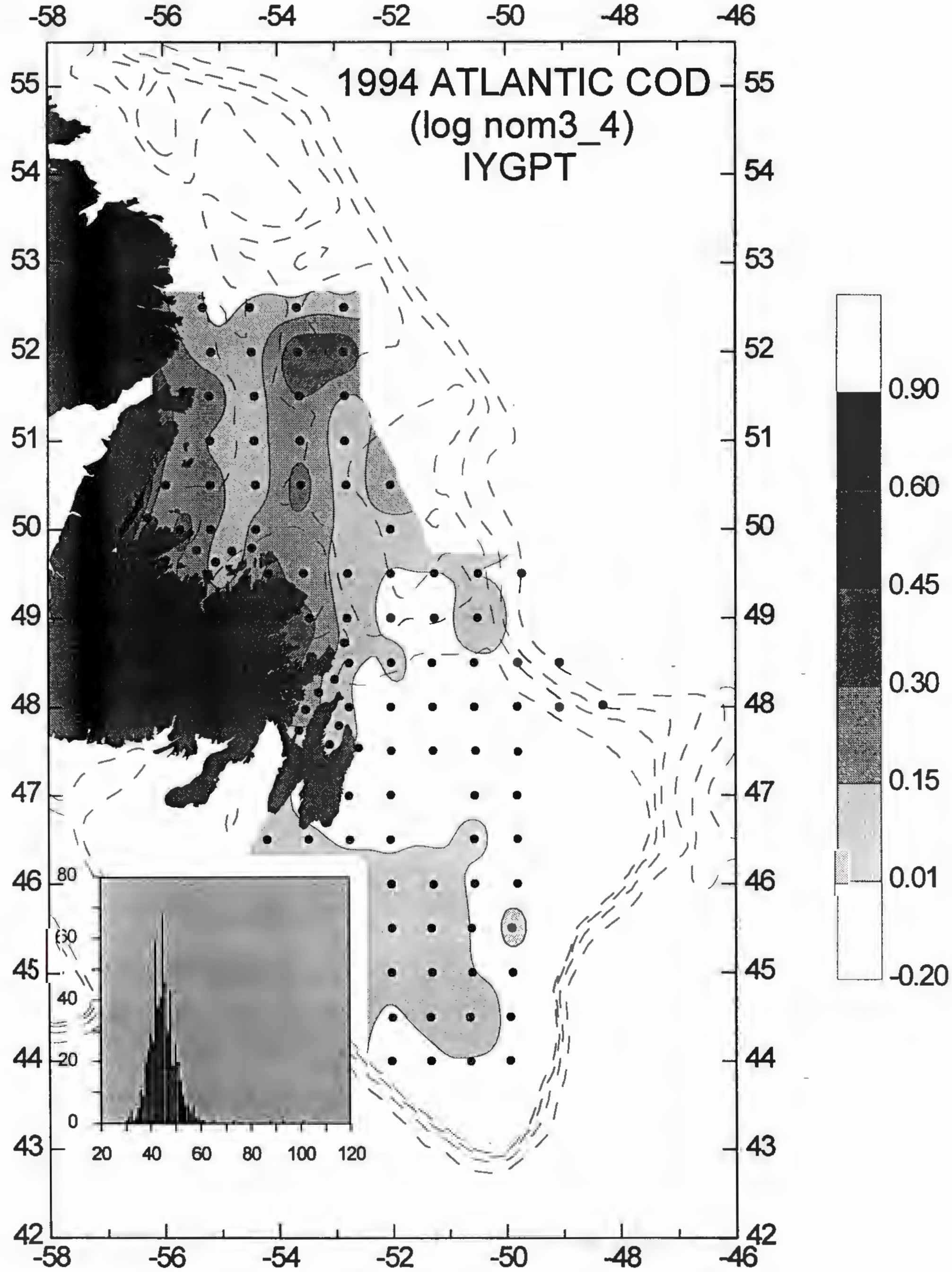

1994 ATLANTIC COD
(log nom3_4)
IYGPT
-58
-56
-54
-52
-50
-48
-46
55
54
53
52
51
50
49
48
47
46
45
44
43
42
0.90
0.60
0.45
0.30
0.15
0.01
-0.20
80
60
40
20
0
20
40
60
80
100
120

Figure 3.

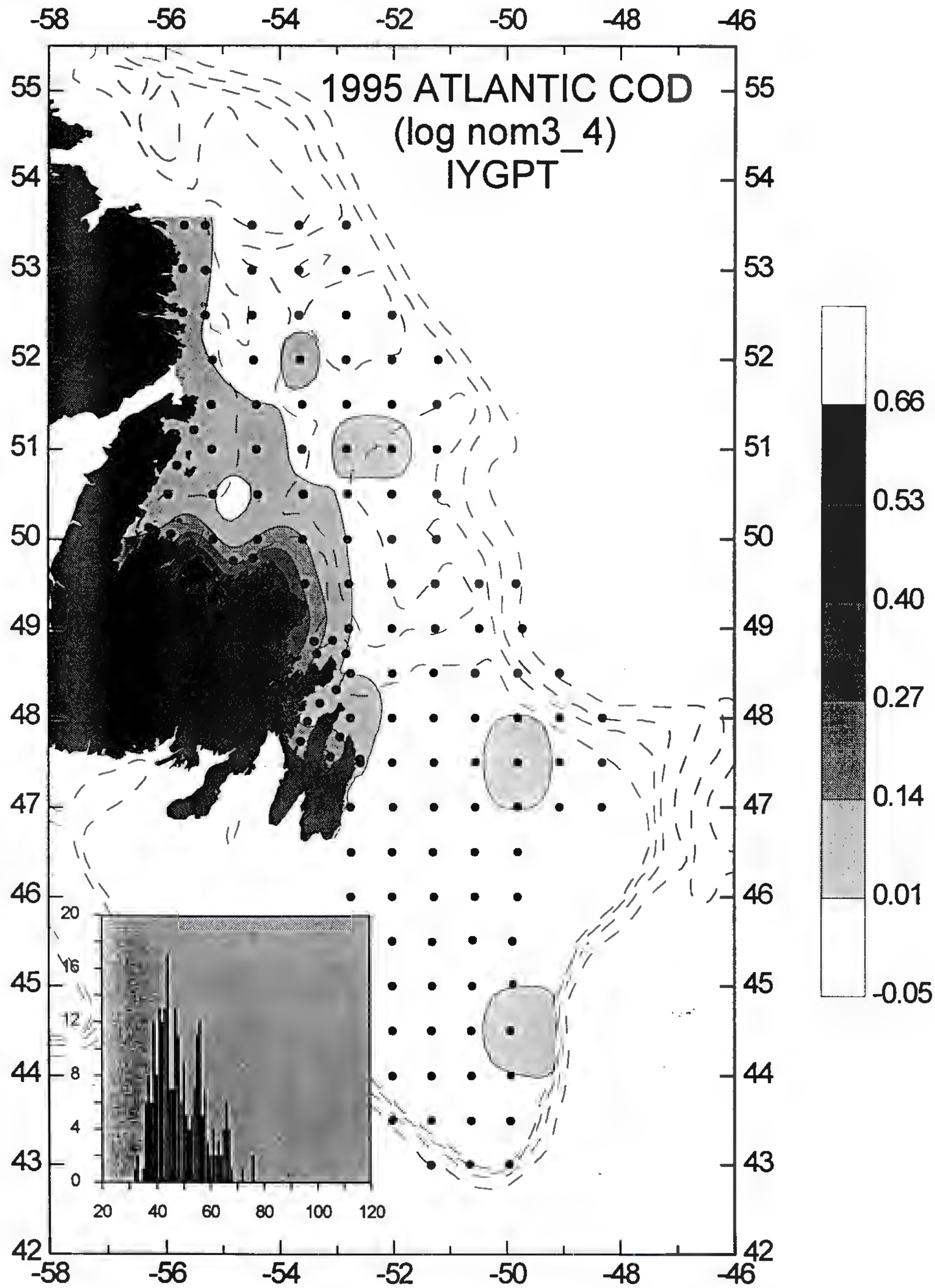

1995 ATLANTIC COD
(log nom3_4)
IYGPT
-58
-56
-54
-52
-50
-48
-46
55
54
53
52
51
50
49
48
47
46
45
44
43
42
20
16
12
8
4
0
20
40
60
80
100
120
0.66
0.53
0.40
0.27
0.14
0.01
-0.05

Figure 4.

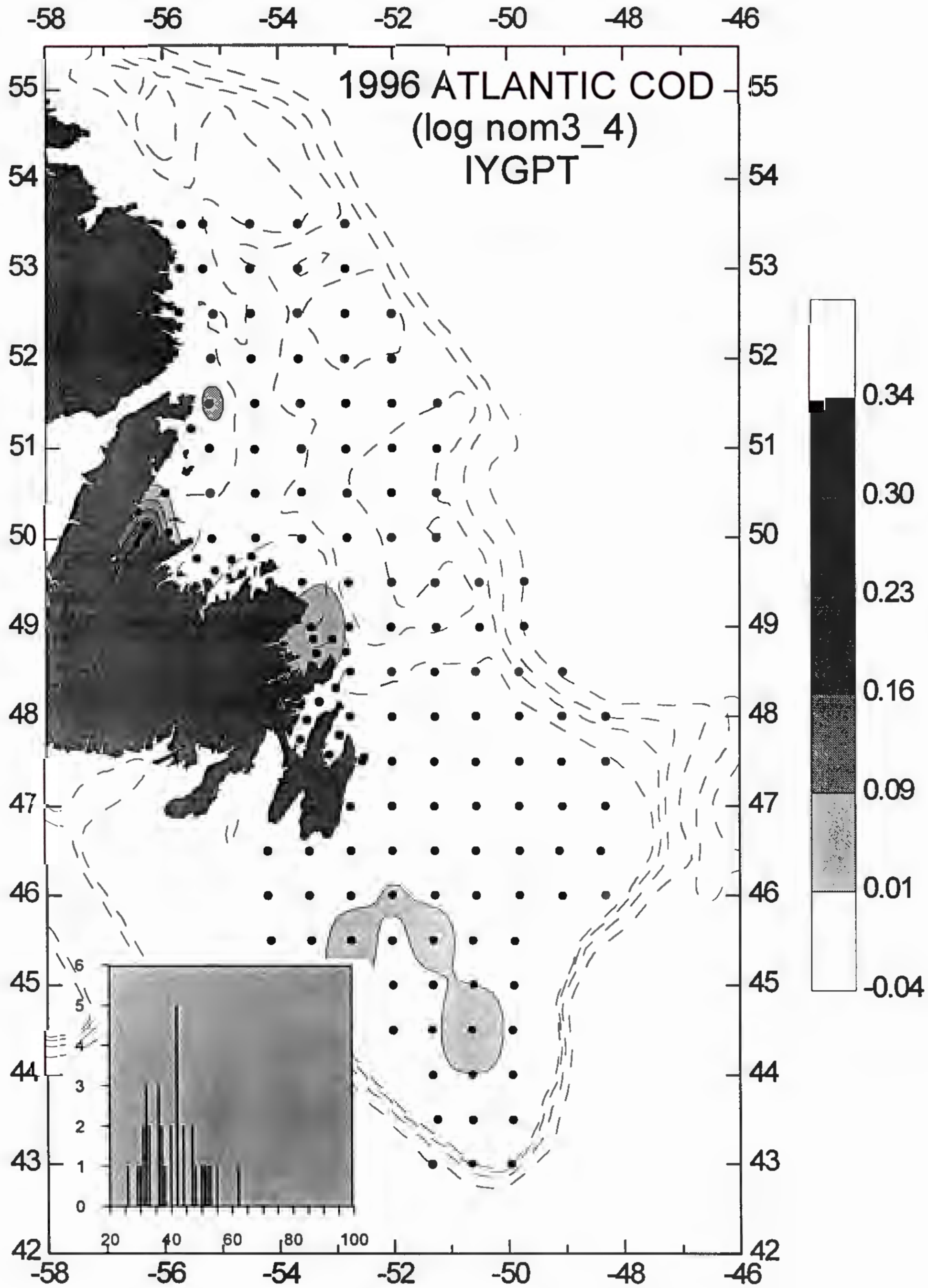

1996 ATLANTIC COD
(log nom3_4)
IYGPT
-58
-56
-54
-52
-50
-48
-46
55
54
53
52
51
50
49
48
47
46
45
44
43
42
0.34
0.30
0.23
0.16
0.09
0.01
-0.04

Figure 5.

Title: **Tracking the 1990 year class in the inshore of NAFO Divisions 3K and 3L** - J. Brattey

The age composition of the catch of juvenile cod in pelagic traps set at three inshore sites off northeast Newfoundland during May-Dec 1991-94 indicated that the 1990 yr class was consistently strongest at three of the four sites sampled over a 3-4 yr period; the only exception was at the most northerly site (St. Lunare) in 3K. Reconstruction of the age composition of juvenile cod found in seal stomachs from inshore areas off northeastern Newfoundland revealed similar findings, with age 1's dominating in 1991, age 2's in 1992, and age 3's in 1993. The appearance of aggregations of adult fish in the inshore off northeastern Newfoundland in recent years coincides with this year class reaching commercial size. Sampling of inshore cod during the recreational fishery, the Sentinel Survey, and inshore hydroacoustic/tagging surveys are also consistent with these findings and indicate that the 1990 year class is generally the most abundant in catches with various gears. These fish were spawned prior to the moratorium, but due to their small size (approx 20 cm) probably did not suffer much fishing mortality relative to previous year classes. Although detectable at age 1 in the inshore, whether these fish originate from inshore or offshore cod components remains unclear.

A Brief Overview on the Distribution of Demersal Juvenile Northern (NAFO Div. 2J3KL) Cod (Ages 0-3)

by E.L. Dalley and J.T. Anderson

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Summary

Historic Russian data, from the 1950's to the early 1990's (eg. Bulatova 1963, 1970, 1971, 1980, 1990; Kuzman and Tevs 1991) indicated that juvenile Atlantic cod occurred throughout the Newfoundland and Labrador areas (NAFO Divisions 2GHJ,3KLMNOPs). Age 0 cod were absent from the most northern areas (2GH), and occurred in only low numbers in 2J and on the Northeast Newfoundland Shelf, generally close to the Labrador and Northern Newfoundland coasts. From there numbers generally increased to the south. There was a distinct distribution on Flemish Cap, and western Grand Banks. Larger juveniles (12 -35 cm or 1-3 years old) were widespread throughout the area from northern Labrador to the southern Grand Banks. Highest catch rates were taken off southern Labrador, Flemish Cap and western Grand Banks. No sampling was done within the 12 mile coastal zone.

Canadian Groundfish surveys (2J3KL), carried out between 1981 - 1992 that used an Engels trawl designed to catch larger, commercial size fish, indicated that ages 1 to 4 were widespread on the shelf (Anderson 1993). There was a tendency for more age 1 fish to be taken nearer the coast. By age 3 and 4 there may be distinct concentrations on the shelf and/or shelf edge and age 2's were considered intermediate in their distribution between age 1's and older juveniles. Again neither the large inshore Newfoundland bays, nor the 12nm coastal zone was sampled.

Demersal juvenile cod surveys (3KL) carried out from 1992 to 1995, using a Campelen survey trawl, and including 25 fixed inshore stations (minimum depth ~ 60m), indicated an ontogenetic pattern in distribution (Dalley and Anderson 1997, Dalley *et al.* 1997). Age 0's, for the years examined, were almost entirely restricted to the large inshore bays. With increasing age, there is a logarithmic decrease in mean catch rate inshore, compared to offshore (See figure). Catch rates in Conception and Trinity Bays consistently ranked high, those in Bonavista and White Bay low, and Notre Dame Bay intermediate. Higher mean catch rates inshore in 1994 were largely driven by relatively high abundances in a low number of stations in inner

Trinity Bay. It is suggested that low abundances in Bonavista Bay are the result of the survey being restricted to trawlable areas. There is evidence to suggest that juvenile cod, through habitat selection, may be abundant in untrawlable areas (Gregory *et al.* 1996).

Historic data (Lear *et al.*1980) from 1959-64, and recent (Schneider *et al.* 1997) beach seine data indicated that relatively high numbers of juvenile cod, particularly age 0 and 1, also occurred in the very nearshore, in the late summer and fall. Also passive, small meshed Japanese pelagic traps set at 4 sites from Conception Bay in the south, to the tip of the Great Northern Peninsula (Dalley *et al.* unpublished data) indicate that thousands of age 0 to 3 juveniles migrate along the coast during the ice-free season. Monthly age frequency distributions, and weekly length frequency distributions indicated that cohorts of juveniles appearred , increased , decreased and disappearred from particular trap sites. From the southern to the northern site there was an increase in incidence of older (age 3 and 4) juveniles coupled with a decrease in incidence of age 1 and 2 juveniles. It is suggested that a tagging program carried out on these migrating juveniles might be useful in determining the interrelationships between northern and southern, and inshore and offshore components, particularly with regard to recruitment patterns, if in fact they are distinct between components.

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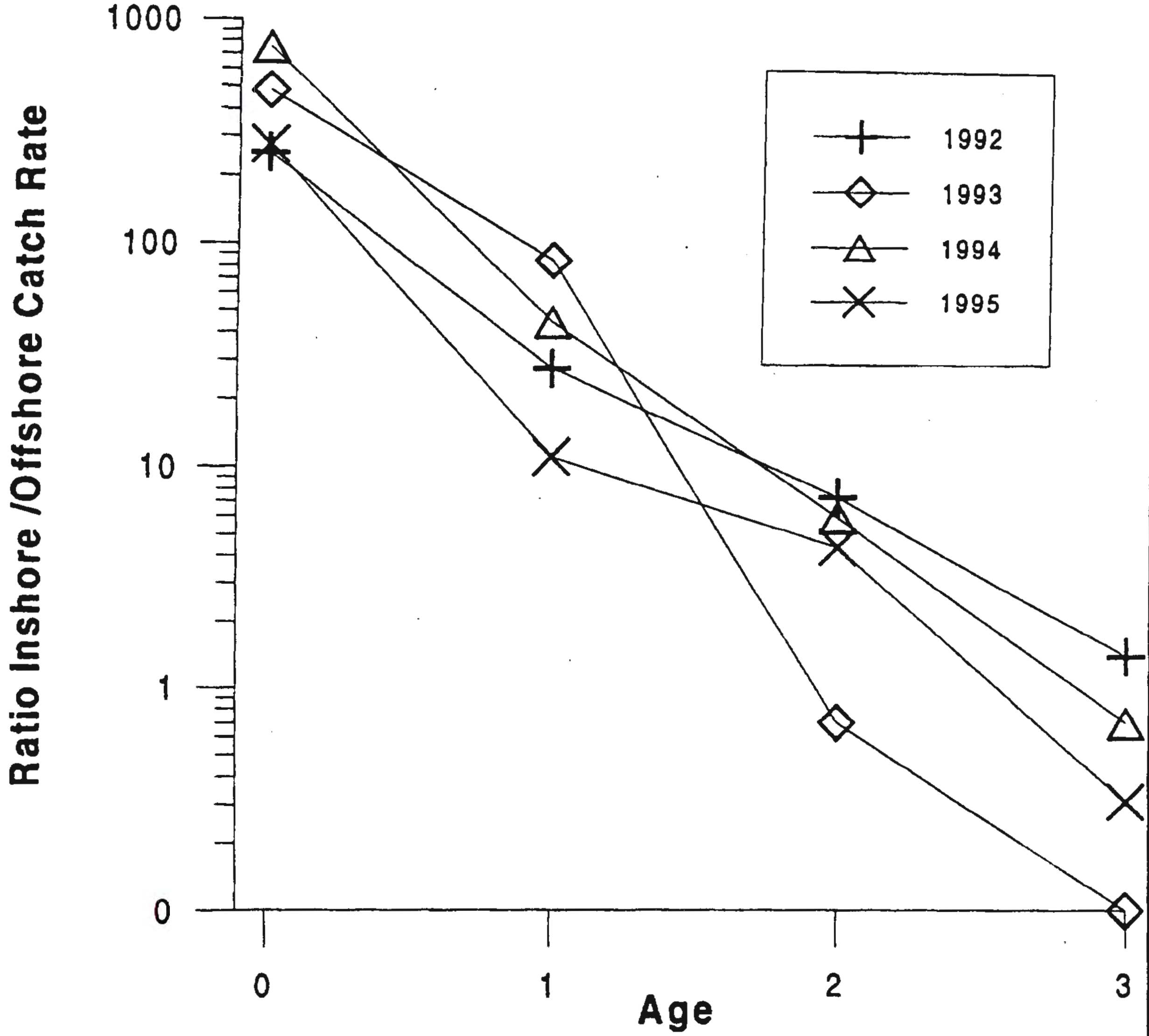

Ratio of mean inshore/offshore catch rate for age 0 to 3 demersal juvenile cod caught in demersal surveys in 3KL, 1992 - 1995.

An overview of current genetic methods and prospects for use in inshore-offshore stock differentiation

Terry D. Beacham

The major uses of genetic variation in fisheries management were reviewed: (1) species identification, (2) determination of population or stock structure, (3) estimation of stock composition in mixed-stock fisheries, and (4) identification of individuals to specific stocks. Techniques to measure genetic genetic variation reviewed were: (1) protein electrophoresis, (2) sequencing or restriction fragment length polymorphism (RFLP) of mitochondrial DNA, (3) probing of polymerase chain reaction (PCR) of minisatellite DNA, (4) PCR of microsatellite DNA, (5) RFLP or denaturing gradient gel electrophoresis (DGGE) of non-coding nuclear DNA sequences, and (6) DGGE analysis of major histocompatibility complex (MHC) genes. It was predicted that minisatellite DNA and non-coding nuclear DNA sequences would be useful in determination of local population structure, but because they are RFLP based, would be of limited practicality in estimation of stock composition. Microsatellite DNA and DGGE analysis of MHC genes would be very useful in determination of population structure, and practical to implement for determination of stock composition in mixed-stock fisheries.

Analysis of variation at MHC genes of cod sampled from the Flemish Cap, offshore 3K, and inshore 3K indicated that there were differences in frequencies of MHC alleles among the three samples (Fig. 1), and that there was signfiicant genetic differentiation among the samples as indicated by principal component analysis (Figs. 2, 3). Before one can conclude that the stocks are genetically distinct, it is necessary to compare differentiation among stocks to annual variation within stocks.

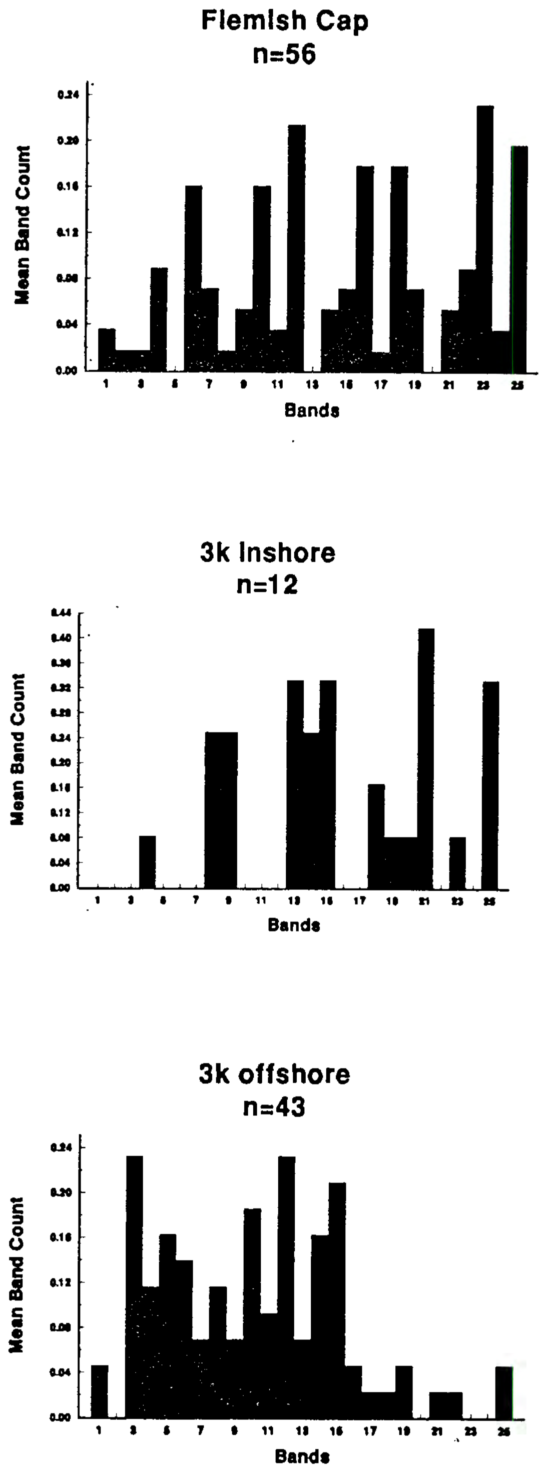

Fig. 1. Mean allele (band) counts at MHC loci for cod sampled from the Flemish Cap, inshore Div. 3K, and offshore Div. 3K.

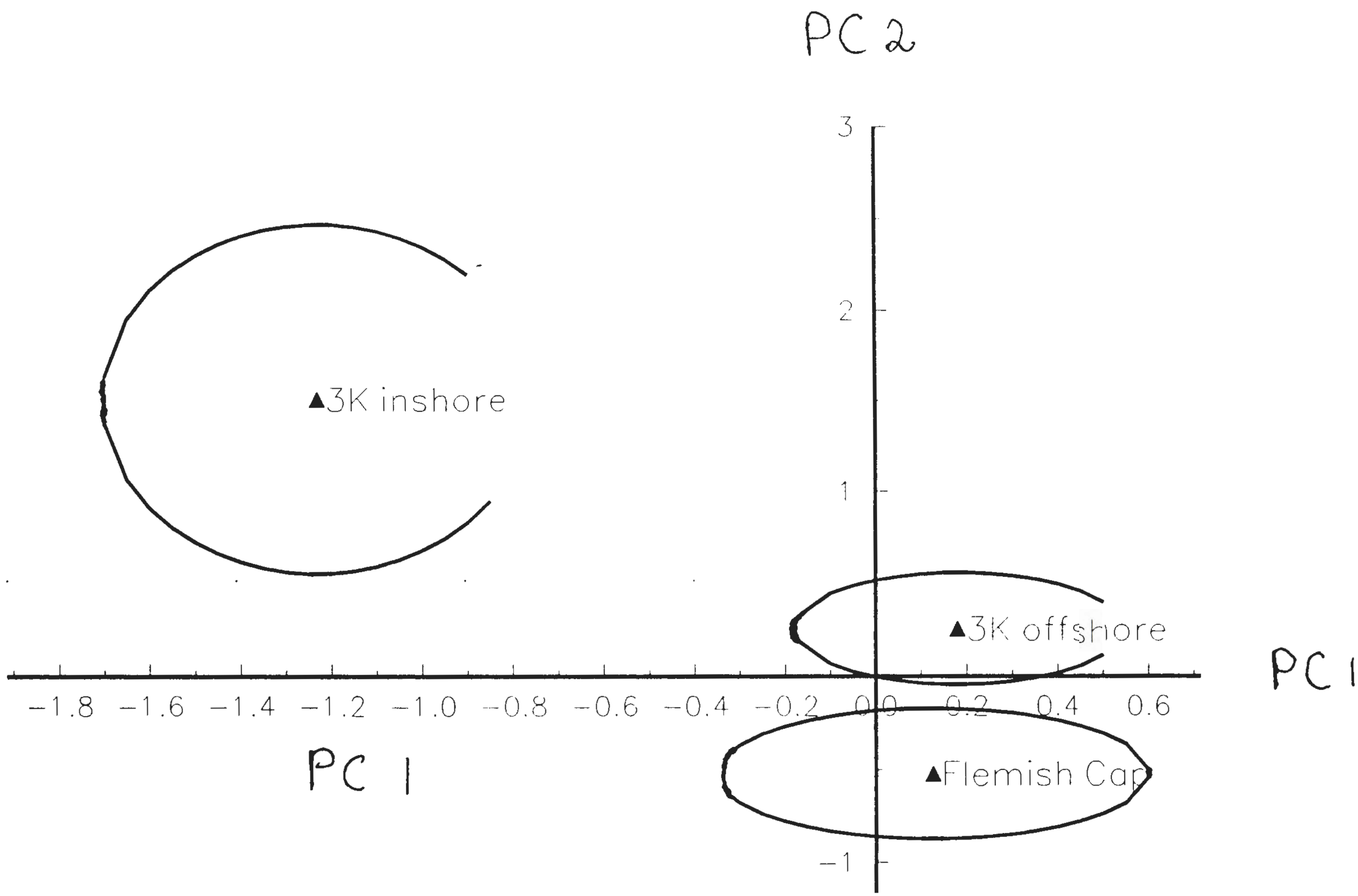

Fig. 2. Principal component analysis outlining population centroid and 95% confidence ellipse for centroid.

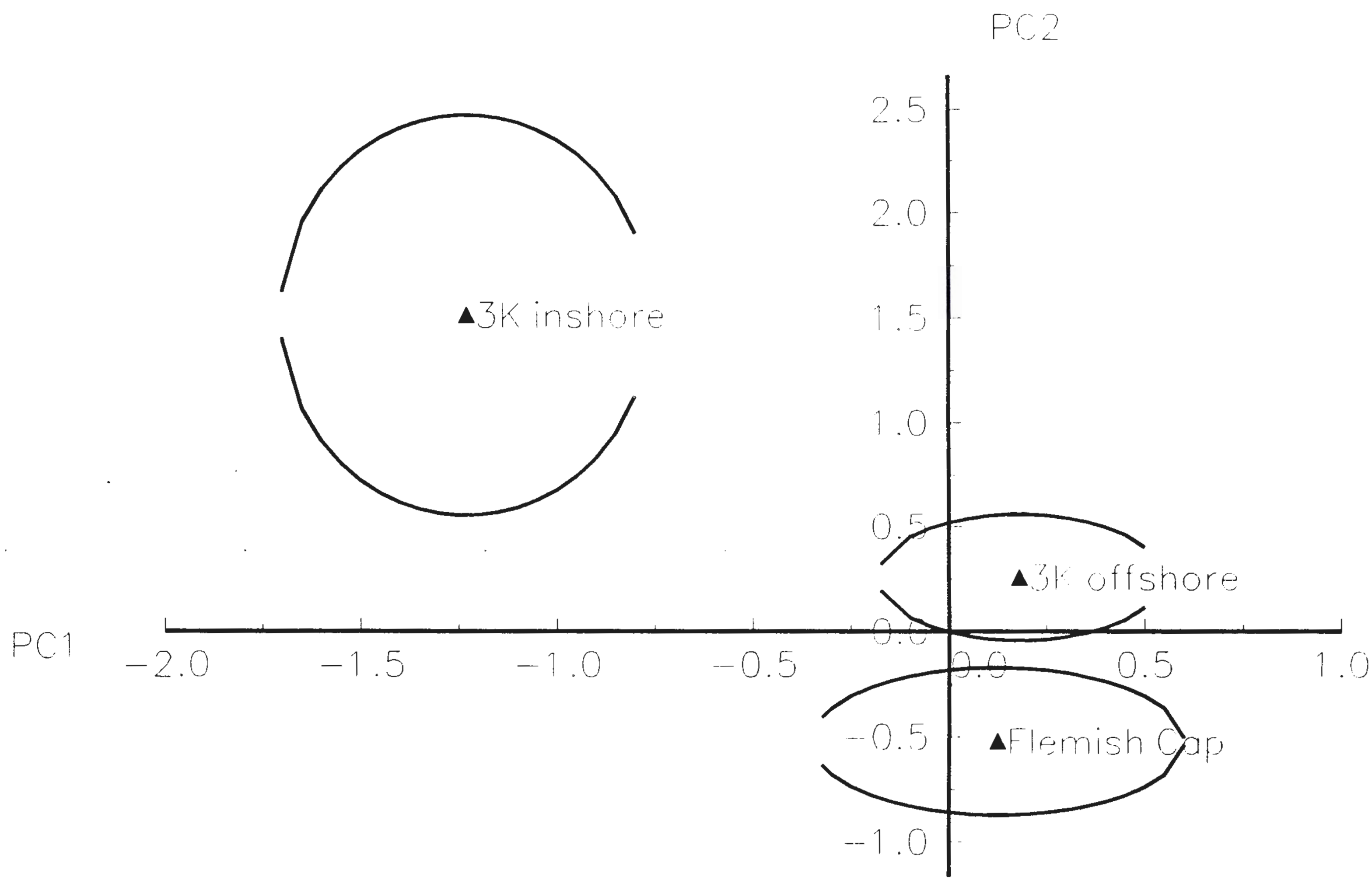

Fig. 3. Principal component analysis outlining population centroid and 95% confidence ellipse for centroid.

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Contrasting patterns of mitochondrial DNA population genetic structure in Atlantic Cod (*Gadus morhua*) from the western and eastern Atlantic and Barents Sea

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"Canadian Journal of Fisheries and Aquatic Sciences," in preparation.

Abstract

The nucleotide sequence of a 401 base-pair region of the mitochondrial cytochrome *b* gene was obtained for 294 Atlantic cod (*Gadus morhua*) from the Barents Sea and seven locations in the Northwest Atlantic. A total of 32 genotypes were identified. Population genetic structures of the Northwest Atlantic and Barents Sea samples differ significantly. Whereas all samples from the Northwest Atlantic are dominated by a single common genotype and show low haplotype and nucleotide diversity (h = 0.40 and π = 0.00018, respectively), the single Barents Sea sample supports two major genotypes at equal frequencies and shows much higher genetic diversity (h = 0.79 and π = 0.00038). Genotype distributions differ significantly between the Northwest Atlantic and the Barents Sea; the former samples are not differentiated among themselves. Essentially none of the genetic variance in the Northwest Atlantic is attributable to subdivision among samples (coancestry coefficient ≈ 0.00), whereas a substantial proportion (= 0.24) of the trans-Atlantic variance exists among samples. Present levels of gene flow are sufficient to preclude formation of genetically distinct subcomponents or stocks within the Northwest Atlantic.

Similar patterns are observed among samples from elsewhere in the western Atlantic (T. Kocher, pers.com.). In contrast, data on cod populations from Norway and Iceland (Einar Arnason, pers. com.) show substantially higher levels of variation and among-sample subdivision. Samples from two Norwegian fjords are more differentiated than any pair of populations in the western Atlantic. These results support the theory that cod throughout the western Atlantic have experienced a bottleneck in population size relative to their source population in the Old World. The results show that mtDNA haplotypes are sensitive markers of population structure; much more so than nuclear alleles, they are sensitive indicators of fluctuations in population size.

A critique of some common misconceptions about genetic markers in Atlantic cod

1. "MtDNA is not very polymorphic compared to nuclear loci."

WHAT THE DATA SHOW: **Polymorphism** should be distinguished from **heterogeneity**: the former measures the multiplicity of genotypes, the latter measures the probability that two genotypes will be different. MtDNA in the Northwest Atlantic is highly polymorphic and not very heterogeneous: more than 46 genotypes have been identified at the cytochdrom *b* locus, but most of these are rare. MtDNA in the eastern Atllantic and Barents Sea is both highly polymorphic and highly heterogeneous: multiple genotypes exist at sub-equal frequencies.

2. "Nuclear DNA has a greater potential to detect variation and population structure than mtDNA."

WHAT THE DATA SHOW: Population structure of mtDNA can be measured by the coancestry coefficient, which is analogous to the F_{ST} statistic used for nuclear loci. MtDNA is more sensitive to fluctuations in population size ("bottlenecks" and "founder events") than are nuclear loci. The pattern of variation noted in the Northwest Atlantic is characteristic of a bottleneck: nuclear markers have failed to detect this important phenomenon in the biology of Northern Cod.

Unlike diploid markers, mtDNA is transmitted maternally, without recombination. This permits reconstruction of the phylogeny of genotypes, something that is difficult or impossible with nuclear markers. The "star phylogeny" characteristic of a bottleneck was detected in this way.

3. "MtDNA fails to detect evidence of population structure."

WHAT THE DATA SHOW: MtDNA data have been used to measure the proportion of the observed genetic variance that is attributable to among-sample heterogeneity of genotypes. This value (the coancestry coefficient) ihas been measured as essentially zero in the Northwest Atlantic, which indicates that there is no population structure. **Estimating a parameter as zero is not equivalent to a 'failure' to detect the value of the parameter.** In contrast, a signficant proportion of the trans-Atlantic or inter-European variance is attributable to among-sample variation. Thus, the absence of structure in the Northwest Atlantic is a feature of their biology, not a 'failure' of the method. Similar results are obtained in Greenland halibut, a highly polymorphic and heterogeneous species, in which genotype frequencies are uniform throughout the commercial range and on both sides of the Atlantic.

4. "Nuclear DNA and mitochondrial DNA show contrasting patterns of stock structure."

WHAT THE DATA SHOW: Patterns are actually quite similar: it is interpretations that vary. Both genetic systems indicate that populations in the western and eastern Atlantic differ significantly: Both systems indicate that Flemish Cap samples are distinguishable. Nuclear markers indicate differentiation of allele frequencies across the Gulf of St. Lawrence; mtDNA markers indicate somewhat more variation south of the Gulf but no differences in allele frequencies. **Most importantly, both nuclear and mtDNA indicate that little or none of the genetic variation detected in the western Atlantic is attributable to among-sample differentiation consistent with the notion of distinct stocks:** the measured coancestry coefficient for mtDNA is 0.0, and the measured F_{ST} for microsatellites is less than 2%. Equivocal evidence that nuclear markers can sometimes be used to distinguish samples drawn from different management areas should not be misinterpreted as evidence of distinct stocks in those areas.

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S. M. Carr, A. J. Snellen, K. A. Howse, and J. S. Wroblewski. 1995. Mitochondrial DNA sequence variation and genetic stock structure of Atlantic cod (*Gadus morhua*) from bay and offshore locations on the Newfoundland continental shelf. Can. J. Fish. Aquat. Sci. 4:79-88.

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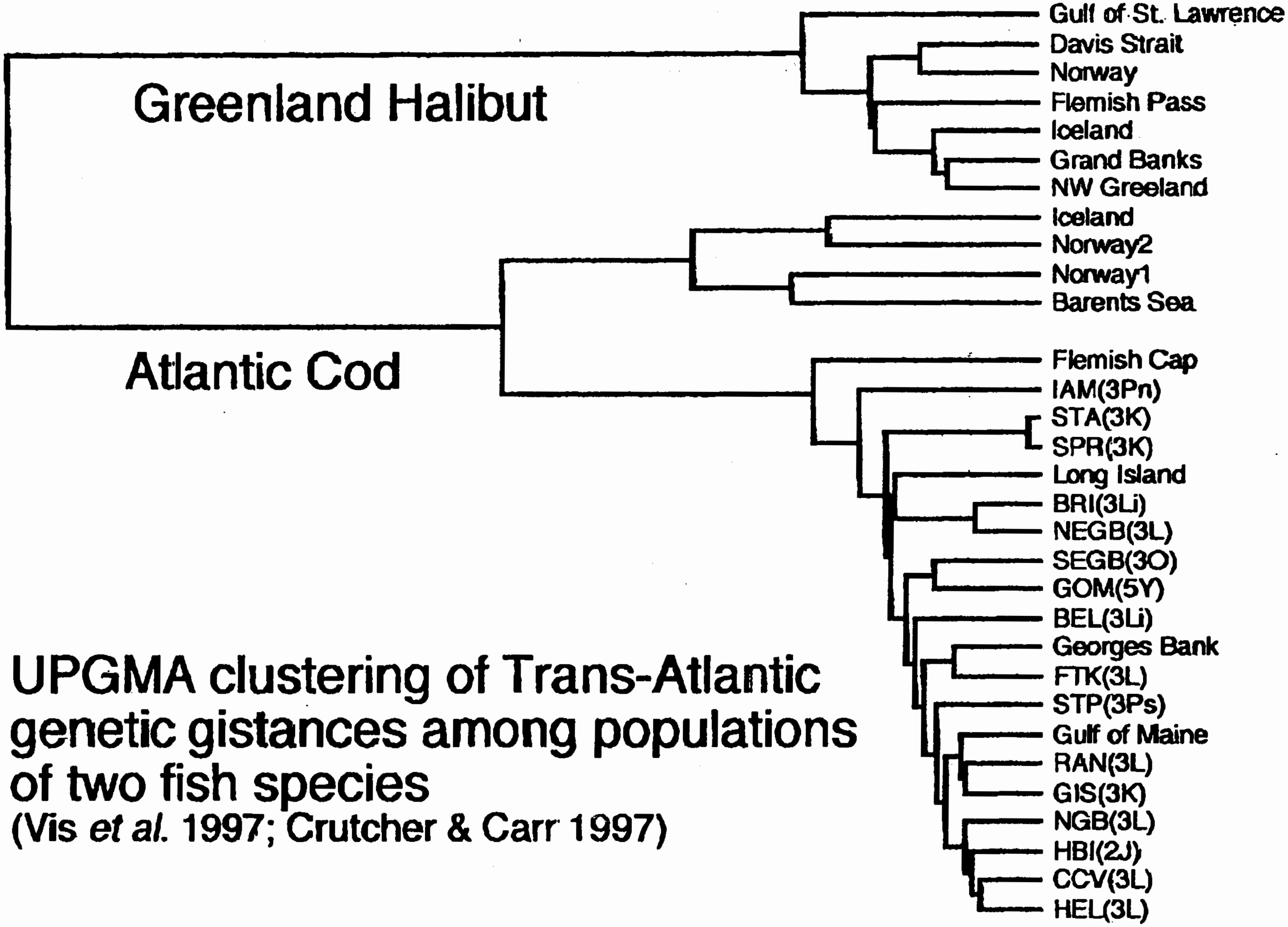

UPGMA clustering of Trans-Atlantic genetic gistances among populations of two fish species

(Vis *et al.* 1997; Crutcher & Carr 1997)

Genetic structure of NW Atlantic cod using nuclear DNA microsatellites.
Presented by C.T. Taggart and D.E. Ruzzante.

- **Genetic evidence of population structure in Northwest Atlantic cod.** Allelic variation in six highly polymorphic microsatellite loci (mean heterozygosity, 86%) provided evidence that cod (*Gadus morhua*) in the Northwest Atlantic belong to multiple genetically distinguishable populations, and further, that genetic differences may also exist between north-western and south-eastern cod aggregations within the northern cod stock complex off Newfoundland. Cod were sampled from winter aggregations ranging from Hamilton Bank to the northern Grand Bank in the northern cod complex, and from the Flemish Cap, the Scotian Shelf and the Barents Sea. Tests of allele frequency homogeneity (χ^2), F_{st}, and $(\delta\mu)^2$, allele sharing and Rogers' distance measures revealed significant differences among northern cod, Flemish Cap, Scotian Shelf and Barents Sea samples. Within the northern cod complex, two pooled samples, NORTH (Hamilton, Funk and Belle Island Banks) and SOUTH (northern Grand Bank area) were distinguishable using χ^2, $(\delta\mu)^2$ and allele sharing measures. Both $(\delta\mu)^2$ and Rogers' distances clustered western Atlantic samples in two groups distinct from the divergent Barents Sea sample; one comprised NORTH, SOUTH and Scotian Shelf, and the other, Flemish Cap. *For more information see: Bentzen, P., C.T. Taggart, D.E. Ruzzante and D. Cook. 1996. Microsatellite polymorphism and the population structure of Atlantic cod (Gadus morhua) in the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 53(12): 2706-2721.; or contact Paul Bentzen <pbentzen@fish.washington.edu> or <chris.taggart@dal.ca>*

- **Historical DNA test of disrupted population structure in the northern cod.** Cod otoliths collected during 1964 and 1978 from Hamilton, Belle Isle, and Funk Island banks and from the Flemish Cap and the Grand Bank were used as sources of nuclear DNA (using PCR techniques) for genetic comparisons with contemporary cod tissue collected during 1992-93 in similar regions. The genetic analyses of the samples was based on frequencies of alleles at four microsatellite loci. Pre- and post-collapse genetic distances did not differ significantly; i.e. there was no genetic evidence for a loss of geographical substructure of the cod populations during their recent decline in abundance, at least up until 1992-93. The possibility of changes in population structure between the 1964-78 period and the 1992-93 period was also tested by cross-validation of the post-collapse latitudinal positions using genetic data from the pre-collapse samples. No systematic differences between the true and cross-predicted latitude of the post-collapse samples were evident. *For more information on the analysis of historical data contact <roger.doyle@dal.ca>*

- **Tagging evidence of population structure in Northwest Atlantic cod .** Proper resolution of population structure is necessary not only for the interpretation of temporal and spatial variations in the biology of a species, but also for successful management. This is particularly true for the seriously depleted northern cod stock complex (NAFO Divisions 2J, 3K, and 3L). Data collected over the last three decades from tagging studies conducted in Winter on Hamilton and Belle Isle Banks and in the North Cape region of the northern Grand Bank were employed to assess migrational patterns in northern cod and to compare those patterns to the population structure described in recent genetic studies conducted on populations from the same regions (*Bentzen et al. Can. J. Fish. Aquat. Sci. 53(12): 2706-2721).* The results revealed that the average geographic distribution of cod tagged in the vicinity of Hamilton Bank in Winter overlaps in the offshore Winter distribution with those tagged on Belle Isle Bank (i.e. the populations can intermingle during the offshore spawning period). The average geographic distribution of cod tagged in Winter in the North Cape region does not overlap with those fish tagged on either Hamilton or Belle Isle Bank. Likewise, the average Winter distributions of cod from the latter two banks do not overlap with those from the North Cape region. These results are entirely consistent with recent and earlier genetic studies of populations from the same regions and suggest that the northern cod stock complex is comprised of at least two discrete offshore populations. The results from this study were used to present a testable hypothesis to explain anomalous distributions in recent years for northern cod in the offshore and inshore regions of Newfoundland. *For more information see: Taggart, C.T. Bank-scale migration patterns in northern cod. 1997. NAFO Sci.Counc.Stud. in* *press.; Taggart, C.T., P. Penney, N. Barrowman, and C. George. 1995. The 1954-1993 Newfoundland cod-tagging database: statistical summaries and spatial-temporal distributions. Can. Tech. Rep. Fish. Aquat. Sci. 2042.; or contact <chris.taggart@dal.ca>*

- **The population structure of Atlantic cod (*Gadus morhua*) in the northwest Atlantic from Northern Newfoundland to the Bay of Fundy and the Gulf of Maine.** In this study we examined the genetic structure of cod (*Gadus morhua*) aggregations spanning the species' native range in the North West Atlantic, from Northern Newfoundland (Hamilton Bank, Belle Isle Bank, and Hawke Channel) to the Gulf of Maine (Georges Bank) and the Bay of Fundy. Allelic variation in five microsatellite DNA loci provided evidence of population structure at several scales of spatial resolution. Using $(\delta\mu)^2$ and D_{sw} measures of genetic distance as well as correspondence analysis based on allelic frequencies we describe differences among populations on neighbouring banks that are separated by relatively deep channels or that are characterized by distinct oceanographic regimes, as well as among populations that are geographically further apart. Cod aggregations on Georges Bank are genetically distinguishable from cod aggregations on Brown's Bank and Bay of Fundy, and cod on Brown's Bank are genetically distinguishable from cod in the Bay of Fundy. There is a cline in the genetic composition of cod aggregations on the Scotian Shelf with the southernmost population on Brown's Bank being more different from Northern cod than the more northerly aggregations of Western Bank and Banquereau Bank. Cod sampled on Flemish Cap are genetically distinct from neighbouring cod aggregations located within the Northern Cod stock complex. Within the Northern Cod stock complex, cod from the northern part appear genetically distinguishable from cod aggregations sampled in the area of the Grand Bank. Cod sampled within Placentia Bay appear to belong to multiple genetically distinguishable stocks with collections made as part of the Interim Funding Research Project (IFRP - February-April 1995) being indistinguishable from cod collected in the area of Scatarie (collected July 1994), Trinity Bay (collected at different times between 1992 and 1995, but in general thought to be representative of inshore overwintering fish), and St. Anthony Basin and Notre Dame Channel (collected June 1994), but collections made in the summer of 1995 in the area of North Harbour and Saint Brides being genetically distinguishable from most other populations and thought to represent inshore fish. These latter results clearly indicate that sampling times and locations, relative to spawning times and locations are critical for interpretive analyses. *For more information see: Ruzzante, D. E., Taggart, C. T., and Cook, D. The population structure of Atlantic cod (Gadus morhua) in the northwest Atlantic from Northern Newfoundland to the Bay of Fundy and the Gulf of Maine (manuscript in preparation) or contact <ruzzante@cs.dal.ca> or <chris.taggart@dal.ca>*

- **Spatial and temporal variation in the genetic composition of a larval cod cohort.** Polymorphism at six microsatellite DNA loci among cod larvae sampled repeatedly over a three week period from an aggregation on Western Bank of the Scotian Shelf provided evidence of several heterogeneous groups within the aggregation. There was strong evidence of heterozygote deficiency and departure from Hardy-Weinberg expectations for the larval aggregation as a whole (N=1337) and for all larvae sampled within a single water mass (CW larvae), but not for a subset of these larvae considered to be part of a single cohort on the basis of age-at-length. These results suggest that both the entire aggregation and the CW subset originated from several distinct spawning events involving spawners with heterogeneous allelic compositions, but that the larvae forming the cohort originated from a single spawning event. The results establish a link between the ecological match-mismatch hypothesis and the genetic "sweepstakes" selection hypothesis. There was no evidence that the larvae originated from different populations as measured by $(\delta\mu)^2$ distance, R_{st}, and F_{st} estimates among subsets. Additional analyses showed the larval cohort to have greater genetic similarity to adult cod sampled on Western Bank two years later than to adult cod sampled on Banquereau Bank (»150 km away) also two years later. These results suggest the genetic composition of cod on Western Bank remains stable over time. *For more information see: D.E. Ruzzante, C.T. Taggart, and D. Cook. 1996. Spatial and temporal variation in the genetic composition of a larval cod (Gadus morhua) aggregation: cohort contribution and genetic stability. Can. J. Fish. Aquat. Sci. 53(12): 2695-2705.; or contact <ruzzante@cs.dal.ca> or <chris.taggart@dal.ca>*

- **Bias and variance in genetic distances and population structure using microsatellites.** Because of their large number of alleles inherited in a Mendelian fashion, microsatellite DNA are well suited to examine the genetic/demographic structure of fish populations. However, the large number of alleles imply large sample sizes are required for accurate reflection of genotypic frequencies. Measures of genetic distance are often biased at small sample sizes, and biases and sampling variances can be affected by the number of, and distance between alleles. Using data from a large collection of larval cod (*Gadus morhua*) from a single population the effect of sample size on nine measures of genetic distance was examined. Pairs of samples of various sizes were drawn at random from a pool of 856 individuals scored for six microsatellite loci. Sample sizes were either equal or different. $(\delta\mu)^2$, D_{sw}, R_{st}, and F_{st} were the most informative measures. Sample sizes of $50 \leq N \leq 100$ individuals were in general necessary for precise estimation of genetic distances and this value depended on number of loci, number of alleles and range in allele size. Differences in sample sizes increased the sampling variance of R_{st} but not that of other measures. $(\delta\mu)^2$ and D_{sw} were biased at small sample sizes. *For more information see Ruzzante, D.E. A comparison of several measures of genetic distance and population structure with microsatellite data: bias and sampling variance. Can. J. Fish. Aquat. Sci.: In review (Submitted Sept. 1996); or contact <ruzzante@cs.dal.ca>*

Treatment of inshore-offshore data in the 1996 Div. 3Ps cod assessment

Peter Shelton

An attempt was made to carry out separate SPAs of inshore and offshore subcomponents of the 3Ps cod stock (Shelton et al. DFO Atl. Fish. Res. Doc. 96/91). This was thought to be necessary because of apparently different trends in the abundance of fish in the inshore and offshore. The offshore SPA was calibrated with RV data and the inshore SPA was calibrated with catch rate data from fixed gear (log book data for vessels >35' representing a small percentage of the fixed gear landings). For the inshore, the estimated numbers at age suggested a fairly constant population size, whereas for the offshore the estimates suggested that the population increased rapidly in the early 1980s and then declined steeply. Although the two analyses were indepenent, both indicated a relatively strong 1989 year class, suggesting either some degree of mixing, or a similar responsed to environmental conditions by both components of the stock. The peer review of the assessment concluded that the underlying assumption of separability on which the analyses were based was too tenuous and uncertain to provide a quantitative estimate of current stock size or F0.1 catch.

Fixed gear catches and catch rates

Eugene Murphy and Peter Shelton

Catch statistics for the 2J3KL and 3Ps cod fisheries are obtained from purchase slips and log-books. Only vessels greater than 35' complete log-books and these vessels comprise a very small portion of the inshore fixed gear catch. Thus the bulk of the catch data comes from purchase slips. Purchase slips do not contain information on the amount of gear, number of sets, soak time, etc., thus no estimate of effort can be derived from them. A field was created on the purchase slip for amount of gear at some point, but these data were infrequently recorded and almost never punched. In the 1986 and 1987 2J3KL cod assessments an attempt was made to
used catch per purchase slip as an index. However, the splitting of the catch between several purchase slips after 1986 precludes a similar analysis with the more recent data. Instead we have calculated the catch per month for the period 1975 to 1992 by NAFO Unit Area and fixed gear type (traps, gillnets and line trawls). The data do not indicate a universal decline in fixed gear catches in the late 1980s and early 1990s. Some areas had declining catches whereas other areas had increasing catches and still other areas had more or less constant catches.

Update of recent RV data for 2J3KL cod

Don Stansbury

Cod were scarce in the fall 1996 2J3KL survey, even though 16 new nearshore strata were added to the survey area. The length frequency distributions in the offshore strata were quite symmetrical, with a mode at around 30 cm in 2J and 3K and around 45 cm in 3L. In the new inshore strata the mode was slightly less - about 25 cm, whereas the length frequency for the inshore strata in 3L was quite skewed toward smaller fish with a mode at about 20 cm. In terms of recruitment, the distributions are of some concern because they do not, with the exception of inshore 3L, indicate any abundance of small fish, despite the increased selectivity of small fish by the Campelen trawl. The mode in 3L is of a length that could attribute these fish to the Smith Sound spawning aggregation which was considered to be fairly abundant in 1995. These fish came mainly from the stratum at the mouth of Conception Bay. Overall, recruitment into the 2J3KL cod stock looks poor and there are also few fish over 50 cm. It should be noted that the Smith Sound aggregation has been estimated to be much smaller in 1996. Prospects for stock rebuilding are bleak, and dependent on the few remaining mature fish in the inshore.

Including harp seal removals in the SPA for 2J3KL cod

Don Stansbury, Peter Shelton and Garry Stenson

The harp seal population is estimated to have been at about 4.8 million in 1994 and growing at about 5% per year. Although cod is not a major component of the seal diet, if is a fairly consistent prey item. Estimates of cod removals by harp seals have been made by the Marine Mammal Section for the period 1981 to 1994 based on a consumption model and stomach content data. Lengths of cod eaten have been reconstructed for 1986 and for the 1990s from otoliths by the Marine Mammal Section. Using RV age keys, the harp seal removals of cod at age can be calculated. The removals of cod by seals ranged between 400 million and 600 million age 1 to 3 fish between 1992 and 1994. The removals were treated as an additional commercial catch in an SPA while retaining the assumption of M=0.2 to represent non-seal mortality. The SPA was run back to numbers of cod at the beginning of age 1 because harp seals eat mainly age 1 to 3 cod. The SPA was calibrated with RV data on ages 1 and older. The results, while very tentative, are never the less, quite interesting. There is an indication that the 1990 year class may have been relatively strong. There is no evidence of this in the RV numbers at age. It seems possible that the large seal population could have hastend the decline of the 2J3KL cod stock and could retard the recovery. It is possible that the dynamics could be that of a classic "predator pit" and that it would require a very large year class to result in stock rebuilding.

The 1996 Sentinel Survey for Cod in NAFO Divisions 2J3KL with Comparisons to 1995

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Abstract

The DFO Newfoundland Region sentinel survey for cod has been operational since 1994 in NAFO Divisions 2J3KL and Subdivision 3Ps. The 1996 survey in Divisions 2J3KL was conducted from June 24 to December 31. Each of the sixty-six sentinel sites conducted sampling activity over a twelve week period between June and December. Catch rates were higher in all NAFO Divisions in 1996 over 1995. Fishers described catch rates in many locations in Divisions 3KL as good (20+ fish/net/day). Catch rates in Division 2J were very low. Fish size distribution in the catches was similar between the two years. It is interesting to note that increases in catch rates in 2J3KL were made up primarily of 50+ cm fish rather than an increase in the catch rate of small fish. This suggests that in 1996, existing fish in the population were more densely aggregated in the inshore areas rather than any significant recruitment.

What can acoustic, trawl, and egg surveys conducted in the northern Gulf of St. Lawrence tell us about cod stock structure? by M. Castonguay, P. Ouellet, and Y. Lambert

Extended abstract of presentation at the Cod Inshore/Offshore Stock Workshop held in St. John's, NF, 3-5 March 1997. Presentation drawn from the following paper: Ouellet, P., Y. Lambert, and M. Castonguay. 1997. Spawning of Atlantic cod (*Gadus morhua* L.) in the northern Gulf of St. Lawrence: a study of adult and egg distributions and characteristics. Can. J. Fish. Aquat. Sci. 54 (1). In press.

Surveys were conducted in May 1994 and 1995 whose objectives were to locate spawning sites of 3Pn4RS cod with acoustic and trawl surveys, to describe the distribution of cod eggs, and to determine the size structure and maturity composition of the spawning stock. This work was accomplished through a combination of acoustic, trawl, and egg surveys carried out simultaneously with two vessels in 1994 (CSS Gadus for trawling and CSS Parizeau for egg and acoustics) and a single one in 1995 (CSS Teleost) aboard which all work was conducted. In 1994, despite a large trawling coverage off Newfoundland's West Coast, only one spawning shoal was detected with trawling and acoustics, 40 km off Bay St. Georges at a depth of about 250 m in 5-6°C. Acoustic and trawl surveys above the shoal showed that shoal size varied from day to day suggesting that fish were regularly joining and leaving the shoal. Largest shoal size was estimated to be 10 x 2 km. The dynamic aspect of the shoal was reinforced by the apparent mismatch between advanced egg development and the fact that most (60%) adult cod from the shoal had not begun spawning. This suggests that most eggs had been spawned by previous "waves" of cod that had left the shoal on their way to northern 4R and 4S. In 1995 as in 1994, only one spawning shoal was detected at the same location as in 1994 despite extensive acoustic coverage but the shoal was more dispersed as it was spread over 30-40 km instead of 10 km. Cod spawned later in 1995 as egg densities 1-2 orders of magnitude smaller than in 1994 at the same date. Despite later spawning in 1995, the maturity stages were identical between 1994 and 1995. This also indicates that the spawning shoal was temporally unstable and that eggs sampled in 1994 had been spawned by previous waves of cod. In conclusion, cod begin spawning as part of large shoals at the entrance of the Esquiman Channel but disperse soon thereafter and most spawning occurs as fish disperse in the northern Gulf, which is consistent with egg distributions in northern 4R in June. The evidence for a single spawning aggregation suggests that most 3Pn4RS cod begin spawning as part of a single shoal and hence may belong to a single genetic stock. However the depressed state of cod stocks and variability in spawning time among putative stock components makes it difficult to detect other possible spawning aggregations.

Distribution of Atlantic Cod Detected in an Acoustic Survey of Bonavista Bay - Trinity Bay During the Fall of 1996

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As part of the annual research program to assess Atlantic herring stocks, an acoustic survey was conducted during the fall of 1996 in the coastal waters of Bonavista Bay - Trinity Bay to estimate herring biomass. Similar surveys have been conducted annually each fall in coastal waters along the northeast coast of Newfoundland since the early 1980's. However, due to the use of improved acoustic technology in 1996, it was possible, for the first time, to detect and integrate concentrations of fish in close proximity to the bottom. This paper describes preliminary results of these analyzes and provides distributional and relative density estimates of Atlantic cod, as detected during the survey.

Title: A hydroacoustic survey of cod in western Trinity Bay during April 1996. - J. Brattey

A survey of cod in Smith Sound, Northwest Arm, and Southwest Arm was conducted in April 1996 with a Biosonics 102 echosounder and a 38 kHz dual beam transducer using the MV Shamook as both an hydroacoustics and fishing platform. The area was divide into three strata and each one surveyed using a series of parallel equidistant (1 nm apart) transects perpendicular to shore with a randomly assigned starting point. Sampling to verify the identity of targets detected hydroacoustically was conducted with hand-lines (feathered hooks), a Yankee 36 otter trawl, and gill nets; sampling indicated that cod were widely distributed in each of the areas and generally of large size (mean lengths around 53-57 cm). Targets identified as cod were detected on approximately 75% of the 50 transects. Densities were generally low ($\leq$0.05 fish/m^2) in most areas, but a more dense aggregation (0.10-0.27 fish/m^2) of spawning cod was detected in deep water (200 m) in the outer reaches of Smith Sound. These inshore areas were extremely difficult to survey quantitatively for cod using hydroacoustics, due to the extreme changes in depths and rough bottom. We used an algorithm that essentially deletes all signals 2 m up from the detected bottom to ensure that bottom signals were not included in the estimates of cod density; consequently, a proportion of the cod remain undetected. Our survey gave an estimate of 193 mt for the three areas combined.

An overview of pre-1990 analysis and speculation regarding inshore cod in Divisions 2J3KL

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Cod in Divisions 2J+3KL (the "northern cod") have historically migrated on a seasonal basis between a summer-autumn feeding area in shallow water along the coast of southern Labrador and eastern Newfoundland and an overwintering area offshore, primarily near the shelf break. However, not all cod move offshore in the winter. Some remain near the coastal shelves in deep water below the Cold Intermediate Layer (CIL) of the Labrador Current, and some remain within the bays of eastern Newfoundland, often in narrow fjord-like environments. In recent years the quantity of cod caught during autumn research bottom-trawl surveys in offshore waters has been very low, but there are numerous reports of cod in shallow coastal waters, and dense aggregations have been found and studied in deep inlets in the inner reaches of Trinity Bay. There is much uncertainty and speculation regarding the stock affinities of the cod which are now found in inshore waters. The purpose of this paper is to provide a brief overview of pre-1990 scientific commentary and speculation regarding the distribution and stock affinities of cod in inshore waters.

Linking the inshore to the offshore

Several studies in the 1960's demonstrated a close association between the cod caught in inshore waters and the cod caught on the outer shelf. In addition to tagging studies (reported elsewhere in this Proceedings), there were analyses of catch rates, fish size and growth rate. Fleming (1965), Hodder (1965) and May (1967) showed that the catch per fisher in the inshore declined as catches by distant water fleets increased in the offshore in the late 1950's and early 1960's. Referring to sampling during 1955-1962, Hodder (1965) concluded: "The decreased abundance of fish older than 6 years in the inshore trap fishery is attributed to the decreased abundance of these older ages on the offshore fishing grounds as a result of increased effort by trawlers in all areas off the east coast of Newfoundland and southern Labrador in recent years." May et al. (1965) used random samples of research vessel trawl catches and catches by various gears in the inshore commercial fishery in 1960-1962 to calculate mean length-at-age of cod in ICNAF Divisions from 2H to 3Pn. They found that von Bertalanffy growth curves "... derived from the offshore data provide an adequate representation of the inshore material as well, lending evidence to the hypothesis that there is no inshore-offshore stock separation in the areas concerned." It should be noted, however, that the inshore samples came from communities on headlands and exposed coasts, and may have been dominated by migrating fish.

Cod in deep waters off headlands

The presence of cod in deep water off the coastal shelves of eastern Newfoundland has been recognised since exploratory longlining in the early 1950's (Templeman and Fleming 1956, 1963). Not all the cod in these areas, just below the depth at which the Cold Intermediate Layer of the Labrador Current impinges on the bottom, arrive from near the shelf break following spawning. In the 1980's the fishery in the deep water started each spring very soon after the disappearance of the ice, and often long before the sudden increase in landings toward the middle or end of June in adjacent shallow waters (unpubl. data). In addition, research trawling off Cape Bonavista and in the mouth of Trinity Bay has yielded good catches in February-April (Lilly 1982; unpubl. data). Thus, some cod are in this deep-water coastal environment months before the migration of cod from the offshore. Templeman (1962) presented several arguments in support of a suggestion that "... each large shelf region, such as the Bonavista Shelf, the Fogo Shelf and the St. Anthony Shelf, projecting seaward with deep water on each side has a basic stock of its own, some of which it loses temporarily in the summer by coastal or pelagic feeding migrations and in the winter by movements in the deep water, while receiving some migrants from other areas."

As reported by Hutchings et al. (1993), there is evidence of spawning in the deep water off Cape Bonavista. Cod caught in the commercial gillnet fishery northeast of the Cape in 275-350 m were sampled weekly in 1983 and 1984. A plot of a gonad-somatic index versus time illustrates that there were many cod with relatively large gonads when the first samples were collected (May 11 in 1983 and May 30 in 1984), and that the proportion of cod with elevated indices, and the maximum values of the indices, declined to a minimum by the middle or end of July (Lilly 1996). The decline in gonad indices provides only circumstantial evidence that cod spawn in deep water off the Bonavista Shelf. The cod with low gonad indices could have spawned elsewhere before migrating into the area, and cod with large gonads may have moved elsewhere to spawn if they had not been caught.

Cod in eastern bays

Reports of the presence of cod in spawning condition in the bays of eastern Newfoundland may be found in the scientific literature as early as the 1890's, when Neilsen described how he obtained fish in spawning condition for the Dildo Island Marine Hatchery in May-June in Trinity Bay. In discussing an early run of cod at the head of Trinity Bay in 1894, Neilsen (1895) was of the opinion that the "... early occurrence of fish seems clearly to indicate that those fish do not enter the bay from the outside, but that they are *local-bred* fish, which keep in deep water during winter, and on the first opportunity in the spring, seek the shoaler waters in the head of the bay ...".

Additional evidence of the presence of spawning cod within eastern bays may be found in unpublished trip reports (Marinus 67-1, 68-1, 68-2) which describe the maturity of cod caught during experimental gillnetting in the deep water of Trinity and Bonavista bays. These data have been summarised by Hutchings et al. (1993). Cod were caught with 6- and 7-inch mesh monofilament gillnets off Tickle Harbour Point and the Horse Chops in Trinity Bay and near

Little Denier and Cabot Island in Bonavista Bay in April-June of 1967 and 1968. All gillnet sets were made in deep water with the nets usually running from cold water into the underlying warmer water. In 1967 many of the cod were in spawning condition or close to it (Fleming 1967), and in 1968 the cod were in maturity stages indicating spawning was soon to occur (Fleming 1968). Fleming (1968) thought that the gillnet experiments were sampling "... a segment of the stock which ... consists of large old cod which have escaped other gears, and which spawn in the coastal areas and bays in contrast to the younger fish being caught by traps and handlines which spawn before arriving in the coastal areas in the spring."

It is interesting to note that Templeman (1962) considered his Avalon-Burin stock to be "... an inshore stock ... extending from the outer coast of the Avalon Peninsula into Fortune Bay". In concluding his discussion of the Labrador-Newfoundland stock, he stated: "Very likely in the future enough differences will be found to indicate a number of north-south and inshore-offshore sub-stocks ..." (Templeman 1962). However, to my knowledge, Templeman never did present evidence of inshore stocks north of the Avalon Peninsula (other than the coastal shelf "sub-stocks" discussed above), and he did not speak of "bay stocks".

Cod in fjord-like environments

Cod have for many years been caught through holes cut in the ice in sheltered inlets of the major eastern bays. The only such areas which have been studied scientifically are the three fjord-like arms near Random Island on the western side of Trinity Bay. For details, see other summaries in this Proceedings.

Cod in the shallow-water fishery

Cod in shallow water along the coast of southern Labrador and eastern Newfoundland supported a fishery with hook and line for centuries. Since the late 19th century this fishery has been strongly augmented by the use of the cod trap, and since the 1960's by the use of synthetic gillnets. The geographic pattern of the catch in 1947-1949 does not support the supposition that "bay stocks" made important contributions to the total inshore catch. Templeman (1958) stated: "Within the east coast area, cod are most abundant near the projecting island and headland areas such as the Cape Bauld - St. Anthony, Fogo Island, Cape Freels, Cape Bonavista, Bay de Verde - Grates Point areas and in the areas to the east of the Avalon Peninsula. .... As a rule far fewer cod are available in the deep inlets and warmer water at the heads of the east coast bays than at the headlands."

The areas of largest catch have in common a closeness to the schools of cod migrating toward the coast from their offshore overwintering areas. If all cod caught in the inshore shallow-water fishery arrived from the offshore, then the earliest landings would be expected at the headlands. However, substantial landings occur in the inner parts of Bonavista and Trinity Bays several weeks prior to the big increase in landings at the tips of the headlands. See Lilly (1996) for some preliminary analyses of these patterns based on purchase slips. These patterns appear to correspond to the descriptions of herring fish and capelin fish as reported by fishers (Neis et al. 1996). Additional research is required to determine if the early landings (prior to about mid-

June) in the inner parts of Bonavista Bay and Trinity Bay were supported by cod which remained within the bays throughout the winter and the later landings were supported by cod which migrated into the coastal areas from farther offshore.

It is tempting to speculate that cod taken in the early landings belong to "bay stocks". It would be of interest to determine if cod taken in the early landings differed from cod taken from later landings with respect to length-at-age, relative year-class strength, otolith structure, and other biological characteristics Unfortunately, the data required to conduct these analyses may not have been collected prior to the 1990's. Most routine sampling of inshore catch was conducted on the outer shores and headlands after mid-June. The early catch in the inner parts of the bays may have been rarely sampled.

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Fishers' Ecological Knowledge and Cod Stock Components in Trinity and Bonavista Bays

by

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Such resource users as commercial fishers often develop detailed knowledge of their resources and their environments that can provide a useful supplement to data from traditional scientific sources (Berkes, 1993; Freeman and Carbyn, 1988; Johannes, 1981; Scheibling and Mladenov, 1987). Both scientific knowledge and fishers' ecological know ledge depend upon systematic observations. The qualitative character of commercial fishers' observations and their often inshore, local and multi-generational spatial and temporal scales are, in some ways, complementary to the quantitative focus, more recent temporal scale and offshore, large spatial scale of stock assessment science (Eythorsson, 1993; Freeman, 1985).

Discussions concerning cod stock structure have tended to hinge on the identification of genetically and/or morphologically distinct populations. Fishers cannot provide information on genetic differences. They can however, provide data related to observed behavioural differences in cod behaviour that appear to be linked to age and population. These differences have implications for the design and accuracy of stock assessments. These observations, as well as observed differences in colouring, can help guide scientific research on population structure and the identification of spawning areas in Trinity Bay. Such data are particularly valuable when combined with purchase slip data, tagging data and data from acoustic and other monitoring of spawning aggregations.

Data from 20 interviews with inshore and nearshore, longliner fishermen with a history of fishing in the areas between Princeton and King's Cove Bonavista Bay and between Port Rexton and Dildo, Trinity Bay were examined for information related to the timing and location of particular cod fisheries, fishers' taxonomic categories for different types of cod, their observations on the timing and direction of cod movements, as well as information on diet and observations of sexually mature cod with eggs or milk "running" at the point of capture.

We have selected interviews from these areas because observations from fishers in these areas provide stronger evidence of observed cod spawning, overwintering and possibly settling out in deepwater trenches than we found in interviews closer to the Bonavista headland. This observed difference in reported observations between headland and bay fishers is itself an indication that the dynamics of cod fisheries in these two areas are somewhat different. The pattern in the data suggests that fishers at the bottom of the bays and at the mouth of long arms where cod are believed to overwinter relied more consistently on such cod for their catches than fishers further out the bay and in the headland areas. With the exception of some longliner fishermen who had fished the large, deepwater cod off the Bonavista Headland and down into Trinity Bay (Templeman and Fleming, 1956) the latter reported relying more on "northern" cod migrating from offshore during the caplin scull.

There are basically four types of cod that fishers in the bottom of Trinity and Bonavista Bays associate with a bay stock: small cod observed most frequently near wharves or particularly as a bycatch in caplin traps (Neis et al., 1996); smaller brownish coloured cod in cod traps in shoal water berths harvested in the early spring; larger, darker coloured "herring" cod believed to overwinter in the arms of the bay feeding on herring aggregations and to disperse with the herring as they and the herring move to spring and summer spawning areas; and so-called "mother" fish or "breeders", large, old, pale leaner fish, believed to have settled out in the deeper areas of the bays and to have been fished out as a consequence of the introduction of gillnets and otter trawling in the bays between the 1960s and 1980s (see also Neis, et al., 1996 for an earlier version of this analysis and Fischer et al., 1997 for an analysis based on fishermen's observations but collected using a somewhat different methodology).

Small, shoal bay cod and larger "herring" bay cod:
Across the bottom of Trinity Bay and in the Southern Bay area of Bonavista Bay (this was as far west as our interviews went), early trap fisheries in April and May are believed to have intercepted the small, bay cod in shoaler berths and the larger "herring" bay cod in deeper berths and in gillnet fisheries. The early trap fishery tended to be short-lived because "herring fish is not like caplin fish, they don't hang around as long. They don't glut and lay on the bottom and that kind of stuff. You don't get two or three weeks. When herring is moving and there's lots of herring and there's fish with the herring then you will get some fish right". Descriptions of fisheries in Southwest Arm, T.B., Smith Sound, the Chance Cove area and Southern Bay, B.B. that improved during the fall were another indication of cod movements that did not correlate with those generally assumed to occur with northern cod. A late fall and early winter cod gillnet fishery took place in the Chance Cove area at depths of between 80 and 150 fathoms in the late 1970s and early 1980s (see Figure 1). Small fisheries involving jigging and gillnetting through the ice were reported to have occurred in Bull Arm, Southwest Arm above Hatchet Cove, and in the Charleston area (Southern Bay), Bonavista Bay. A January gillnet fishery experiment by two longliners was reported to have confirmed what fishermen suspected from handline and herring fisheries, that there were lots of cod up in Smith Sound at that time. According to a Princeton, Bonavista Bay fisher, in December, cod would begin moving back into Southern Bay and these cod could be jigged and gillnetted through the ice up as far as Charleston until mid-January. At this point they "seemed to go afloat" and were no longer available to the gillnets.

The Southern Bay cod were next intercepted by the cod traps on their way out of the arm in April. They were harvested in early trap berths in the King's Cove area in May, an area that was supposed to be "famous for spring fish, April and May fish". In the 1960s, these early cod were very abundant but they became scarcer in recent years. Potter (1996) identified a spawning area for cod in this region based on interviews with Bonavista Bay fishers.

The bay cod are believed to have intermingled with the cod migrating from offshore with the capelin in June and July. Fishermen differentiate between the bay cod and the offshore cod by the timing of their arrival, the direction of their movement (from out of the arms as opposed to from offshore), and sometimes by the presence, with offshore runs of fish, of other "offshore" species such as pollock and redfish that did not normally occur in the bay. In the words of a Port

Rexton fisherman, "I always believed in bay stocks. I always thought that there is so much fish that never leaves Trinity Bay, it goes to the deep holes and stays there and feeds. In the spring of the year it moves back in again."

"Breeders" or "Mother" fish

These very large, pale fish were harvested in gillnets in the 1960s and 1970s in the arms and deeper areas of Trinity Bay and Bonvavista Bay. A Butter Cove fisherman said he had not caught a lot of large, "mother" fish but the older fishermen used to talk about having caught the "breeders" in nylon gillnets in the mid 1960s. A St. Joan's Within fisherman said the big fish gradually disappeared in Smith Sound but they used to get a lot of big mother fish there. He had never heard much talk of it in North West Arm. Most of the big breeders they would get in his area they would get in the spring. Fishermen described fishing out populations of large, old breeders in a gully off of Red Cliff Bonavista Bay in the 1960s and in 100 fathoms of water about 20 miles off Bonavista Headland during the Bonavista longliner experiments in the 1950s and later with gillnets in the 1960s. The pattern of feeding and movement of the large, old "breeders" or "mother" fish seems to have differed from that of the other bay fish. The "breeders" appear to have fed primarily on smaller cod, crabs and, in Trinity Bay, bottom organisms including so-called "bakeapples" and "sucker rocks" , a form of reddish sea anenome that attached itself to their line trawls if they moved onto the wrong kind of bottom. These fish are believed to have settled out and stayed in deep gully areas or channels year-round. Depths?

Accounts of Inshore Spawning cod

Aggregations of cod "running" with eggs and milt were described in a June-July gillnet fishery off of Hopeall Head in 50-60 fathoms of water (fished out by the mid 1980s) (see Figure 1); they were observed once in a fall trap fishery in Chapel Arm; and in a summer gillnet fishery northeast from the Bellevue Peninsula that targeted large "breeders" in deepwater in the 1960s.

Spawning cod were also reported as having been observed in the June trap fishery near Thornlea, and during the spring gillnet fishery between March and May in the Chance Cove area. A Chance Cove fisherman described what appeared to be a spawning aggregation on Heart's Ease Ledge in the summer months (see Smedbol and Wroblewski, 1997 for scientific confirmation of this).

Fishermen in the Butter Cove and St. Jones Within areas also described catching spawning cod in the summer months in May or June. These were primarily harvested in gillnets and if they were the deeper, big old cod, they were referred to as "breeders" or "mother" fish. A Butter Cove fisherman said you could see spawning cod in May or June. The St. Jones Within fisherman said that they always got some spawning cod in the summer time. Most of the spawny cod they would get would be in the gillnets.

Two spawning aggregations were described in the Smith Sound area, one in earlier years, around the time of the introduction of the gillnets in the 1960s in an area above Bluff Point in Smith Sound in 30-50 fathoms of water, and the second fished more recently in the area off of Hickman Harbour (an area adjacent to the Thoroughfare between Ireland's Eye and Random Island) in depths of 90 fathoms and deeper. These latter fish were harvested further up the Sound in the spring and followed out to the Hickman Harbour area where they were believed to be spawning between early May and mid June. They dispersed after mid-June. Fishermen in the Smith Sound area had an explanation for fluctuations in the amount of fish in Smith Sound observed in recent acoustic studies of these spawning fish. They said that during years when you had a lot of spring winds from the northeast, the cod would go into Smith Sound. They said this was the case during the year when a lot of fish were seen in the Smith Sound aggregation. During years when the winds came from the north or the northwest, they said, there would be few fish in Smith Sound as they would be driven down into the deeper water and "to the southard" with the bait fish.

The relative importance of bay stocks for inshore fisheries:

A Chance Cove fisherman suggested that their winter gillnet fishery could be as important as their summer cod fishery when it was pursued commercially between the late seventies and mid-1980s. Fishermen at the bottom of Trinity Bay suggested that the spring (April-May) cod fishery could constitute as much as 30% of their catch before it declined. A spatio-temporal analysis of purchase slip data that contrasted cod landings at the bottom of the bays with those in the outer areas for the years 1983 and 1984, indicates a bimodal pattern to cod landings in the bottom of the bays during these years with peaks in May and in June and July. Landings data for the outer areas do not have this bimodal pattern and are concentrated in the period from June onwards (Lilly, 1996). A King's Cove fisherman commented that they could always tell how goodtheir fishery would be the following spring by the amount of fish that was jigged through the ice in the winter in the arms of Bonavista Bay. The Princeton winter fishery was generally only for personal use but it was fished commercially for a few years. Fishermen blamed the decline of the bay stock partly on the spring-winter gillnet fishery of the late 1970s and early 1980s, the deepwater gillnet fishery out in Trinity Bay, and on the bycatch of small cod in the capelin trap fishery.

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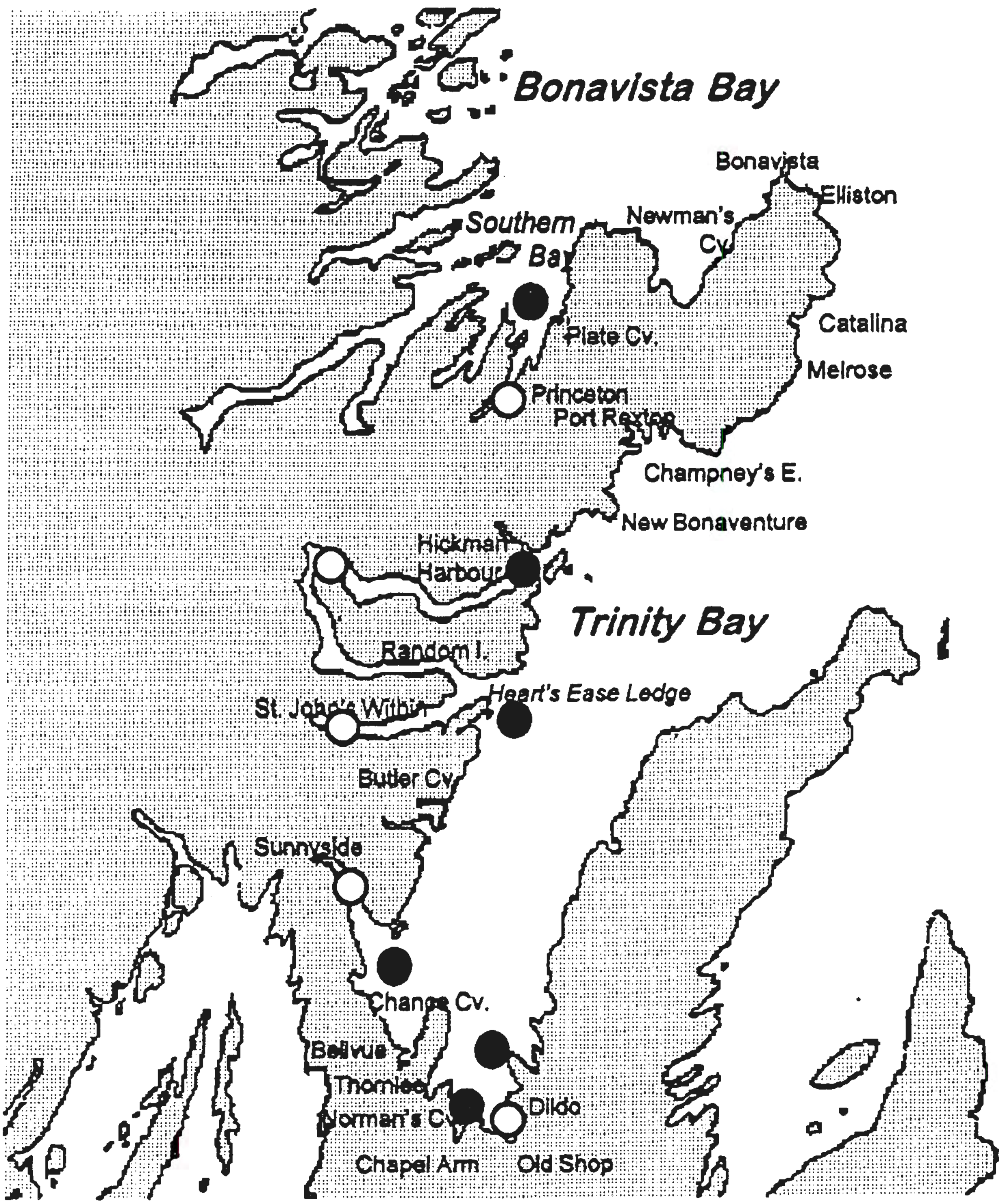
TEK - Interviews:



○ Locations of winter gillnetting of cod

● Locations of spawning aggregations of cod

The population consequences of inshore spawning by northern Atlantic cod (*Gadus morhua*) at low stock levels.

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The largest inshore spawning aggregation ever observed (16,800 tonnes; G. Rose pers comm) was discovered in Smith Sound, Trinity Bay, three years after the collapse of the northern cod stock, and one year after the last offshore spawning aggregation was recorded. We hypothesised that spawning by this large aggregation of cod would increase the abundance/density of eggs, larvae, and settled 0+ group juveniles that could be detected against the "background" spawning of the bay cod population. Data from 1995 were compared to previous ichthyoplankton and juvenile surveys. Egg density was significantly higher in 1995 than the pooled average of the previous years (1991 and 1993) (Figure 1). When all survey stations are included, the 1995 mean (0.51 $eggs \cdot m^3$) was 14 times greater than the pooled mean of the previous surveys (0.04 $eggs \cdot m^3$). When just the stations that were sampled during each year are considered, the 1995 mean (0.58 $eggs \cdot m^3$) was 30 times greater than the pooled mean of the previous surveys (0.02 $eggs \cdot m^3$). Increase in numbers of post-settlement, age 0+ fish was tested at three different spatial scales: the entire northeast coast of Newfoundland, individual bays, and areas within bays. There was no detectable increase in density of settled juveniles within Trinity and Conception Bays, or at any larger scale (Figure 2, 3, 4). This may be due to advection/diffusion of eggs/larvae to low concentrations, leading to the conclusion that the spawning aggregation was not large enough to have produced a detectable pulse in juvenile recruitment.

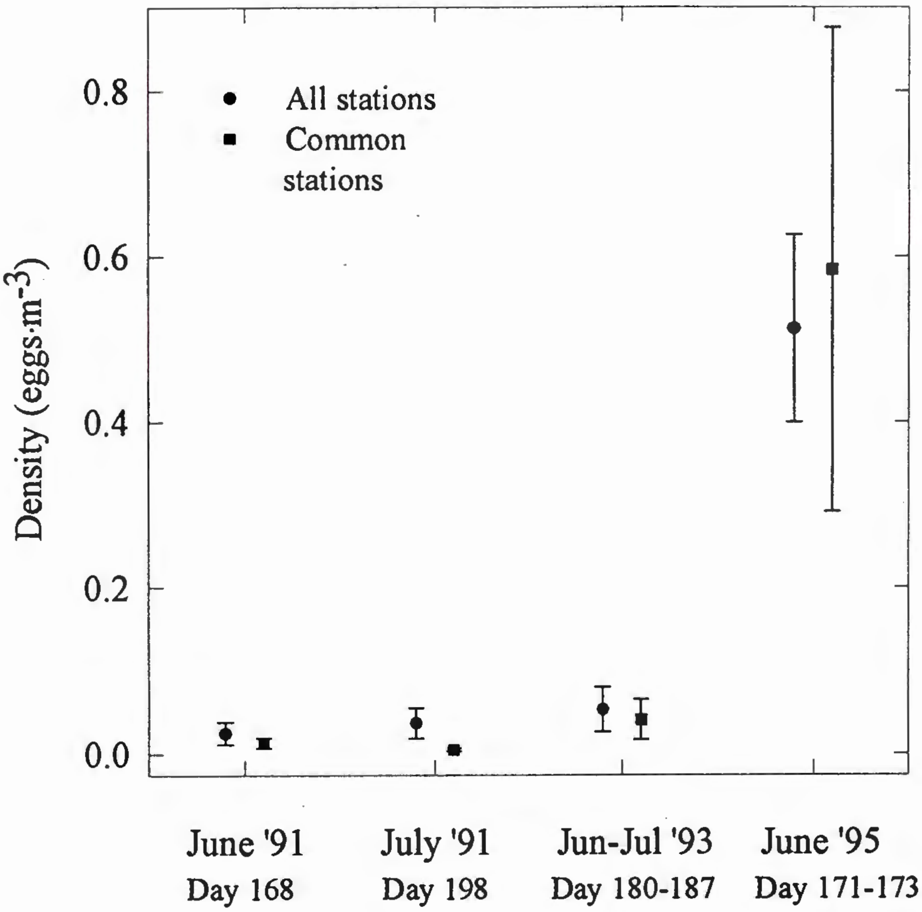
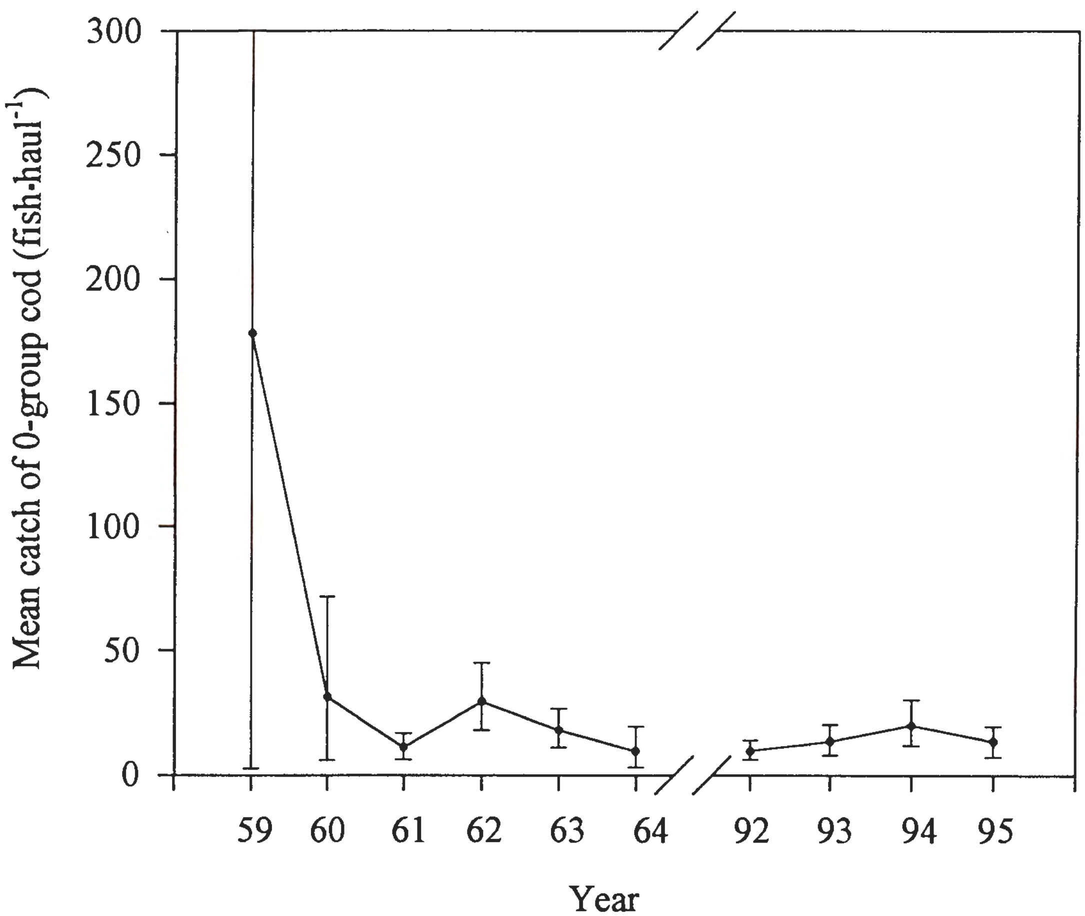
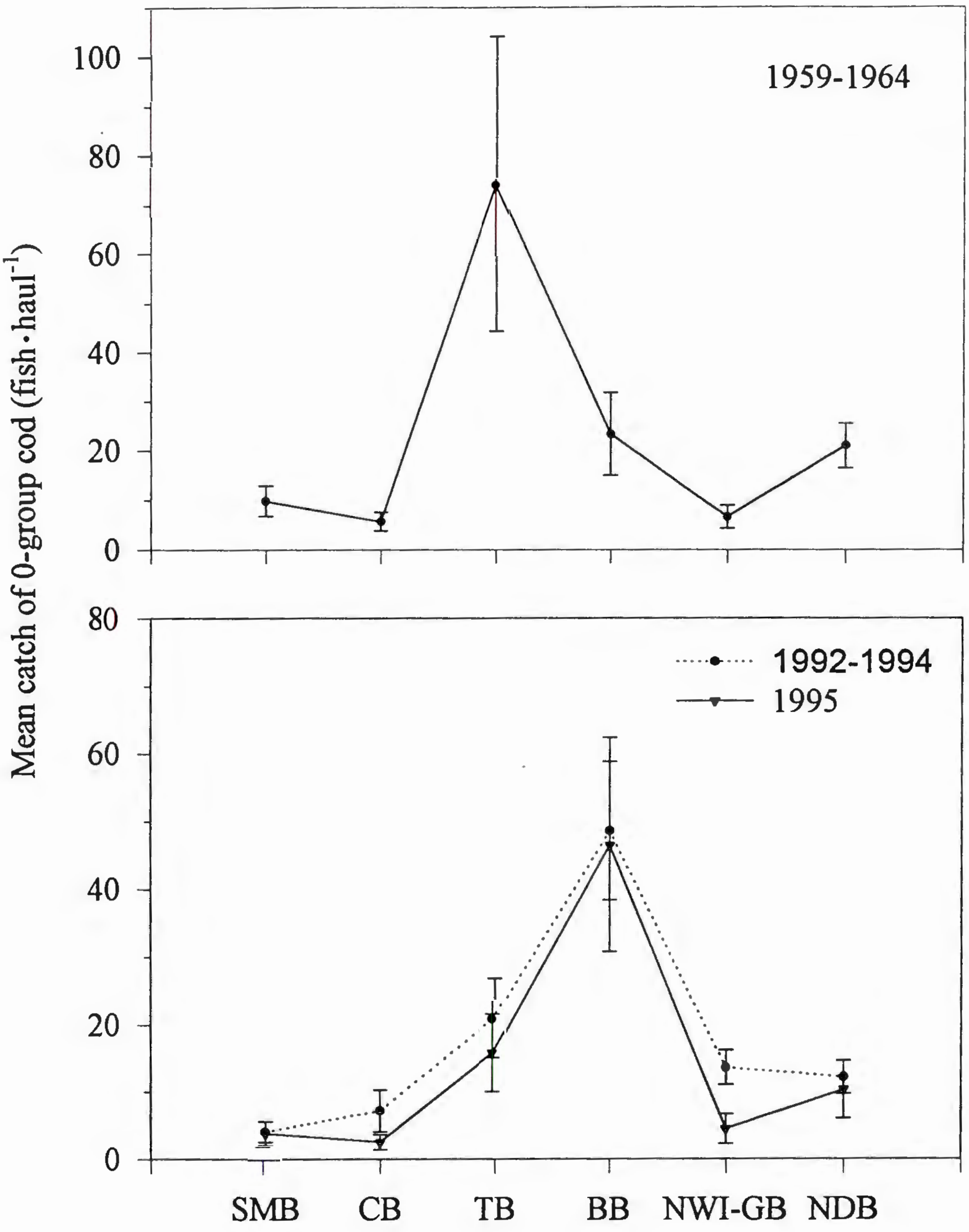

All stations
Common stations
Density (eggs·m-3)
0.8
0.6
0.4
0.2
0.0
June '91
Day 168
July '91
Day 198
Jun-Jul '93
Day 180-187
June '95
Day 171-173

Figure 1



300
250
200
150
100
50
0
Mean catch of 0-group cod (fish·haul-1)
59
60
61
62
63
64
92
93
94
95
Year

Figure 2



Mean catch of 0-group cod (fish·haul⁻¹)
1959-1964
1992-1994
1995
SMB
CB
TB
BB
NWI-GB
NDB

Figure 3

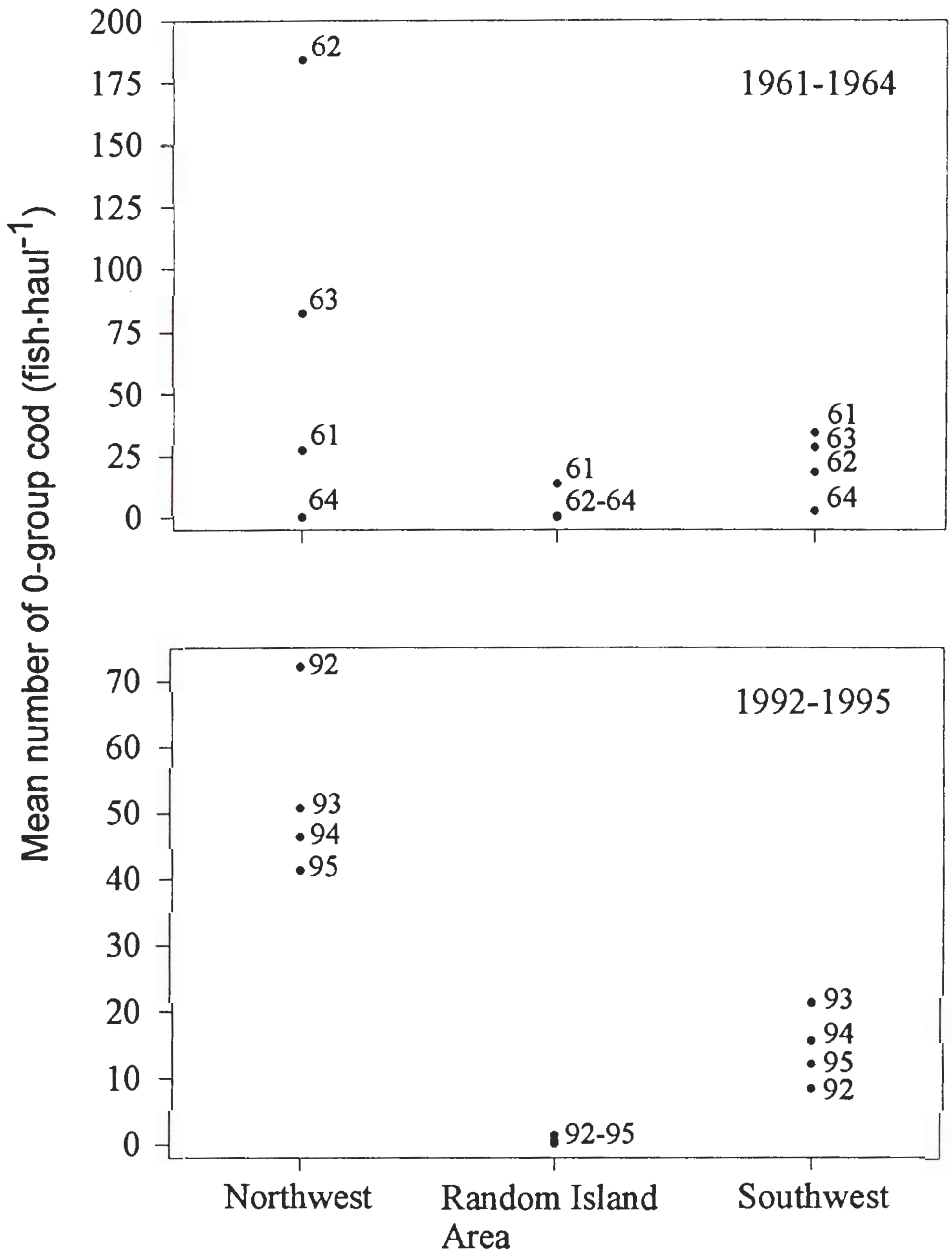

200
175
150
125
100
75
50
25
0
Mean number of 0-group cod (fish·haul^{-1})
62
63
61
64
1961-1964
61
62-64
61
63
62
64
70
60
50
40
30
20
10
0
92
93
94
95
1992-1995
92-95
93
94
95
92
Northwest
Random Island Area
Southwest

Figure 4

An integrated approach to stock identification: preliminary results of the High Priority Project on cod stock mixing in the Gulf of St. Lawrence.
Presented by C.T. Taggart and D.E. Ruzzante.

- **Overview.** Current management of fish stocks by DFO assumes the presence of a single stock per management area, with no stock mixing during periods of fishing. However, these conditions are likely not met with respect to cod in the Gulf of St. Lawrence. There appear to be several spawning areas in both the northern Gulf (4RS) and the southern Gulf (4T) management units, and cod off Cape Breton (4Vn) may not be distinct from the neighbouring areas of 4T and the eastern Scotian Shelf (4Vs). Furthermore, the cod stocks of both the northern and southern Gulf of St. Lawrence migrate out of the Gulf each fall, where they mix with resident stocks from other regions (4Vn, 4Vs, 3Ps) while overwintering. These mixing zones have traditionally been heavily fished, thus introducing error into the assessments of all of the affected stocks. Since the cod stocks of the Gulf and its approaches comprise most of the biomass of the east coast cod stocks (aside from Nfld's northern cod), it is important to be able to identify the location and stock composition of mixed stock catches, as well as determine methods for monitoring stock identity in mixed fisheries on a routine basis. The goal of the study summarized here is to identify the cod stocks of the Gulf and its approaches, and through the use of otolith elemental and genetic markers, and vertebral count variations, determine the stock composition and geographic extent of the winter mixing zones. These aspects of the project are summarized below and address the formation of otolith elemental fingerprints in relation to the elemental and physical composition of the ambient seawater, and the use of otolith elemental fingerprints, vertebral counts and nuclear DNA variation to determine the number and geographic extent of cod stocks in the Gulf of St. Lawrence and approaches (3Ps, 3Pn, 4RS, 4T, 4Vn and 4Vs). *For more information contact <s_campana@bionet.bio.dfo.ca>*

- **Temperature history of cod at the entrance to the Gulf of St. Lawrence and surrounding regions.** Temperature is the seawater characteristic, next to elemental metal concentration, that is the most influential in controlling the formation of otolith elemental fingerprints. Therefore, accurate interpretation of the elemental fingerprints requires comparison of the exposed temperature fields for each of the stocks. To determine and compare the annual temperature history of five cod stocks that reside for at least part of the year in the Cabot Strait/Laurentian Channel area bottom temperature data are combined with information on the geographic location and depth of the cod for each of the stocks. Seasonal bottom temperature fields have been optimally estimated onto a rectangular grid for the Gulf of St. Lawrence, the northeastern Scotian Shelf and off southern Newfoundland. The data used were taken from the historical (AFAP) temperature and salinity database assembled at the Bedford Institute and cover all available years. The cod stocks investigated include 4T, 4RS, 4Vn, 4VsW and 3Ps and initial work concentrated on the 4T stock. Location and depth information for the 4T cod was obtained from a variety of sources including literature searches, annual groundfish surveys, recent winter surveys in the Laurentian Channel region and fisheries scientists working on the stock. With suggestions that there may be two populations within 4T, cod on the western and eastern Magdalen Shallows were treated separately and were also separated by age categories (3-5 yr and >5 yr). The cod reside on the Shallows in the summer and in the deep waters of the Laurentian Channel near Cabot Strait in winter, migrating into the Gulf in spring and out in fall. For each area, age group and season, cod-depth distributions based upon the available observations were developed. These were then converted into cod-temperature distributions for each season using bottom temperature fields. Whereas the location and depths of the cod in summer and winter were assumed to be relatively constant throughout each season, the spring and fall seasons were each divided into two separate time periods with the cod occupying different areas and depth distributions, simulating their migration pattern. Results show that from late fall to early spring cod typically occupy the deeper waters of the Laurentian Channel within area 4Vn at temperatures of 4 to 6°C but as they migrate onto the Magdalen Shallows the majority inhabit waters with ambient temperatures of <2°C. The exposure temperatures for cod increase slightly in summer and again in the fall. Differences between the eastern and western areas were small.

Temperature information for the different seasons have been combined to estimate the degree days the cod would experience. This is expressed in terms of probabilities which allows determination of both the mean temperature the fish are exposed to and the range. Similar analyses have been carried out for the 4RS, 4Vn and 4VsW cod stocks. Results suggest that the 4T cod experience the lowest temperatures of the four stocks examined. The 4RS cod remain at temperatures in the 4 to 6°C range throughout the year resulting in an approximate mean annual degree day 25% higher than that of the 4T cod. However, the depth distribution of cod in the nearshore region of 4RS were not included. These data are presently being assembled and will be included during the next phase of the study. The mean annual degree days for 4Vn cod are similar to those for the 4RS cod but have a larger range. The stock with the highest number of degree days in a year is 4VsW, in particular, those that reside during part of the year on Sable Island Bank. For all stocks there is a tendency for the younger fish to occupy slightly warmer waters than older fish. The largest difference was on Sable Bank where the youngest (0-3 y old) fish have an annual exposure temperature approximately 1°C higher than the older (3-5 y)fish. *For more information contact <k_drinkwater@bionet.bio.dfo.ca>*

- **Otolith elemental content variations among stocks in the Gulf of St. Lawrence and approaches.** Trace elements incorporated into the growing surface of the fish otolith(ear stone) reflect the physical and chemical characteristics of the ambient water, although not necessarily in a simplistic manner. Since otoliths grow continuously without resorption throughout the life of the fish, individuals which spend at least part of their lives in different water masses produce otoliths of different elemental composition. Thus the otolith elemental composition ("elemental fingerprint") serves as a stable environmentally-induced marker of natural aggregations of fish, independent of genetic identity. Using ID-ICPMS to maximize the accuracy of the otolith assay procedure, we determined the elemental fingerprint of 1825 adult cod, representing 5 Atlantic cod (*Gadus morhua*) stocks in and around the approaches to the Gulf of St. Lawrence. There were highly significant differences among the elemental fingerprints of each of the stocks. To confirm that these fingerprints are robust indicators of stock origin, we compared the fingerprint of samples taken in the fall (prior to out-migration) and in the spring (on the spawning grounds just after in-migration) for each stock, as well as various locations within each stock area. The results indicated that the otolith elemental fingerprint was very stable across seasons, and that there was no indication of sub-stock differentiation within the 3Pn 4RS cod stock. These results lend support to the validity of the current 3Pn 4RS stock management area. On the other hand, the elemental fingerprint of fish collected in spawning condition in 4Vn in May was significantly different from that of the fall 4Vn fish, and almost identical to that of 4T spring spawners, suggesting that significant numbers of 4T cod are still present in the 4Vn area at a time when fisheries management assumes that they are absent. Preliminary analysis of the stock composition of the mixed winter aggregation sampled on the Jan 1996 RV survey indicated a predominance of 4T and 3Pn 4RS cod on the western and eastern slopes of the Laurentian Channel respectively, with increasing proportions of other cod stocks towards the east. The accuracy of these initial stock composition estimates will be improved as MLE-based stock identification methods are applied. *For more information contact <s_campana@bionet.bio.dfo.ca>*

- **Genetic variations among stocks in the Gulf of St. Lawrence and approaches.** The genetic information for this project is based on a suite of six microsatellite DNA loci, five of which are common to our existing and expanding data base for other regions of the North West Atlantic. For the Gulf project we added information on allelic variability at a sixth locus which provided enhanced discrimination for samples in this region. To date we have scored the complete suite of six microsatellite loci for eight cod aggregations sampled in the spring 1996 during the stock separated period - this is our baseline data set. We also have information on five of these loci for five winter aggregations collected in January 1996, two winter aggregations collected in Jan 1995, and one spring/summer sample collected within the Gulf in July 1995. Preliminary analyses using the complete suite of six microsatellite DNA loci for the eight spring (stock-separated) cod aggregations suggests the two southern Gulf samples are genetically indistinguishable from each other but are different from all other samples, including cod from Sydney Bight, a collection of cod aggregations sampled in St. Georges Bay, regions 3Ps and

3Pn and a sample from Banquereau Bank. Preliminary analyses based on variability at five loci have also been conducted on the available set of spring and summer samples (14 sampling locations). In future analyses we will include information on variability at the sixth locus and will concentrate on a mixed stock analysis approach for the winter-mixed samples using the spring/summer separated samples as hypothesized base-line material. *For more information contact <ruzzante@cs.dal.ca> or <chris.taggart@dal.ca>*

- **Vertebral count variations among stocks in the Gulf of St. Lawrence and approaches.** Since the inception of the project several comprehensive collections of cod have been made during routine (standard) RV surveys and during special surveys of the Gulf of St. Lawrence and its approaches. Each survey retained cod carcasses from the detailed sampling protocol and were later processed in the laboratory for enumeration of vertebral numbers (sum of abdominal and caudal vertebrae). Because the characteristic vertebral count for a given cod stock has both a genetic and environmental component, all vertebral count data is evaluated on a yearclass specific basis. It was predicted that fish collected from the northern extremes of the survey area that experience relatively colder water conditions would have higher mean vertebral counts at all ages in comparison to fish collected from more southerly (warmer water) areas. Deviations from this expected pattern was consider evidence of stock mixing. The 1996 winter survey provided the most geographically expansive collection to date. Mean vertebral counts ranged from 55.5 in Div. 4R (the northernmost extreme of the survey area) to less than 54 from Div. 4Vs (the southernmost sampling location). With the exception of a few age classes in Div. 4Vs and 4T there was a gradient in vertebral numbers among subdivisions from north to south within each age class. The unusual high mean count at ages 4 and 5 in Div. 4Vs could reflect the intrusion of fish originating from other areas to the north. The 1995 winter survey, while less geographically expansive than in 1996, revealed similar results in terms of Div. 3Pn fish exhibiting higher mean vertebral counts at all ages (4 to 8) relative to fish from Div. 4Vn. Yearclass specific vertebral counts of cod from the putative spawning aggregations with each subdivision were also evaluated. In contrast to the 1996 winter survey where evidence of mixing based on crossovers occurred, the spawning surveys conducted from April-June 1996 revealed no such crossovers and instead a gradient (high to low) of mean vertebral counts at all ages was evident from Div. 3Pn to Div. 4R to Div. 4T (Cheticamp) to Div. 4T (Shediac). We plan to broaden our analyze beyond the evaluation of geographic variation in mean vertebral counts and envision the analysis of the frequency distributions of vertebral numbers, particularly the mixtures that makeup the heterogeneous winter distributions. This will involve using the mean and variance of the vertebral counts of the putative spawning populations to isolate groups from the mixed winter distributions from the entire survey area rather than on the basis of NAFO statistical divisions. It is also expected that the analysis of the genetic material and otolith chemistry, in combination with the vertebral count data, will yield the most definitive interpretation of the composition of cod mixtures. *For more information contact <k_frank@bionet.bio.dfo.ca>*

Observations of northern cod overwintering in Trinity Bay, Newfoundland and in Gilbert's Bay, Southern Labrador

Dr. Joe Wroblewski, Ocean Sciences Centre, Memorial University

Adult northern Atlantic cod reside throughout the year in Trinity Bay, and likely other major bays of eastern Newfoundland. More than fifty years ago, Thompson (1943) reported that cod were fished year-round in the deeper waters of Trinity Bay. Templeman and Fleming (1962) described cod being caught off the headlands of Trinity Bay during the spring, before offshore stocks migrated to the coastline. Wroblewski et al. (1994) sonically tracked cod in the Random Island region of Trinity Bay throughout the winter of 1990-91. Based on antifreeze glycoprotein levels in the blood of inshore cod sampled between April 1991 and June 1993, Goddard et al. (1994) deduced the thermal history of adult cod in Trinity Bay. They concluded that after their inshore summer feeding period, considerable numbers of adult cod overwinter in Trinity Bay in subzero water. From May onwards, "cold-adapted" cod move into warming surface waters, where they become available to an early inshore trap fishery (Wroblewski, et al., 1995). The DFO historical data base on tag-recaptures of northern cod provides evidence of a group of cod resident year-round in the Random Island region of Trinity Bay (Wroblewski, et al., 1996).

There is historical evidence of northern cod spawning in Trinity Bay during the spring-summer. Nielsen (1895) used cod spawning in the bay as brood stock for enhancement experiments. Wroblewski, et al. (1996) observed a school of cod spawning on Heart's Ease Ledge, near Random Island, Trinity Bay. Smedbol and Wroblewski (1997) reported evidence of inshore spawning by northern cod in western Trinity Bay for the years 1991-93. Smedbol, et al. (in manuscript) described the production and fate of eggs spawned by the large aggregation of cod discovered in Smith Sound, Random Island region, during the spring of 1995.

Recent observations provide evidence of inshore cod overwintering in Gilbert's Bay, southern Labrador. Gilbert's Bay is located at about 52^0 35' N, 55^0 55' W, just north of the 2J-3K NAFO Divisions boundary. The local bottom topography is not similar to the fjords of the Random Island region of Trinity Bay. Rather, Gilbert's Bay is shallower than 100 metres, with few deeper holes. Memorial University researchers are currently tracking sonically-tagged cod overwintering in Gilbert's Bay during this winter of 1996-97. The tagged cod are in shallow water, less than 50 metres depth, in narrow arms of the bay. An interesting observation is that some of the cod travelled several miles to return to their point of capture in Long Arm.

Other evidence for a "bay stock" in Gilbert's Bay comes from experimental fishing, the Sentinel Fishery during the summer-fall of 1996, and the "recreational/food" fishery of September, 1996. Only 26 cod were caught on the headlands of Gilbert's Bay during the eight weeks of the sentinel fishery. However, about two thousand cod were caught in Gilbert's Bay during the six days of the recreational fishery. Length-age analysis of seventy cod from Gilbert's Bay indicates a slow-growing group of fish, mixed with cod of more typical length-at-age. Research is currently being conducted to determine if some Gilbert's Bay cod are genetically distinct. The reddish colour of many Gilbert's Bay cod may be a phenotypic expression of an unusual genotype, or it may be related to diet and/or habitat.

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RESEARCH ON COASTAL COD IN NORWAY

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Introduction - otolith structure and other differences

It was early recognized that there are two different types of cod in Norwegian waters: One which seems to be restricted to coastal areas and banks, commonly referred to as Coastal cod, and an oceanic type, the Northeast Arctic (Arcto-Norwegian) cod. For many years the two types were separated in the catch statistics, based on fishing grounds and seasons more than examination of the catches. The coastal type is darker in color, has a shorter head and a rounder body. Rollefsen (1933, 1934) discovered that the two types also could be distinguished by the otoliths. In particular, the first winter ring of Coastal cod otoliths is easily recognizable, being very distinct, but also the shape of the otolith and the relative width of the zones are different. Coastal cod was also found to have a lower number of vertebrae, faster growth and earlier maturity. Classification of otoliths according to type (coastal/oceanic) is routine in Norwegian sampling programs.

Early tagging experiments

Tagging experiments on Coastal cod were first carried out on the Skagerrak coast in southern Norway and showed only local migrations of the cod. The next experiments were in Lofoten, the major spawning ground for the Northeast Arctic cod, but also an important spawning ground for Coastal cod. In this area, catches by Danish seine during the spawning season contained predominantly coastal cod whereas catches by other gears were dominated by Northeast Arctic cod («skrei»). Comparing recaptures of cod tagged from Danish seine and purse seine catches, respectively, showed that the former had much more restricted migrations, being recaptured only in coastal areas (Hylen 1964). The next experiments were carried out further south, about 65°N, on Coastal cod caught in traps. The results showed only local migrations (Hylen, report in Norwegian).

Genetic research

The tagging experiments were followed by genetic research. Møller (1968, 1969) found differences between coastal and oceanic cod in the polymorphic hemoglobin locus HbI and concluded that Coastal and Northeast Arctic cod were «sibling species». More recent work focused on enzymes gave similar results. In general the genetic differences corresponded well with the otolith types. However, it was argued that the differences could be a result of genetic selection (Mork et al. 1984) and no firm conclusions could be drawn. Current research uses DNA techniques, but results have not yet been published.

Management of cod north of 62°N

National economical zones were in effect from 1977. In negotiations with the Soviet Union on the sharing of the cod resources, Norway claimed that Coastal cod, estimated to account for 40,000 t (approximately 5%) of the cod catch north of 62°N (i.e., north of the North Sea region), was a Norwegian resource and should be set aside before the rest was split. This was not accepted by the Soviet Union and although the issue on Coastal cod is not formally settled, practical management gives a 50-50 sharing of the cod catches north of 62°N, with no separate management for Coastal cod.

More recent tagging experiments

Godø (1987) tagged Coastal cod in the area just north of 62°N which confirmed the local migration pattern previously found in areas south of Lofoten. More extensive tagging experiments were carried out in the northernmost part of Norway in 1980-1983. The tagging was carried out in fjords on the spawning grounds of Coastal cod as identified by fishermen. Typically these spawning grounds are found in relatively shallow side arms of the fjords. The otoliths showed that the cod was predominantly of the coastal type, although there were examples of considerable mixing with Northeast Arctic cod, especially in some of the westernmost fjords. The results showed a high rate of returns from the same spawning ground one and two years after the tagging, but approximately 10% of returns from fjord areas were from other fjords, and there were examples where most of the recaptures during the next spawning season came from a neighboring fjord. The results indicate that some of the cod remain in the fjord until next spawning. The recaptures on the coast tend to be more to the east than to the west of the fjord. A few examples of longer migrations, to Lofoten and the Barents Sea, presumably are from the relatively few Northeast Arctic cod which mix with the Coastal cod on the spawning grounds.

Cod have been tagged in coastal areas outside the fjords in northern Norway for many years. Otolith samples indicate that these cod have been a mixture of the coastal and oceanic types. Assuming that returns from fjords during the first half of the year represent spawning migration, those tagged in a given area on the coast are widely dispersed. The main pattern is, however, that most have migrated westwards and that the number of returns is highest in the first fjord west of the tagging locality. The results indicate more mixing between the fjords than the fjord tagging experiments do, but could be differently interpreted if there is a homing instinct.

Are Coastal cod and Northeast Arctic cod separate stocks?

There is yet no conclusive evidence that the characters which separate Coastal cod and Northeast Arctic cod are not caused by the environment. The difference in otolith structure is probably caused by the great differences in habitat, especially during the first part of life. While Coastal cod after the pelagic phase settle near the shore at a depth of a few metres, Northeast Arctic cod settle offshore at depths of 200 m or more. Differences in growth, maturity, vertebrae and the genetic characters so far investigated may also be environmentally induced and laboratory experiments indicate that there is no difference in growth rate and maturity given the same environmental conditions (Godø and Moksness 1987).

After the earliest life stages, Coastal cod and Northeast Arctic cod clearly have distinct life histories, although mixing in both feeding and spawning areas regularly occur. The unresolved questions regarding stock identity therefore concern the recruitment mechanisms. The vast majority of 0-group cod are found in offshore areas and are, considering the relative size of the two components, undoubtedly primarily the result of spawning of Northeast Arctic cod. The most crucial question is whether the Northeast Arctic cod also adds to the recruitment in coastal areas and the cod becomes a coastal type simply because it grows up in shallow waters inshore.

Most of the available evidence suggests that Coastal cod and Northeast Arctic cod are separate stocks with distinct life histories, even if some degree of interchange might occur. It would seem strange if the distinct life cycle of the Coastal cod from 0-group to spawning does not reflect a self-sustained cycle, which in fact seems to be the case on the southernmost parts of the coast where a major influence from oceanic stocks is very unlikely. Northeast Arctic cod, on the other hand, will at any rate not be much influenced by the much less numerous Coastal cod, even if recruits from Coastal cod spawning grounds should be transported offshore.

Is there more than one stock of Coastal cod?

The tagging experiments on Coastal cod show a high rate of return to the same spawning ground year after year, but also some degree of mixing (Jakobsen 1987). There are unresolved questions regarding the recruitment mechanisms and, at least on the northeasternmost part of the coast, some evidence that the fjord systems are unstable. Thus, the northeasternmost fjords seem to be nearly depleted in periods, corresponding to east-west shifts in the distribution of Northeast Arctic cod, which are linked to variations in the influx of warm Atlantic water into the Barents Sea. A gradual spreading eastward of the fjord spawning was demonstrated in 1987-1989 (Jakobsen and Clausen, report in Norwegian). The distribution of Coastal cod along the Norwegian coast is continuous with no apparent borders, and we are probably dealing with basically one major system which is comprised of a large number of sub-stocks with varying degree of stability and isolation. There are, however, threshold fjords where there are strong indications of locally isolated stocks, but these represent only a minor part of the Coastal cod.

The size of the Coastal cod resource

The estimated catches of Coastal cod have fluctuated around 40,000 t, which represents 5-10% of the total catch north of 62°N. Compared to the Northeast Arctic stock of 2-3 million t, this indicates that the stock size is in the range 100,000 -300,000 t. This is supported by an acoustic survey carried out north of 62°N over a three year period (Eliassen et al. 1993, 1994, 1995). The survey gave a stock estimate of 201,000 t and a spawning stock estimate of 153 000 t. A more recent and less comprehensive survey (Anon. 1997), gave an estimate of 144,000 t with a spawning stock of 75, 000 t. It is not clear whether this reduction is real or just reflects the considerable methodological problems with surveys in restricted fjord areas.

Management of Coastal cod

As long as the current management system restricts the total cod catches, there is also some protection of Coastal cod, but this does not extend to the single fjord. There is some pressure from local fishermen for a separate management of Coastal cod and it is possible to do this even if Norway and Russia do not agree on the Coastal cod issue. However, the considerable mixing of the two types on coastal fishing grounds means that an effective management of Coastal cod would be costly, because it would require a large effort in separating the types in the catch statistics. In addition to this, there is the cost of monitoring the resource. It is therefore questionable if the benefit of Coastal cod management justifies the cost.

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Random island region and the inshore/offshore stock question.
Presented by C.T. Taggart and D.E. Ruzzante

- **Inshore-offshore genetic structure in Newfoundland cod.** Microsatellite DNA provided evidence that Atlantic cod overwintering in inshore Newfoundland are genetically distinguishable from cod overwintering offshore. Variation in five loci in samples from inshore locations around Trinity Bay, Newfoundland, and from an offshore region on the northern Grand Bank (North Cape) were compared. Cod collected inshore were divided into two groups based on antifreeze level in blood, those with high antifreeze levels and are presumed to have overwintered in cold (<0 °C) inshore waters and those with low antifreeze levels and are presumed to have overwintered offshore in warmer (>2 °C) waters. Fish overwintering inshore differed from offshore fish in allele-sharing and $(dm)^2$ distances, while fish with low antifreeze levels did not. Subpopulation structure (Rst) was detected when offshore cod were compared to inshore cod with high-, but not when compared to those with low levels of antifreeze. These results suggest that cod overwintering inshore are genetically distinct from offshore cod. Inshore and offshore cod from the areas studied remain genetically distinct despite the fact that individuals from both populations intermingle inshore during the summer and fall feeding migration. Thus, there is genetic evidence of population structure at a finer geographical scale than has been shown to date for this species. *For more information see: Ruzzante, D.E., C.T. Taggart, D. Cook and S.V. Goddard. 1996. Genetic differentiation between inshore and offshore Atlantic cod (Gadus morhua) off Newfoundland: microsatellite DNA variation and antifreeze level. Can. J. Fish. Aquat. Sci. 1996. 53(3): 634-645.; or contact: <d.ruzzante@cs.dal.ca> or <chris.taggart@dal.ca>*

- **A test of inshore-offshore genetic structure in Newfoundland cod.** The genetic difference between inshore overwintering cod from Trinity Bay, Newfoundland, and offshore overwintering cod from the Grand Bank region (Ruzzante et al. 1996; Can.J.Fish.Aquat. Sci. 53: 634-645) has remained stable during 1992 to 1995. Cod collected inshore during 1995 in Trinity Bay (N=150) were again genetically distinguishable (using $(\delta\mu)^2$ and D_{sw}) from offshore cod (N=140) collected between 1992 and 1994, and were genetically indistinguishable from inshore cod (N=123) also collected between 1992 and 1994. Farm-held cod (N=30), captured inshore in 1992 and pen-reared until 1995 were most likely to have been drawn from an inshore overwintering population; they were genetically different from offshore cod and were indistinguishable from wild inshore cod showing high antifreeze activity and from cod collected in relatively cold (~0.2 °C) water in December 1995. The farm-held cod were genetically different from cod collected in relatively warm (~3.3 °C) water but were indistinguishable from cod with low antifreeze activity. Despite evidence of weak genetic heterogeneity within the pool of wild cod collected inshore in 1995, which was not associated with antifreeze activity nor with water temperature, the magnitude of the genetic differences between inshore and offshore cod has remained unchanged during the period 1992-1995. *For more information see: Ruzzante, D.E., C.T. Taggart, D. Cook and S.V. Goddard. 1997. Genetic differentiation between inshore and offshore Atlantic cod (Gadus morhua) off Newfoundland: a test, and evidence of temporal stability. Can. J. Fish. Aquat. Sci. 54: In press.; or contact: <d.ruzzante@cs.dal.ca> or <chris.taggart@dal.ca>*

- **Evidence from tagging for resident inshore cod in Newfoundland.** During the periods of 27-28 March 1988, 24-29 March 1990 and 20-27 January 1991 live cod were collected by otter trawl at an average depth of 224 m (SD=29m) along the length of Southwest Arm in Trinity Bay where the bottom temperatures ranged between -0.7°C and 1.5°C (mean=0.0°C). A total of 5021 (692, 1639, and 2690 in 1988, 1990 and 1991 respectively) of these cod were tagged and released in the immediate vicinity of capture. Details of these tagging studies can be found in Taggart et. al 1995 (Can. Tech. Rep. Fish. Aquat. Sci. 2042.). As of 1 January 1995, a total of 1398 of these tagged cod had been captured by the commercial and recreational fisheries and the tags had been returned. A total of 1160 tags had accompanying information on at least the month and year for the date of capture as well as the location of capture with a radius of ~30 nm or better. By the end of the first post-release Winter-Spring period (end of May) 471 of these tagged cod had been captured; 95% of them within 30 nm of the release location, and all but one within 60 nm . By the end of the first post-release Summer-Autumn period (end of November) a further 548 tagged cod had been captured of which 83% were within 30 nm of the release site. All but 12 (2%) of these cod were reported from locations <60 nm from the release location. A similar pattern was observed in the following year when by the end of the second Winter-Spring period an additional 49 of the tagged cod had been captured of which 40 (82%) were within 60 nm of the release location. Clearly 9 of these cod (18%) had emigrated offshore to the shelf break sometime during the first 12 to 14 months following their release. By the end of the second post-release Summer- Autumn period a further 63 cod were captured, and again the majority were from the local region (70% within 30 nm of the release location and 91% within 60 nm), although offshore migration was again illustrated by at least one cod. This pattern of tag reporting for cod tagged and released in the Southwest Arm area continued through the end of the third Winter-Spring and Summer-Autumn periods (8 of 10 and 8 of 11 tagged cod reported from within 60 nm respectively), and though the end of the fourth Winter-Spring and Summer-Autumn periods (2 of 2 and 4 of 5 from within 30 nm respectively). It is clear from these results that there is a relatively high probability that cod tagged during the January to March period in the Southwest Arm region of Trinity Bay will subsequently be captured in the local area, even three or more years subsequent to release, consistent with the concept of local residency or fidelity at coastal-bay scales (30 to 60 nm). *For more information see: Wroblewski, J.S., R. K. Smedbol, C.T. Taggart, S.V. Goddard. 1995. Movements of farmed Atlantic cod (Gadus morhua) released in Trinity Bay, Newfoundland. Mar. Biol. In Press.; Taggart, C.T., P. Penney, N. Barrowman, and C. George. 1995. The 1954-1993 Newfoundland cod-tagging database: statistical summaries and spatial-temporal distributions. Can. Tech. Rep. Fish. Aquat. Sci. 2042.; or contact <chris.taggart@dal.ca>*

Title: Observations on cod in western Trinity Bay during April 1996 - J. Brattey

Biological sampling conducted during a hydroacoustic survey indicated that adult cod were widely distributed and locally abundant in Smith Sound, Northwest Arm, and Southwest Arm, Trinity Bay during April 1996. Cod were sampled with handlines, otter trawl, and gill nets. Lengths of cod ranged from 17 to 124 cm, with means typically around 55 cm in each area. Ages of cod sampled ranged from 2 to 25, but most fish were less than 11 yrs old and 6 yr olds (1990 yr class) were most common. Spawning cod were found in deep water (200m) in the outer reaches of Smith Sound and cod in other areas appeared destined to spawn later that year. Age at maturity was comparable whereas length at age was slightly greater than that observed in 3L cod collected during offshore trawl surveys in recent years. In contrast, the prevalence of the parasitic copepod Lernaeocera branchialis was much higher than that of offshore cod, suggesting that these cod had remained inshore since at least the previous fall when parasite transmission occurs. The origins of these cod remain somewhat speculative. There is much debate as to whether they represent "bay" components that remain inshore throughout the year, offshore components that have recently changed their migratory patterns and remained inshore, or a combination of the two.

Appendix II

List of Workshop participants

Name	Affiliation
Bruce Atkinson	DFO - St. John's
Terry Beacham	DFO - PBS
John Brattey	DFO - St. John's
Scott Campbell	DFO - St. John's
Jim Carscadden	DFO - St. John's
Martin Castonguay	DFO - IML
Denis Chabot	DFO - IML
Donald Clark	DFO - St. Andrew's
Edgar Dalley	DFO - St. John's
Ben Davis	DFO - St. John's
Ross Dunphy	Fisherman
Geoff Evans	DFO - St. John's
Paul Fanning	DFO - BIO
Alain Fréchet	DFO - IML
Dominique Gascon	DFO - IML
Sally Goddard	MUN
Bob Gregory	OSC - MUN
Joe Hunt	DFO - St. Andrew's
Tore Jakobson	IMR - Bergen, Norway
Harvey Jarvis	FFAW - Sentinel
Jon Lien	FRCC
George Lilly	DFO - St. John's
David Methven	OSC - MUN
Dan Miller	DFO - St. John's
Byron Monk	Sentinel Fishery
Eugene Murphy	DFO - St. John's
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Jake Rice	DFO- CSAS
Denis Rivard	DFO - Ottawa
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David Schneider	OSC - MUN
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Don Stansbury	DFO - St. John's
Rick Stean	DFO - St. John's
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Trevor Taylor	FRCC
John Wheeler	DFO - St. John's
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