Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

C S A S
Canadian Science Advisory Secretariat

S C C S
Secrétariat canadien de consultation scientifique

Research Document 2002/082

Document de recherche 2002/082

Not to be cited without
permission of the authors *

Ne pas citer sans
autorisation des auteurs *

Review of population structure, distribution and abundance of cod (*Gadus morhua)* in Atlantic Canada in a species-at-risk context

Survol de la structure de la population, de la distribution et de l'abondance de la morue (*Gadus morhua)* dans le Canada atlantique dans le contexte des espèces en péril

By / Par

R. K. Smedbol[1], P. A. Shelton[2], D. P. Swain[3], A. Fréchet[4], and G. A. Chouinard[3]

[1]Fisheries and Oceans Canada, Biological Station, 531 Brandy Cove Rd., St. Andrews, NB, E5B 2L9

[2]Fisheries and Oceans Canada, Northwest Atlantic Fisheries Centre, St. John's, NF, A1C 5X1

[3]Fisheries and Oceans Canada, Gulf Fisheries Centre, P.O. Box 5030, Moncton, NB, E1C 9B6

[4]Fisheries and Oceans Canada, Institut Maurice-Lamontagne, Mont-Joli, PQ, G5H 3Z4

ISSN 1480-4883

Canada

Abstract

The structure, abundance, and distribution of 10 cod stocks in Atlantic Canada were reviewed under four terms of reference. Cod population structure was evaluated in the context of "evolutionarily significant units". The review did not provide evidence to indicate the existence of ESUs within current management units, therefore all subsequent analyses were undertaken at the level of current unit stocks. In general, all 10 stocks across Atlantic Canada exhibited some level of decline during the available time series of abundance. Seven stocks underwent declines that reached at least 90% for at least some portion of the time periods examined. Two stocks underwent both declines and recoveries, depending upon the time interval used in the analysis. Exploitation was considered to be the main cause of abundance decline in all stocks, although unfavourable environmental changes and elevated natural mortality (from either poor fish condition or seal predation) have been proposed as possible factors in the decline or lack of recovery within several management units. Mature population estimates of all cod stocks in Atlantic Canada were at least two orders of magnitude greater than the COSEWIC threshold of 10 000 mature individuals. Three indices were calculated: the area of occupancy, the minimum area occupied by 95% of the stock, and the Gini index of aggregation. No general pattern or trend in geographic distribution was evident. Most stocks that underwent a large (at least 90%) decline in abundance also demonstrated at least some decrease in area occupied and a corresponding increase in the degree of aggregation. Several stocks showed little change in occupancy. Evidence exists that suggests the loss of a population (spawning) component on the Eastern Scotian Shelf (4VsW). No evidence was presented for an increase in the degree of population fragmentation within management units.

Résumé

La structure, l'abondance et la distribution de 10 stocks de morues de la côte Atlantique du Canada ont été examinés selon quatre termes de références. La structure des populations de morue a été évaluée dans le contexte d'unités importantes sur le plan de l'évolution (UIPÉ). Cette revue n'a pu mettre en évidence de UES à l'intérieur des unités de gestion courantes, donc toutes les analyses subséquentes ont été faites selon la définition actuelle des stocks. Les 10 stocks de la zone Atlantique du Canada ont démontré un certain niveau de déclin pour les séries temporelles d'abondance disponibles. Sept stocks ont subi un déclin d'au moins 90% pour au moins une portion des séries temporelles examinées. Deux stocks ont connu à la fois un déclin et une reprise dépendamment de l'intervalle de temps utilisé dans l'analyse. L'exploitation a été considérée comme étant la principale cause du déclin de l'abondance de tous les stocks. Cependant, les piètres conditions environnementales et un taux de mortalité naturelle élevé (qui soit lié à une mauvaise condition des poissons ou à la prédation par les phoques) ont également été suggérés comme des facteurs possibles dans le déclin ou le manque de rétablissement de plusieurs unités de gestion. L'estimation des effectifs matures de tous les stocks de la côte Atlantique du Canada excède par au moins deux ordres de magnitude le seuil des 10,000 individus matures établi par le COSEPAC. Trois indices ont été calculés: l'aire occupée, l'aire minimale occupée par 95% du stock et l'indice d'agrégation Gini. Il n'y avait aucun patron général ni aucune tendance au niveau de la distribution géographique. La majorité des stocks qui ont connu d'importantes diminutions d'abondance (au moins 90%) ont aussi subi certaines diminutions de l'aire occupée et une augmentation correspondante dans le degré d'agrégation. Plusieurs stocks n'indiquaient pas de changement important de l'aire d'occupation. Il y a des évidences à l'effet d'une perte d'une composante de fraie à l'est du plateau néo-écossais (4VsW). Il n'y a aucune évidence présentée concernant une augmentation de fragmentation des populations à l'intérieur des unités de gestion.

Table of Contents

General introduction and rationale

This paper presents a review of information held by Fisheries and Oceans Canada (DFO) that could be used by the Committee on Status of Endangered Wildlife in Canada (COSEWIC) in assessing status and extinction risk of Atlantic cod (*Gadus morhua*) in Canadian waters. In this document relevant information was compiled, vetted, and summarized. In addition, the methods, context, and caveats of data collection have been provided. Information on distribution, abundance and life history characteristics was reviewed under four terms of reference. A substantial portion of the information presented here is already available in stock assessment Research Documents that are available from the CSAS website.

The first term of reference required that the population structure of Atlantic cod in Canada be reviewed in the context of "evolutionarily significant units" (*sensu* Waples 1995). Existing stock definitions were to be considered *inter alia*, in light of the results of the Workshop on Cod Stock Components (1997) and other relevant research. Conclusions are provided regarding the degree to which population units at and below the scale of stocks (as used in current management) are evolutionarily independent and the scientific evidence for those conclusions. Population units identified are used as the basis for all subsequent analyses.

Under the second term of reference, summaries are presented for overall trends in population size (both number of mature individuals and total numbers in the population) over as long a period as possible, and in particular for the past three generations (taken as mean age of spawners). Further, where declines have occurred over the past three generations, summaries are provided for the degree to which the causes of the declines are understood, and the evidence that the declines are a result of natural variability, habitat loss, fishing, or other human activity. Where declines have occurred over the past three generations, the possibility that declines have ceased, are reversible, and likely time scales for reversibility are discussed.

The third term of reference dealt with area of occupancy and change or fluctuation in spatial distribution of identified population units. Current area of occupancy is summarized, and changes in area of occupancy are reviewed over as long a time period as possible, and in particular, over the past three generations. Population units are investigated for any evidence that there have been changes in the degree of fragmentation of the overall population, or a reduction in the number of meta-population units.

Finally, under the fourth term of reference, information on the abundance of each population unit is summarized. The best scientific estimates of the number of mature individuals are presented. If these estimates are less than 10 000 mature individuals, further summaries were required concerning trends in numbers of mature individuals over the past 10 years or three generations, and, to the extend possible, causes for the trends.

ToR 1: Population structure of Atlantic cod in Canada in the context of "evolutionarily significant units"

1.1 Introduction

One element in the evaluation of species and populations in relation to risk of extinction is the unit of consideration. One such unit is the Evolutionarily Significant Unit (ESU), proposed by Ryder (1986) as the minimal unit of conservation management. There exists a range of definitions for the ESU (see Fraser and Bernatchez 2001 for a recent review), and a number of techniques have been proposed to identify potential ESUs. The result is a debate that has stretched over the last 10 years, and has yet to be resolved (papers in Neilsen 1995; Dimmick et al. 1999; Dimmick et al. 2001; Young 2001).

The debate over what constitutes an ESU focuses on two separate issues. The first part of the debate involves the role of neutral genetic markers in the evaluation of potential ESUs relative to other (possible) criteria. To date, neutral markers have been used extensively in the determination of population level genetic structure, yet have no adaptive significance. The second question addresses the point along the evolutionary continuum, from intrapopulation units to species, at which conservation efforts should be concentrated (Fraser and Bernatchez 2001). In this section (1.1), some popular definitions and current uses of the ESU concept are briefly reviewed. These examples are then evaluated in the context of defining appropriate conservation units for marine fish populations currently under the jurisdiction of Fisheries and Oceans Canada.

1.1.1 The ESU under the National Marine Fisheries Service

One commonly cited approach to ESU evaluation is that developed by the US National Marine Fisheries Service (NMFS) to delineate conservation units for Pacific salmonids (*Oncorhynchus* spp.; e.g. Waples 1995). Waples (1991) has defined an ESU as a population (or group of populations) that is (1) substantially reproductively isolated from other conspecific population units, and (2) represents an important component in the evolutionary legacy of the species. Under the definition proposed by Waples (1991; 1995) (and in its use by the NMFS), only partial reproductive isolation is necessary, as long as this level of isolation is sufficient to allow for the development of evolutionarily important differentiation between population units. This differentiation contributes to the "evolutionary legacy" of the species. Thus the important issue is to evaluate the potential contribution of a proposed ESU to this legacy. Waples (1995) proposes that a key criterion in terms of evolutionary legacy of an ESU is that the extinction of the unit in question would represent a significant loss to the ecological and genetic diversity of the species. If extinction would not result in an important loss of diversity, then the candidate unit is not an ESU. Important information in the determination of evolutionary significance is not limited to genetic differentiation, but rather includes patterns derived from mark-recapture studies, potential rates of recolonization, and existence of potential barriers between species units (potential for vicariance). Differences in phenotypic and life history traits are also important, but environmental effects upon these characteristics must be taken into account. In evaluating a possible ESU, Waples (1995) suggested that three questions should be addressed. Is the population genetically distinct from other conspecific populations? Does the population occupy unusual or distinctive habitat? Does the population show evidence of unusual or distinctive adaptation to its environment?

The ESU concept as developed by the NMFS has two valuable characteristics. The first is that it integrates information from a variety of sources, including genetics, ecology, life history, and geography. Secondly, the NMFS ESU is the only working approach that includes procedures for conserving the populations that comprise ESUs in order to avoid future extinction (Fraser and Bernatchez 2001; see Waples 1991 and McElhany et al. 2000). However, the approach taken by the NMFS also has several drawbacks. For instance, the final decision concerning a potential ESU still requires the reviewer to weigh the evidence and make a professional judgement. This lack of rigorous, definitive criteria for ESUs may be a major reason for the continuing debate in the literature concerning the efficacy of the ESU as the minimum unit of conservation management. The idea of "evolutionary significance" may be too subjective to apply in practice (Moritz et al. 1995). Additionally, the applicability of the NMFS approach to taxa other than Pacific salmonids has been questioned (Pennock and Dimmick 1997).

An example that illustrates the flexibility and integration in the evaluation of potential ESUs by the NMFS is the case of chinook salmon (*Oncorhynchus tshawytscha*) that spawn in the Snake River system. The evaluation of these salmon populations was reviewed by Waples (1995), and is only briefly summarized here. Snake River chinook exhibit three spawning runs: spring, summer and fall. Fall spawners differed from spring and summer spawners in several characteristics. Genetic analyses revealed differences in allele frequency variation of 25-50% between fall and spring-summer spawners. Differences in life history were documented also. Fall run chinook migrate to the sea as subyearlings (age 0+), whereas the offspring from spring-summer run spawners initiate their oceanic migration as yearlings (age 1+). Additional evidence for reproductive isolation was derived from genetic and tagging studies that provided no evidence for straying of Snake River fall-run chinook into the fall-run on the neighbouring Columbia River. Thus, evidence for reproductive isolation was detectable, but were the above differences of *evolutionary* significance? Waples (1995) states that two factors were key in the final decision. First, the Snake River has higher turbidity, pH, total alkalinity, and greater temperature variability than the adjacent Columbia River, into which it drains. Secondly, several years of mark-recapture data from hatchery-raised chinook revealed that fall-run fish from the two rivers exhibited different distributions during the oceanic life history phase. These factors pointed to possible physiological or behavioural adaptations in fall-run spawners to different environmental and feeding conditions. Thus, fall-run chinook in the Snake River were declared a separate ESU and listed under the Endangered Species Act.

1.1.2. Phylogeographical approaches to ESU designation

Proponents of phylogeographical methods tend to consider the guidelines to ESU designation adopted by NMFS as subjective, and prefer the more rigorous and objective techniques used in the fields of phylogenetic systematics (e.g. Moritz et al. 1995; Dimmick et al. 1999). In this section the approach to ESU evaluation advocated by Moritz (1994) and Moritz et al. (1995) is briefly summarized. Moritz (1994) defined an ESU as a population (or set of populations) that is reciprocally monophyletic for mitochondrial DNA alleles and exhibits significant divergence of allele frequencies at nuclear loci. Reciprocal monophyly is the condition where all the genetic lineages in each population in question share exclusively most the recent common ancestry. This requirement favours structure that has been present for long periods, given the time necessary for diverging populations to develop reciprocally monophyletic alleles in mtDNA ($4N_e$ generations; Neigel and Avise 1986). Given the relatively large effective population sizes in north temperate marine fishes, this corresponds to time periods that may extend beyond the post-glaciation period (e.g. cod; see Carr et al. 1995). Significant divergence in nuclear DNA is also required in case populations are linked only by nuclear and not mitochondrial gene flow (Moritz 1994).

This approach is valuable in that the requirement of reciprocal monophyly is a qualitative criterion (does it, or does it not, exist?), and thus allows the use of molecular genetics while avoiding the problematic question of how much differentiation is enough (Moritz et al. 1995). However, this approach is not without drawbacks of its own. No single method for construction of phylogenies provides the best reconstruction in all cases (Waples 1995). In addition, the rigour provided by reciprocal monophyly can be misleading, as a single anomalous individual in a new sample can result in the rejection of condition of reciprocal monophyly in the system under consideration (Fraser and Bernatchez 2001). Perhaps most importantly, the concept may undervalue the potential of species to maximize evolutionary success through the maintenance of adaptive diversity (Lande and Shannon 1996).

1.1.3. A hierarchy of units in marine fish conservation

COSEWIC is the entity responsible for the listing of at-risk species in Canada. COSEWIC defines a “species” as any indigenous species, subspecies, or geographically defined population of wild fauna and flora. Thus protection may be extended down to the population level. Interpretation of this definition has lead to use of the ESU concept to define the appropriate scales for conservation units. However, the species definition provided by COSEWIC includes “geographically defined” population units, which may be similar to the stock concept used in marine and fisheries management. An appropriate question to ask is whether stock divisions used currently reflect levels of population (sub)division necessary for ESU designation. If management units based on putative stock divisions occupy a spatial scale finer than potential ESUs, then the issue of what population segments constitute ESUs is of little relevance, since conservation efforts already target a finer scale. If, however, it is determined that a designated stock unit contains more than one ESU, then data from the stock unit must be evaluated on a finer spatial scale that is more reflective of individual ESUs.

Both of the approaches to ESU identification outlined above define population units at finer scales within the ESU, and advocate that effort be undertaken to conserve these units and thus increase the probability of persistence for the overall ESU. These smaller population units have much in common with the stock concept used in fisheries management.

1.1.4. Pacific salmonids

In the case of Pacific salmonids the working ESU concept has been expanded to include what are called Viable Salmonid Populations (VSP). The VSP and the updated procedures under the NMFS ESU concept are presented in McElhany et al. (2000). Basically this addition to the NMFS approach covers activities following the designation of an ESU. Effort shifts to ensuring the persistence of the component populations of the ESU, with the goal of enhancing the long-term viability of the ESU. The NMFS defines a VSP as an independent population of any Pacific salmonid (genus *Oncorhynchus*) that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes over a 100-year time frame McElhany et al. (2000). Independent populations comprise a collection of one or more local breeding units whose population dynamics or extinction risk over a 100-year time period are not substantially altered by exchanges of individuals with other populations. If one independent population were to go extinct, it would not have much impact on the 100-year extinction risk experienced by other independent populations (McElhany et al. 2000). Independent populations are likely to be smaller than a whole ESU.

This definition of an independent population is purposely similar (McElhany et al. 2000) to the definition of a stock proposed by Ricker (1972). McElhany et al. (2000) define an independent population as a "group of fish of the same species that spawns in a particular lake or stream (or portion thereof) at a particular season and which, to a substantial degree, does not interbreed with fish from any other group spawning in a different place or in the same place at a different season". Again, the important characteristic here is the scale or degree of reproductive isolation. Some exchange occurs among VSPs, but not enough to synchronize their population dynamics. Therefore, they exist as separate entities. However, any genotypic or adaptive divergences among VSPs are not sufficiently different to be of evolutionary significance. Immigrants from neighbouring populations would not exhibit lower fitness relative to indigenous salmon. At the scale of the ESU, immigrants may well suffer such a decrease in fitness. By definition the genetic or phenetic differences exhibited by a particular ESU represent an important component in the evolutionary legacy of the species.

1.1.5. Management units under phylogeographic approaches

Even some proponents of rigorous definitions for ESUs (e.g. Moritz 1994) acknowledge that phylogenetic structure can be detected on the continuum of genetic variation at levels below reciprocal monophyly. In response to this finer-scale differentiation, Moritz (1994) proposed the Management Unit (MU). This unit comprises a population or set of populations that exchange substantial numbers of individuals, but are functionally separate from other such sets (Moritz et al. 1995). Once again, this unit has much in common with the stock concept, especially the stock definition provided by Dizon et al. (1992). The MU was presented as a management and conservation unit at a finer scale than the ESU. This unit is identified only by statistically significant differences in nDNA or mtDNA allele frequencies, and phylogenetic differentiation is not required. Moritz et al. (1995) stated that the purpose of such units of "functionally independent sets of populations" is to define the geographic scale for population management. An important characteristic of the MU from a management perspective is that it centres on contemporary population organization, rather than historical (i.e. phylogenetic) structure (Moritz 1994; Fraser and Bernatchez 2001).

1.1.6. Conclusions: ESUs, stocks, and marine fish populations

The debate over what should constitute an ESU is roughly divided into two approaches for evaluation, (1) multi-metric procedures that weigh adaptation and evolutionary legacy (e.g. Waples 1991; 1995), and (2) phylogeographic or phylogenetic techniques that set rigid criteria (e.g. Moritz 1994; Moritz et al. 1995). However both of these rather disparate definitions of ESUs explicitly incorporate population and management structure at finer scales within ESUs. Differences among putative ESUs are considered to be of evolutionary significance, whereas the separation among population units within an ESU (either VSPs or MUs) is not of evolutionary significance. Both the VSP and MU concepts hold much in common with the stock concept, and this similarity is acknowledged and discussed explicitly (Moritz 1994; Moritz et al. 1995; McElhany et al. 2000). Thus the case can be argued that the stock concept (as currently defined) incorporates population structure of a finer scale than that that embodied by an ESU.

The number and location of fish stocks was a consideration in the construction of Canadian fisheries management units (e.g. Halliday and Pinhorn 1990). Generally, the boundaries of management divisions have been arranged to encompass unit stocks (Halliday and Pinhorn 1990; Smedbol and Stephenson 2001). One can conclude, therefore, that if fish stocks within Canadian waters have been identified correctly, Canadian fishery management units are already defined on a finer scale than potential ESUs. Therefore, under the Terms of Reference for National Assessment Process on Species at Risk Issues, we have reviewed what is known of population structure *within* current assessment and management units. Only if this review provides evidence of *evolutionarily* important differences *within* stock boundaries should current stock designations be dropped in favour of new conservation units based on criteria for delineation of potential ESUs. However, detectable stock differentiation may not be of evolutionary significance. The review may provide evidence of population structure at this finer scale within current management units that is not currently incorporated into management planning. Such evidence should lead to a re-evaluation of the current management units encompassing the population components in question.

1.2. General population structure of Atlantic cod in Canadian waters

The range of Atlantic cod in the western Atlantic ranges from the northern tip of Labrador to Cape Hatteras in the south. Within the area under Canadian jurisdiction, cod exhibit a number of adjacent populations. These populations are recognized as ecological units within management divisions defined by the Northwest Atlantic Fisheries Organization (NAFO; Fig. 1.1). The evolution of NAFO management divisions was reviewed by Halliday and Pinhorn (1990). Some management units may contain stock or population complexes, and other units contain single stocks. Of current concern is the relative degree of population isolation both among and within management divisions, and the importance of this possible isolation in effective fisheries management. Rice (1997), in the proceedings of the Workshop on Cod Stock Components, stated that clarification of the relationships among putative population components of cod in the Northwest Atlantic is a fundamental requirement for effective management of cod populations and for conservation of biodiversity. This section reviews the large scale, general population structure of cod in Canadian waters. The discussion is largely limited to genetic studies of population structure. The following sections review population structure at the scale of stock divisions, and include additional metrics of structure.

Highly abundant and widely distributed marine fishes often demonstrate relatively high levels of gene flow among populations (Ward et al. 1994; Waples 1998). Northwest Atlantic cod appear to follow this general rule. Bentzen et al. (1996) used nuclear DNA microsatellites to reject the hypothesis of no genetic distinguishability among cod in the northwest Atlantic cod. Statistically significant differences in allele frequency variation were detected between samples from the Scotian Shelf and the Northeast Newfoundland Shelf-Grand Bank. Differences were also detected between pooled samples from the northern and southern regions of the Northeast Newfoundland Shelf-Grand Bank area. Ruzzante et al. (1996; 1997) extended these analyses. Ruzzante et al. (1998) reported statistically significant differences in nuclear DNA that were distinguishable at the scale of continental shelves (Northeast Newfoundland Shelf, Grand Banks, Flemish Cap, Scotian Shelf, and Georges Bank). Additionally, Ruzzante et al. (1998) provided evidence for the presence of genetic structure at the finer spatial scale of offshore banks and major bays. Beacham et al. (2000) have provided evidence to suggest even finer population structuring in the waters around Newfoundland and Labrador.

1.3. Evidence (or lack of evidence) for evolutionary independence of population unit below stock level, stock by stock.

1.3.1. Cod in 2GH

Although there is a cline in fish growth rates off Labrador and the east coast of Newfoundland (Fleming 1960), which would indicate that there is not widespread mixing, Templeman (1962) defined a single Labrador-Newfoundland stock from Northern Labarador (2G) to approximately off St John's (northern half of 3L). He acknowledged that future data may substantiate the existence of separate stock components within this large area. Based on the distribution of eggs in different stages in the 1960s, it appeared that relatively large quantities of cod must have spawned off northern Labrador (Templeman 1979; 1981).

A TAC for 2GH cod (20,000 t) was first introduced in 1974 by ICNAF following computations of F_{max} yield in the range of 20 000 – 40 000 t (Murphy et al. 1992). No directed fishing on cod in the 2GH area has been permitted since 1986 and there has been no reported catch since 1991. Consequently, if a separate stock did at one time exist in the area, it has been commercially extinct for some time. However, the disappearance might also be explained in terms of a density dependent range contraction to the south within the Labrador-Newfoundland Stock area.

1.3.2. Cod in 2J3KL

Based on vertebral and migratory data, Templeman (1962) defined a Labrador-Newfoundland cod stock extending from northern Labrador southwards over the northern portion of the Grand Bank to a position approximately off St John's. This was based on high vertebral counts and the lack of apparent migratory divisions. However, he concluded that it was very likely that "in the future enough differences will be found to indicate a number of north-south and inshore-offshore sub-stocks of this Labrador-Newfoundland stock which either do not intermingle greatly or separate out at certain seasons." The 2J3KL stock has been treated as a single management unit for quota setting since the introduction of TACs in 1973.

Lear (1986) provided a collation of the available information related to stock structure for the 2J3KL cod stock complex, including genetic, parasite, meristic, growth rate, size and age at maturity, spawning time and location and tagging information. Together these data indicated the likelihood of substock structure but nothing definitive was concluded and stock assessments continued to be based on the 2J3KL cod stock complex.

In 1997 a DFO workshop on cod stock components (Rice 1997) gave consideration to the hypothesis of separate inshore cod stock components, particularly with respect to northern cod. This coincided with an intensification of both tagging and genetic studies in the Newfoundland inshore region.

Recent assessments of 2J3KL cod have reviewed the currently available information on stock structure (Lilly et al. 1999; 2000; 2001). Both an intensification of tagging activity from 1995 onwards (Brattey 1999; 2000; Brattey et al. 2001a) and genetic work on the variation at microsatellite loci (Bentzen et al. 1996; Ruzzante et al. 1996; 1997; 1998; 1999; 2000; Beacham et al. 1999; 2000; 2001) have provided much additional data, analysis and interpretation. However, most of these data are for the post collapse period (see however reference to Ruzzante et al. (2001) below).

Beacham et al. (2001) found that cod populations tended to conform to "an isolation by distance" structure, with cod from more distant locations tending to be more genetically distinct. In the offshore the Flemish Cap (3M) stock are most distinct and in the inshore Gilbert Bay fish are most distinct. Gilbert Bay is located on Labrador's southeast coast (2J), is about 20 km long, less than 100 m deep, with two narrow outlets to the sea. In 2000 Gilbert Bay was declared a Area of Interest in the Marine Protected Areas Program under the Oceans Act. Beacham et al. (2001) found no significant genetic differentiation among inshore northern cod in Notre Dame, Bonavista, Trinity and Conception Bays, and thus no support for the concept of separate "bay stocks". However, fish from these bays were distinct from fish in Gilbert Bay and distinct from most but not all fish sampled in the offshore (2G, Hawke Channel, Belle Isle Bank, Funk Isle Bank and northern Grand Bank). The samples from Trinity Bay were not different from those taken on the northern Grand Bank. The offshore samples themselves were quite heterogenous and indicated that at least three distinct offshore spawning populations might exist. The offshore samples were collected during the fall and therefore not on spawning or immediate prespawning fish. This weakens their use in determining population substructure. Also, the extremely low abundance after the collapse makes it difficult to collect adequate samples in the offshore.

Ruzzante et al. (2001) examined variation at microsatellite loci from samples spanning the period 1964-94. The early samples came from DFO otolith collections and the more recent samples from DFO fall groundfish surveys. They concluded that there was evidence of long term stability in the geographic pattern of genetic differentiation among cod collected from spawning banks over the period of 1964-1994 as a consequence of fidelity to natal spawning sites.

Both Ruzzante et al. (2001) and Beacham et al. (2001) draw the conclusion, based on their data, that recovery would more likely be through population resurgence rather than recolonization (e.g. from the only known overwintering aggregation in Smith Sound). In contrast, Frank and Brickman (2000) have suggestion that Allee effects at the substock level may exist undetected in aggregate data, and could preclude self-regeneration. Recovery would thus necessitate recolonization.

In contrast to the recent microsatellite research, earlier studies by Pepin and Carr (1993) and Carr et al. (1995) based on analysis of mitochondrial DNA provided no evidence of substock structure within 2J3KL.

Recent tagging data (Brattey et al. 2001a) indicates that two groups of cod currently inhabit the inshore – a northern resident group extending from western Trinity Bay northward to western Notre Dame Bay, and a migrant group from the adjacent 3Ps stock that migrates into southern 3L in the spring and returns in the fall.

Templeman (1974) identified a Virgin Rocks Population or Stock on the north-western Grand Bank based on tagging data. The area is not amenable to trawling surveys because of the rough bottom and shallow water depths. However a significant gillnet fishery existed briefly on this component in the late 1980s and early 1990s. An industry search for fish in offshore 3KL in November/December 1997 using otter trawls and gillnets encountered virtually no fish with the exception of some catches from gillnets set in the vicinity of Virgin Rocks. This indicates that at least a remnant of this component has survived, although it is thought to be very small.

1.3.3. Cod in 3NO

Templeman (1962) described a (southern) Grand Bank stock extending over 3NO. Fleming (1960) found fish in the southern part of this area to have the greatest size and age at sexual maturity with spawning taking place between April and June with a peak during the last half of May. Templeman (1974), based on tagging studies, considered that a small proportion of this stock migrates in the feeding season (spring-summer) to the southeastern coast of Newfoundland. Ruzzante et al. (2001) concluded that broad scale genetic structure separating northern cod, southern Grand Bank and Flemish Cap cod has remained temporally stable over a period of three decades starting in 1964 and encompassing large changes in population size. Beacham et al. (2001) found that the southern Grand Bank samples were distinct from samples from other locations.

1.3.4. Cod in 3Ps

Templeman (1962) recognised an Avalon-Burin stock, a St. Pierre Bank stock, and a Burgeo Bank stock within the 3Ps area. The traditional 3Ps cod stock, which first came under TAC management in 1973, extends from Cape St Mary's to just west of Burgeo Bank, including Burgeo Bank, St. Pierre Bank and most of Green Bank on the border with 3L and 3O. It has long been known that the distribution of fish does not conform well to management boundaries and the stock is considered to be a complex mixture of subcomponents (Brattey 1996; Shelton et al. 1996). Brattey (1996) provides an overview of the stock structure in 3Ps based on tagging data. He found that there was a seasonal influx of cod from adjacent management units, notably the northern Gulf cod stock from the west during winter, and possibly from the southern Grand Bank (3LNO) from the south and east during the fall. In addition, Brattey (1996) reported evidence for a migration of the offshore components of the stock to inshore areas during the spring and summer, as well as the possible existence of inshore components that remain inshore throughout the year. He discovered that several components contribute to the catches in this area, including northern Gulf, Burgeo Bank, St Pierre Bank, southern Grand Bank and the inshore Avalon-Burin stock complex. Recent tagging data have indicated the importance of a seasonal migration of fish out from Placentia Bay and up the east cost of the Avalon Peninsula in the spring with a return migration in the fall. In the 1996 assessment (Shelton et al. 1996) the lack of fish in the offshore compared to the continued relatively high abundance led to attempts to carry out separate analyses for the inshore and offshore. However, the assumptions for doing this were considered to be too tenuous. There was no assessment in 1997 but the 1998 assessment did carry out separate inshore and offshore analyses (Stansbury et al. 1998). However, from 1999 onwards 3Ps cod in both the inshore and the offshore were again treated as a single unit (Brattey et al. 1999a,b; 2000; 2001b), although it is recognised that fish from the inshore and the offshore do not exhibit complete mixing. Robichaud and Rose (2001) found that cod tagged with sonic tags in Placentia Bay in the spawning season were relocated in subsequent spawning seasons within 10 km of the tagging site indicating a high degree of homing. Genetic analyses however, have not indicated significant differences between cod in the inshore and offshore 3Ps (Beacham et al. 2001). As a consequence of concern regarding mixing of northern Gulf cod into the region and the possible effects of a 3Ps fishery on the recovery of the northern Gulf cod stock, unit area 3Psd has been closed to directed fishing of cod from 15 November to 15 April from the 1998/99 season to the present.

1.3.5. Cod in 4RS3Pn

Generally, the Northern Gulf of St. Lawrence cod stock is considered as a single stock. Results from historical tagging projects have shown its highly migratory behaviour (Templeman 1974; Minet MS 1977). Templeman’s work (1981) on the vertebral numbers of the Newfoundland area is also pointing to a separate stock. A single, large spawning aggregation has been located in research surveys conducted in May 1993, 1994, 1995 (Ouellet et al. 1997) and 1998 (McQuinn et al. 1999). The largest concentration of fish occurred consistently in an area off Bay St. George (4R) in early May. There are also other references to localized spawning in 3Pn, and 4S from fishermen’s questionnaires. With the decline in the cod stock, it is currently hypothesized that the large aggregations found by the annual groundfish surveys in the early 90s aboard the *Alfred Needler* in the western portion of 4S, to the west of Anticosti Island could have been a sub-component of this cod stock and that it could have been fished out, thus eliminating a spawning sub-component. This possibility is currently being tested through analysis of otolith microstructures.

Past tagging has shown little mixing with adjacent stocks (Gascon et al. 1990) only fish tagged at the extreme limit of distribution of the stock have shown recaptures in adjacent stocks

(4T, 2J3KL). In this report, there is a reference to a potential "homing". Fish tagged in a specific area would likely be recaptured years later close to the location of tagging. More recently, tagging conducted by the sentinel program in the Gulf has shown substantial mixing with 3Ps (Chouinard 2000). This may be linked with recent changes in migration patterns (Castonguay et al. 1999; Fréchet and Gagnon 1993)

Localized, isolated small populations are known to be present in the Saguenay Fjord and in LaPoile Bay; both support a small scale fishery.

1.3.6. Cod in 4TVn (Nov-Apr)

There have been suggestions that there may be western and eastern subcomponents to the southern Gulf stock (Templeman 1962), but there is no strong evidence to support this view. Adaptive phenotypic traits that distinguish southern Gulf cod from other neighbouring cod stocks (e.g., vertebral number, length-at-age) do not differ between eastern and western regions of the southern Gulf (Swain et al. 2001; Sinclair and Fanning 1995). Relatively small but significant differences in otolith elemental composition do occur between cod caught in eastern versus western regions of the southern Gulf (Campana et al. 2000). However, these are environmentally-induced differences and may simply reflect a tendency for individual cod to return to the same grounds in the southern Gulf each year during the feeding season. Nonetheless, there has been an eastward 'shift' in cod distribution in the southern Gulf in September in recent years (see below) that may reflect a change in the relative importance of eastern versus western stock components rather than an eastward shift in the distribution of a homogeneous stock. Fine-scale bathymetric trends in vertebral number and length-at-age of cod in the southern Gulf in September do suggest a surprising degree of spatial structure to this population during the feeding season on the Magdalen Shallows (Swain and Frank 2000; Chouinard and Swain 2001).

1.3.7. Cod in 4Vn (May-Oct)

Sydney Bight is a known area of stock mixing. The management unit 4Vn is considered to support a resident stock of cod. These cod are thought to spawn within Sydney Bight during May (Mohn et al. 2001). The degree of separation of cod in 4Vn from adjacent stocks is a focus for current research. Evidence for the existence of a local stock is derived from tagging studies. For instance, a number of early (circa 1920-1950) summer tagging experiments were undertaken within Sydney Bight and along the coast of eastern Cape Breton. Most recaptures of marked cod during subsequent summers came from within 4Vn (McKenzie 1956; Martin and Jean 1964). It is assumed that Sydney Bight does not receive migrants from adjacent stocks during the summer (Mohn et al. 2001). These migratory components originate from the Gulf of St. Lawrence and the Scotian Shelf. Cod from the southern Gulf of St. Lawrence that migrate out of the Gulf during the late autumn to overwinter in the Sydney Bight region, and return in the spring are the major contributors to this mixing. During the winter, these Gulf cod can be found along the shelf edge from Sydney Bight to as far as Banquereau Bank on the Scotian Shelf (Mohn et al. 2001). Assessments for the resident population are undertaken for the period of May to October, when the migratory component is usually still within the Gulf of St. Lawrence (Mohn et al. 2001).

1.3.8. Cod in 4VsW

Cod in the region of the Eastern Scotian Shelf are considered a stock complex comprising several relatively large subpopulations of various sizes associated with offshore banks, together with smaller, coastal subpopulations or spawning locations (Frank et al. 1994). This stock complex contains at least two major offshore spawning groups associated with Western/Sable and Banquereau Banks, several smaller offshore components that spawn over Middle and Canso Banks, and a number of small coastal spawning groups (Frank et al. 1994; Fanning et al. 1996). The area around Sable/Western Bank also supported discrete spring and fall spawning periods (Frank et al. 1994).

In addition to a collapse in biomass, this population may have suffered the extirpation of several subpopulations (Frank et al. 1994; Younger et al. 1996). Ichthyoplankton surveys contained evidence of spring spawning on Sable/Western Bank in the early 1980s, but this signal was absent in later surveys conducted during the early 1990s (Frank et al. 1994). This lack of spawning has been attributed to an increase in fishing effort on this particular spawning component (Frank et al. 1994; Fanning et al. 1996; Sinclair 1997). In the mid 1980s, the fishery shifted from a pattern of exploitation that spread effort among resident subpopulations, to a concentration of effort on the Sable/Western Bank subpopulation during the spawning period (Fanning et al. 1996). From 1985 onward this concentration of effort ceased, and the fleet fished elsewhere (Frank et al. 1994). This view of changes in the spatial pattern of fishing has been supported through interviews with fishers (Younger et al. 1996). Frank et al. (1994) concluded that this sharp increase in exploitation of spawning aggregations resulted in a loss of reproductive capacity, as evidenced by the ichthyoplankton surveys, and thus led to the collapse of this population spawning component. Following the collapse the fleet targeted other periods and areas due to poor fishing.

In conclusion, while some isolation among population components exist, with the evidence presently available, it appears unlikely that the level of isolation is sufficient to have resulted in the formation of separate ESUs within the management unit of 4VsW.

1.3.9. Cod in 4X/5Y

Cod residing in the coastal and shelf areas of Southwest Nova Scotia and the Bay of Fundy are managed as a stock complex within NAFO Subdivision 4X (Fig. 1.1). As in the Eastern Scotian Shelf, Subdivision 4X contains spawning groups associated with the major offshore banks, as well as a number of components that spawn in coastal areas (Campana and Simon 1986; Clark et al. 2000). During the spring, spawning occurs mainly on Browns Bank, but also in areas of the Bay of Fundy (Neilsen and Perley 1996; Clark et al. 2000). Spawning in coastal areas occurs during the fall (e.g. McKenzie 1940). Mark-recapture experiments undertaken in coastal areas revealed little dispersion from the site of tagging, whereas cod tagged on Browns Bank during the spring were recaptured throughout Subdivision 4X and some in Subdivision 5Z (Clark et al. 2000).

The degree of mixing among these spawning components during other periods is unclear. Returns from fish tagged in coastal areas exhibit little dispersal from the location of tagging, and cod tagged in the Bay of Fundy are usually recaptured within the bay (Clark et al. 2000). In contrast, cod tagged on Browns Bank during the spring disperse through much of Subdivision 4X, with the majority of recaptures occuring in western regions of 4X (Clark et al. 2000). In the past the level of exchange of individuals between Georges Bank and 4X has been assumed to be low, however a recent study has questioned this assumption (Hunt et al. 1999). Clark et al. (2000) have called for more study of population structure within the region.

Growth rate differs among cod in the Bay of Fundy and on the southwestern Scotian Shelf. Separate age-length relationships were developed in the last population assessment for cod caught in the eastern or western sections of the management unit (see Clark et al. 2000). To date, genetic studies of possible population structure within 4X have not been undertaken. However, genetic analyses investigating structure on the larger spatial scale of the Northwest Atlantic have been carried out. Samples from the Scotian Shelf were significantly different than samples from the Northeast Newfoundland Shelf, Grand Banks, Flemish Cap, and Georges Bank (Ruzzante et al. 1998).

In conclusion, while some isolation among population components exist, with the evidence presently available, it appears unlikely that the level of isolation is sufficient to have resulted in the formation of separate ESUs within Subdivision 4X/5Y.

1.3.10. Cod in 5Zej and 5Zem

Following the 1985 World Court decision regarding delineation of the maritime international boundary in the Georges Bank area, fisheries by Canada and the USA were constrained to their respective sides of the boundary. However, the fisheries management unit for cod in the Georges Bank area remained as the entire NAFO Division 5Ze and stock evaluations were completed for landings and survey indices associated with this area. The appropriateness of this management area and the potential for effective management measures was addressed in 1989 and resulted in a recommendation by Canada that a management unit consisting of Unitareas 5Zej and 5Zem be implemented (Hunt 1989). Conclusions on the merit of this management unit were based on tag recapture studies, research survey catch distributions, biological characteristics and fishery distributions. The 5Zej,m area is bisected by the Canada-USA boundary and commercial groundfish fisheries are conducted by both countries.

A number of management measures have been introduced in the 5Zej,m area since 1989 including closure of the Canadian fishery from January to May starting in 1994 and introduction of a large closed area by the USA in 1995. Reduction of temporal and spatial fisheries information limits interpretation of possible changes in stock distribution. However, annual winter, spring and fall research surveys are conducted in the area with no apparent indication of widespread changes in stock movements.

Stock status evaluations (Hunt and Hatt 2001) indicate a gradual increase in abundance in the last few years following a precipitous decline in the mid-1990's. The stock remains at a low level of abundance. Spatial distribution during the historical period when abundance was higher may have been less well delineated.

More recent investigations of stock distribution in the Gulf of Maine have been based on broad-scale tag release and recapture studies. Hunt and Neilson (1993) examined results for the inner Bay of Fundy and concluded that, while some isolation was evident, the degree of mixing precluded definition of separate stocks. Hunt et al. (1999) reported on results of tagging experiments conducted in the mid-1980's and mid-1990's and concluded that about a 15% exchanged occurred between the 5Zej,m and the Browns Bank (4X) area. These results were consistent with those reported by Wise (1963). Widespread tagging initiatives are presently underway in the Gulf of Maine by both Canada and the USA.

In conclusion, there is no evidence to suggest that the management unit of 5Zej and 5Zem contains more than one ESU. The degree of isolation of Georges Bank cod from other populations is currently under study.

ToR 2: Declining Total Population

2.1. Introduction/methods applied to all stocks

While the authors of this document were not tasked with determining the risk status of the cod stocks under review, it is nevertheless necessary to be cognisant of the COSEWIC criteria for determining status so that we can provide data and analyses that will be useful and appropriate for such determinations.

Atlantic cod is presently designated under the "Special Concern" category by COSEWIC. These are species that are particularly sensitive to human activities or natural events but are not endangered or threatened species. These may include species that are particularly susceptible to a catastrophic event; a conservation dependent species that would likely become at risk if not for active protection and management (e.g., a fish or mammal species protected from over-harvest); or a recovering species, no longer qualifying for risk categories but not yet clearly secure, or subject to resumption of threat in future.

Under the population decline criteria, COSEWIC would determine one or more cod populations to be "Threatened" (the next risk category after Special Concern) if the reduction in population size (based on: a) direct observation, b) an index of abundance appropriate to the taxon, c) a decline in area occupancy, extent of occurrence and/or quality of habitat, d) actual or potential levels of exploitation, or e) the effects of introduced taxa, hybridisation, pathogens, pollutants, competitors or parasites) is $\geq 50\%$ in terms of population size reduction that is observed, estimated, inferred or suspected in the past 10 years or 3 generations, whichever is longer, where the causes of the reduction are clearly reversible and understood and ceased, based on any combination of a) – e) above.

"Threatened" would also apply under a lesser decline of $\geq 30\%$ where: a population size reduction that is observed, estimated, inferred or suspected over the last 10 years or 3 generations, whichever is longer and where i) the reduction or its causes may not have ceased or may not be understood or may not be reversible; ii) a population size reduction is projected or suspected to be met within the next 10 years or 3 generations, whichever is longer, or iii) the time period includes both the past and the future and where the reduction or its causes may not have ceased, or may not be understood or may not be reversible based on any combination of a) – e) above.

To address the above, a number of analyses can be carried out on the available data from a) direct observations or b) an index of abundance, and a range of related information can be marshalled on causes of decline, current and future exploitation rates, medium term population projections and factors affecting recovery or lack thereof, to facilitate the task of COSEWIC in deciding whether or not one or more cod populations in Atlantic Canada are "Threatened" or "Endangered".

There has been some debate regarding whether percentage decline is a comparable measure across phyla and habitats (see for example Musick 1999; Musick et al. 2000; Hutchings 2000; 2001). It has been suggested that potential for recovery may vary among species that have experienced similar declines. There is also the question of how to measure and detect decline in species that show very wide natural fluctuations. Further, there is the question of how to incorporate uncertainty into the estimates of decline, both in terms of the past and the projected future population size. Many of these problems are also associated with the application of the precautionary approach in fish stock assessment and are not new to fisheries science.

A number of possible approaches could be considered for measuring decline. The following formula is provided by COSEWIC for computing overall rate of decline over a number of years based on annual rates of decline (http://www.cosewic.gc.ca/pdf/English/Formula.pdf):

The percentage decline over x years is simply $(1-\frac{N_{t+x}}{N_t})*100$.

If the population estimate or the index of abundance trend does not display much short term variation then this measure would seem to be appropriate. COSEWIC suggests that x = 3 x mean generation time or x = 10 years, whichever is longer. Although the decline in total population size may be of interest, it is the decline in the mature population or index of the mature population that is of most concern.

There have been some fairly dramatic changes in age at 50% maturity in a number of Atlantic Canada cod stocks (Trippel et al. 1997). Using the appropriate maturation schedule to compute mature population is important. Also, changes in generation time influence the rate at which the population can grow and thus its resilience. Under the COSEWIC approach, declines in more resilient populations are measured with a shorter "ruler" with the proviso that it can't be less than 10 years in length. Under density dependent assumptions, the ruler can be expected to become shorter as the population declines.

One approach to computing generation time could be to compute the average mean age at 50% maturity (rounded up to the nearest whole age) from annual maturity ogives for the last several cohorts for which sufficient data are available and to compare 3 x generation time against 10 years to determine which is longer. Application of the cohort derived proportion mature at age to the population estimates at age or the index of population size at age is straight forward if the raw data are available and the cohort maturity model has been appropriately fitted (see Morgan 2000 for an outline of the methods). The number of years over which to compute the average is arbitrary. Also, there will be insufficient information for recent cohorts to adequately estimate age at 50% maturity. There are also questions regarding the appropriate maturation schedule to use in projections. These questions are common to traditional fish stock assessments and generally require some level of arbitrariness. Hutchings (2000; 2001) used mature biomass of males and females combined in his analyses of marine fish. These are the units most readily available from recent stock assessments, but in this report we compute mature population numbers to address COSEWIC decline criteria. In addition, the analyses in this report apply the usual arcane convention of including both male and female abundance while applying only female maturity rates to compute spawner biomass. This could be misleading to those not familiar with this convention.

For population abundance estimates or indices that have shown considerable variability over the time period of concern, the appropriate measure of decline may be more complicated. COSEWIC appropriately suggest that a reduction should not be interpreted as part of a natural fluctuation unless there is good evidence for this (COSEWIC Definitions and Abbreviations, 6 November 2001). One approach to variable populations or variable estimates and indices is to fit a model to the data, such as an exponential decay model where $N_t = \alpha \exp^{\beta t}$ where N_t is the abundance at time *t* and β is the instantaneous rate of change. An alternative model would be $\ln(N_t) = \alpha + \beta t$ where β is again the instantaneous rate of change and the error on the log scale is assumed to be normal. The percentage decline over *x* years for either model is $(1 - \exp(\beta * x)) * 100$. If fitted by least squares then it should be noted that these models make different assumptions regarding the error and can lead to different estimates of the percentage decline. In general the logarithm model might be better but could under-estimate the decline.

The time period over which the decline is to be measured is defined by COSEWIC as the past 10 years or 3 generations, whichever is longer. Thus for populations for which there is an estimate for 1 Janaury 2001, the time period over which to measure decline would be 1991-2001 for a 10 year period or 2001-(3 x generation time). However, COSEWIC can also consider population size reductions that may be met within the NEXT 10 years or 3 generations. Consequently, following the scenario above, one could envisage the need to provide projections for the period 2001 to 2011 or 2001+3 x generation time. This is equivalent to long-term projections currently evaluated in some groundfish assessments (e.g. Rivard et al. 1999 for 3NO cod). When the reduction in a fish population or its causes may not have ceased, or may not be understood, or may not be reversible then the 10 years or 3 generations may apply to a time period that includes *both* the past and the future. In terms of fisheries assessments this might be equivalent to the evaluation of data from the current SPA, a short-term projection or a long-term projection.

Experience in cod stock assessments has shown that projections, particularly those that incorporate uncertainty, are not trivial and may require a number of arbitrary assumptions which require discussion and evaluation before projection results can be considered to be valid.

In addition to measurement of decline, as defined above, consideration might also need to be given to the historic decline – i.e. the size of the stock relative to the estimated unexploited mature population size. Where a stock-recruit model can be fitted to the data, or an assumption can be made about recruitment levels at high stock size, then this can be estimated. It may also be important to obtain estimates of the intrinsic rate of natural increase (*r*) for the population under consideration. This can be estimated from the slope at the origin from a model fit to stock recruit data. Estimates for most Atlantic cod stocks can be found in Myers et al. (1997) and these could be evaluated and recomputed and updated if required. Musick (1999) has suggested that decline criteria should be linked to population resilience.

The COSEWIC decline criteria also require a measure of whether or not the decline is reversible. This is difficult to compute, but evaluation of whether or not there is evidence of "regime-shifts (Beamish 1993) or depensation (Myers et al. 1995; Shelton and Healey 1999) may be carried out.

2.2. Evaluation of Declining Total Population by management unit

2.2.1 Cod in 2GH

Evaluation of decline

Line transect surveys were conducted in 2G and 2H in 1978, 1979 and 1981 (Murphy et al. 1992). Random stratified groundfish surveys were started in 1986. The pre-1986 line transect survey data have subsequently been post-stratified (Murphy et al. 1992) so that some comparisons can be drawn. The survey coverage from 1986 onwards has been very varied, both in terms of years in which there is survey coverage, the time of year in which the survey was carried out (between August and December), and the strata sampled in years when there was a survey. In addition to the groundfish RV survey series, a shrimp survey was conducted during the early July to mid-August period in the Hopedale Channel area over the years 1979 to 1990.

Data from the RV survey for the post-1995 period collected with the Campelen shrimp trawl are not directly comparable to the earlier data collected with the Engel trawl. The Campelen gear is more effective at catching small fish (Stansbury 1997) and consequently the recent stratum estimates can be expected to be positively biased relative to the earlier period. Formal treatment of the survey data to provide an overall swept area biomass estimate series is not justfied because of the problems outlined above. Nevertheless, the data may be illustrative of general trends and the combined biomass estimates for 2GH from the RV bottom trawl surveys are compared with the shrimp survey biomass index in Fig. 2.2.1.1.

The biomass index data indicate a substantial decline in the biomass from the early 1980s through to about 1987. Cod off Labrador mature rapidly and Fleming (1960) estimated an age of 50% maturity of about 5.25 for the period 1947-50. Thus three generations for the historic period would span approximately 16 years. Estimates from a fit of the log model to all the data for a 16 year percentage depletion are 94.67% for the groundfish RV data and 99.78% for the Hopedale Channel shrimp survey. It should be noted that the relatively high survey biomass values in the early 1980s may in themselves only represent an echo of much larger stock present in the 1960s, as indicated by the catch data (see below). Also, Templeman (1979) noted that investigations by Serebryakov (1967) in the April to August period in the Newfoundland area found the greatest abundance of cod eggs off Northern Labrador (2G). Because the direction of the Labrador Current is southward, Templeman (1979) concluded that "relatively large quantities of cod must therefore spawn off northern Labrador".

Evaluation of causes of decline

Commercial catch data (Fig. 2.2.1.2) show peak catch of 90 000 t in 1966, largely a consequence of increased effort by the non-Canadian fleet, followed by a precipitous decline in the fishery in the early 1970s. A TAC was first introduced in 1974 (20 000 t) and remained in effect until 1986. Non-Canadian catches continued to be largest component of this fishery throughout this time. Canadian catches averaged only 480 t annually from 1960 to 1990 with a maximum catch of 3 200 t in 1982. The slight increase in the catches in the early 1980s coincides with relatively high values in the survey data. Age composition data from the 1986 survey indicate that the 1981 and 1982 year classes were strongest (Murphy et al. 1992).

There has been no TAC for directed fishing since 1986 and no reported catch since 1991. Based on the available data, it seems reasonable to conclude that the 2GH cod stock collapsed in the late 1960s and early 1970s due to overfishing, persisted at a low level but retained the ability to occasionally produce year classes that were not insignificant in the early 1980s, but as a consequence of continued fishing pressure, was reduced to commercial extinction by the end of the 1980s, a state from which there has been no recovery.

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

It is not known whether the decline in 2GH cod has ceased nor whether the decline is reversible. There have been no reports of any significant amounts of cod in the area for more than a decade.

2.2.2 Cod in 2J3KL

Evaluation of decline

Stratified random bottom trawl survey data are available from fall surveys from 1978 onwards in 2J and 3K and from 1981 onwards in 3L. Spring surveys in 3L are available from 1978 onwards. Surveys in 3L were carried out by a side trawler, RV A.T. *Cameron* between 1971 and 1982. No conversion factors have been developed for these data, consequently the survey series is usually only considered from 1983 onwards. The Campelen Shrimp trawl has been used in all fall surveys from 1995 and in all spring surveys from 1996, replacing the Engel trawl used previously. Engel data have been converted to Campelen equivalent units (Stansbury 1997) to allow comparisons to be made across the time series. Commercial catch data are available back 150 years but are age disaggregated only from 1962 onwards.

The last accepted SPA assessment of this stock was carried out in 1992 (Baird et al. 1992), although a serious problem of lack of model fit, which precluded accepting subsequent SPAs, was already apparent. There was a collapse in spawner biomass (males and females aged 7+) from over 1.6 million t in 1962 to a level of less than 200 000 t by the time of extension of jurisdiction in 1977. Spawner biomass subsequently recovered partially, as a consequence of a pulse of recruitment that arose in the late 1970s and early 1980s. This recovery was, however, short-lived and the spawner biomass began to decline again after 1982 with 3+ biomass declining after 1985.

The problem of lack of model fit in the 1992 assessment relates to the initially strong appearance of the 1986 and 1987 year classes in the data and their subsequent rapid disappearance at a rate which could not be explained by the available catch at age data under the assumptions of constant natural mortality and survey catchability. Shelton and Lilly (2000) carried out a number of diagnostic analyses to examine the problem. Their “missing fish” model produced estimates of the numbers of missing fish that were expected by the SPA conditional on the available survey and reported catch data, and the standard assumptions regarding natural mortality and survey catchability. They concluded that unreported deaths by the offshore fishery may be most plausible as the main contributing factor to lack of model fit, but that other factors also played a role, because the estimates of missing fish were thought to be beyond the range of what could be explained by fishing effort alone.

The missing fish model of Shelton and Lilly (2000) has been extended to the present for the purposes of this report. The missing fish are interpreted as dying due to fishing mortality. As emphasized above, this is one interpretation of the available data and other interpretations are plausible. It should also be borne in mind, that the 2001 assessment of this stock concluded that a considerable change in the proportion of the current stock covered by the survey (Lilly et al. 2001) would count against using the RV data as a tuning index in a whole-stock SPA. Although the survey was extended by adding additional inshore strata from 1996 onwards (excluding 1999), these strata still do not adequately cover the current inshore distribution which is often just a few miles or less from the coast (e.g. Smith Sound). Sentinel surveys using gillnets and linetrawls, were initiated in 1995 and provide the only indices for this near-shore portion of the cod habitat. For the purpose of this report, the missing fish model was extended to the present and was tuned with the fall RV index and the sentinel gillnet index. While not considered reliable for quantitative estimates of stock size for the recent period, the model does represent one plausible realisation of the kind of dynamics the northern cod population has experienced during the last 40 years. In a general sense, the model output should be useful for determining the species at risk status of northern cod.

For the earlier period, the missing fish model provides similar estimates to the Baird et al. (1992) model, although the missing fish model estimates of spawner biomass in the mid to late 1980s are somewhat higher. The missing fish model suggests that the spawner population size (number of mature males and females) collapsed from 800 million in the early 1960s to about 60 million in 1977, increased following extension of jurisdiction to level of about 200 million in the mid-1980s and collapsed again to about 2 million by 1994, and has remained around 5 million since (Fig. 2.2.2.1*a*,*b*). The decline in the RV index of spawning population index (Fig. 2.2.2.1*c*,*d*) reflects similar changes, which is not surprising since it is used in the tuning of the model and there are no major problems with model residuals in the missing fish model. The decline in the population aged 2 and older is from about 4 billion in the early 1960s to about 20-30 million for the recent period (Fig. 2.2.2.1*e*,*f*).

Various estimates of decline rate are provided in Table 2.2.2.1 based on the model estimates for spawner and 2+ population size. Mean age of spawners has varied over the time period as a consequence of both changes in the age of maturity and in the age structure of the population. Average values of about 7 for the early period and 6 for the more recent period are reasonable giving a 3 x generation time of between 18 and 21 years. Estimates of percentage decline over a period of 3 generations for alternative time periods vary but are generally above 90%.

It should be noted that, although northern cod is being considered as a single ESU in the context of this evaluation for COSEWIC, the significance of the inshore component of northern cod has been emphasised in recent assessments (Lilly et al. 1998; 1999; 2000; 2001). In the 1998 assessment of this stock (Lilly et al. 1998) noted that different dynamics appeared to be at play in the inshore and offshore regions of 2J3KL. The assessment discussed a dense aggregation of cod found in Smith Sound on a DFO survey in the spring of 1995 and the good catch rates that were occurring in the inshore sentinel fishery that commenced in 1995. Although assessments have indicated about 20 000 t of fish in Smith Sound from acoustic surveys and around 40 000 t of fish in inshore 3K and northern 3L combined from tagging experiments (assuming an average weight of about 2 kg, this would equate to 20 million fish, some portion of which would be mature), a complete acoustic survey of the coastal area of 3KL in the fall of 1997 (Anderson et al. 1998) provided an estimate of only 18 300 t, 60% of which occurred in Trinity and Bonavista Bays. The most recent assessment of the northern cod stock concludes that the population in the inshore has been declining since 1998, coinciding with the reopening of the fishery and that there has been a progressive contraction in the area in which higher densities of fish are encountered. This was considered in the assessment to be cause for considerable concern (DFO 2002a).

In addition to the decline in the overall stock and the differences that have occurred inshore relative to the offshore, the component of northern cod identified by Templeman as the Virgin Rocks population or stock apparently was fished to very low levels over a very short period in the late 1980s and early 1990s (Fig. 2.2.2.2). An industry search for fish in offshore 3KL in November/December 1997 using otter trawls and gillnets encountered virtually no fish with the exception of some catches from gillnets set in the vicinity of Virgin Rocks. This indicates that at least a remnant of this component has survived, although it is thought to be very small.

Evaluation of causes of decline

The first collapse of the northern cod stock, which occurred in the 1960s and 1970s, can be explained almost entirely by fishing mortality, particularly the increase in the foreign fishery. Following extension of jurisdiction in 1977, the stock began to recover as a consequence of smaller catches and hence lower fishing mortality, entry of the strong 1973-75 year classes and an increase in the growth rate of individual fish. However, fishing effort by an expanding Canadian trawler fleet increased dramatically in the late 1970s and early 1980s while fishing by foreign vessels continued on the Nose of the Grand Banks. Initially, in the post 1977 period, the TAC was set below $F_{0.1}$, a fishing morality reference point which equates to a harvest of roughly 20% if the population, to allow the stock to grow, but by 1984 it was being set at $F_{0.1}$ (Shelton

1998). Stock assessments throughout the early and mid 1980s tended to be over-optimistic and were revised down in subsequent assessments (retrospective problem). The most serious over-estimation occurred in the 1987 assessment based on what was subsequently shown to be an anomalously high 1986 fall RV estimate. At the time this survey estimate did not look unrealistic give the population trajectory of the preceding years. The anomaly was only discovered when the 1987 survey data became available. The 1988 assessment estimates of the $F_{0.1}$ TAC for 1989 were less than half the TAC for 1988. The assessment results were not accepted by DFO managers and the assessment was repeated, with much the same results, early the following year with one more year of survey and catch data. The scientific advice was largely ignored and in an attempt to maintain a high TAC , managers abandoned the $F_{0.1}$ approach in the late 1980s and early 1990s (Bishop and Shelton 1997; Shelton 1998) and fishing mortality was allowed to rocket, precipitating the second and ultimate collapse of the stock.

It has been claimed by Hutchings and Myers (1994) that "the collapse of northern cod can be attributed solely to overexploitation". They refer to the second collapse (late 1980s-early 1990s). Although fishing mortality was clearly the leading cause of the collapse, catches, both reported and assumed, are insufficient to account for the disappearance of two strong year classes (1986 and 1987), and therefore it is possible that other factors also played a role. Although Shelton and Lilly (2000) favour the hypothesis that the missing fish can, in part, be explained by unreported offshore catches, it should be noted that the period of northern cod collapse coincided with substantial changes in the abundance and distribution of several other components of the ecosystem, as well as oceanographic changes (see Lilly et al. 2001 for a summary). Other than an effect of temperature on cod growth rates (Shelton et al. 1999), no other statistically valid relationships between cod dynamics and physical or biological variables have been found.

The apparent further, and ongoing, decline of the northern cod in the inshore following reopening of the commercial fishery in 1998 is almost certainly due to unsustainable commercial harvesting, both within the TAC and in addition to the TAC in the form of illegal or under-reported catches and "recreational" or "food fishery" catches. When combined with mortality rates estimated from bottom trawl survey data, which are equivalent to levels which would be associated with an intensive commercial fishery, and which are possibly attributable to unrecorded bycatch, prospects for any recovery of the stock are very bleak.

Summary graphs of the change in exploitation rate (computed in terms of catch of mature fish over the estimate of the population of mature fish from the missing cod model), spawner and recruit estimates form the missing fish model and exploitation rate plotted against spawner biomass for the period 1962 to 2001 are provided in Fig. 2.2.2.3. These graphs clearly show exploitation rate increasing as the spawner biomass declined precipitating the first collapse, a brief respite during extension of jurisdiction followed by extremely rapid increase in exploitation rate giving rise to the final collapse.

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

As indicated above, it has been suggested that recent levels of fishing mortality have not been sustainable at current stock size and the prevailing levels of recruitment. Thus the remnant of northern cod, restricted to one known over-wintering aggregation in Smith Sound and a few scattered concentrations of fish in the offshore, appears to be declining further. Mortality rates in the survey area are very high, and would be sufficient to prevent recovery unless an exceptionally strong yearclass arose, which is unlikely at current levels of spawner biomass. In addition to fishing mortality, predation by harp seals, and possibly also hooded seals, may also be a factor in preventing recovery. Depensation in the stock-recruit relationship, through either a "predator-pit" kind of phenomenon (Shelton and Healey 1999) or through an Allee effect (Frank and Brickman 2000), could slow or prevent recovery, but would be difficult to detect in existing data. It seems clear that, as a first priority, an attempt should be made to reduce fishing mortality on northern cod to an absolute minimum.

2.2.3. Cod in 3NO

Stratified-random bottom trawl surveys (Stansbury et al. 2001) have been carried out in spring in 3N and 3O since 1971 and 1973 respectively, with the exceptions of 1983 in 3N and 1974 and 1983 in 3O. Surveys from 1971 to 1982 were carried out with the RV *A.T. Cameron* and since 1984 with the RV *Alfred Needler* and the RV *Wilfred Templeman*. Usually only data from 1984 onwards are used as a spring index for this stock due to the lack of conversion data for the RV *Cameron*, a side-trawler. Fall surveys have been carried out in 3NO from 1990 onwards using the RV *Templeman* for shallow water sets and the RV *Teleost* for deeper water sets in recent years. Since the fall of 1995 the survey gear changed from the Engel trawl to the Campelen trawl but data collected with the Engel gear have been converted to Campelen units (Stansbury 1997).

Evaluation of decline

There is an accepted ADAPT sequential population model for this stock (Stansbury et al. 2001). Estimates of the numbers of mature fish in the population over the period 1959 to 2001 show that the population declined steadily from a level of over 40 million fish in the mid-1960s to a minimum of about 3.5 million fish at the time of extension of jurisdiction in 1977 (Fig. 2.2.3.1*a*,*b*). This was followed by a rapid recovery to about half of the mid-1960s level by the early 1980s, a gradual decline over the mid 1980s and a rapid decline in the late 1980s to a very low level by 2001 (1.3 million fish). With the exception of the 1987 data point, the RV estimates show a general declining trend to about 1997 after which they vary without trend (Fig. 2.2.3.1*c*,*d*). The SPA estimates of total population size (2+) show steady decline from nearly 700 million fish in 1986 to about 100 million in 1975 (Fig. 2.2.3.1*e*,*f*). The total population remained at about this level until 1984 after which there was a further decline to about 10 million fish by 2001.

Various decline rates have been computed from these data (Table 2.2.3.1). A mean age of spawners of about age 7 in the early part of the time series and age 6 in the more recent period has been assumed based on visual inspection. More accurate values could be computed from the available data if required. Over the full 42 years of SPA estimates, the spawner population is estimated to have declined by about 95%, equivalent to a 78% decline over a 3 generation period. For the total population the overall decline rate is about 99%,or 89% for a 3 generation period. The decline in the RV index over the period 1984 to 2001 is about 90%. The spawner population declined by about 90% between the start of the data series and extension of jurisdiction in 1977 and by about 97% during the collapse that occurred between 1981 and 2001. The mean generation time has varied from about age 7 in the early part of the time series to around age 6 in the more recent period (this has not been formally computed from the numbers at age data, rather it is based on a quick visual evaluation).

Evaluation of causes of decline

In a similar manner to 2J3KL cod, 3NO cod went through two major declines or collapses. However, unlike 2J3KL cod, the existing catch data, while undoubtedly unreliable (often based in part on Canadian surveillance estimates for foreign catches rather than reported catch statistics), is sufficient to explain the population trajectory under the standard assumptions of the SPA (constant age-independent natural mortality rate, constant age-specific RV catchability) without any serious patterns in the model residuals. This fishing mortality can be considered by far the main cause of the collapses of 3NO cod. Fully recruited fishing mortality has been above the $F_{0.1}$ level throughout the time period for which data have been available, rising as high as 3 to 4 times this level during the first and second collapses. Gavaris (1980) notes that by as early as 1959 this stock was below the MSY equilibrium population size, possibly due to large catches in the early and mid fifties. He states that the fishing effort in the early 1960s was generally low enough that the stock was slowly recovering, but that from 1967 to 1975 the fishing effort "increased beyond the point which would lead to stock extinction". Reduced fishing effort during the initial extension of jurisdiction phase led to a substantial recovery, but subsequent harvests were unsustainable through the 1980s and early 1990s. Shelton and Morgan (1994) found that recruitment had been below the annual replacement threshold at the prevailing level of F from 1983 onwards and that, with the exception of the 1989 yearclass, recruitment was even below the F=0 replacement line over this period, indicating extreme recruitment overfishing. Hutchings (1994), using different methods, came to similar conclusions regarding the unsustainability of the fishery during the late 1980s and early 1990s. The first collapse can be attributed primarily to overfishing by Spain, Portugal and the former Soviet Union. The second and ultimate collapse can be attributed to both Canadian and foreign fishing effort. The foreign fishery continued to catch substantial amounts of cod on the Tail of the Grand Bank as late as 1991. The directed fishery for cod was placed under moratorium by NAFO in February 1994 and has remained closed to date.

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

Although the directed commercial fishery on 3NO cod was placed under moratorium in February 1994, groundfish fisheries on other commercial species continue, both inside 200 n. miles and in the NAFO regulatory area on the Tail of the Grand Bank. All NAFO vessels and some portion of the Canadian fleet carry observers. Ideally, observers would provide useful information for estimating the bycatch of cod. Thus far, however, there has been no statistical analysis of the data and the quality of the reports submitted to NAFO and used in stock assessments are therefore difficult to evaluate. In general the bycatch is thought to be substantially greater than what is reported in catch statistics and may be sufficient to prevent recovery.

Rivard et al. (1999) carried out a simulation study in which the trajectory of the stock was computed in probabilistic terms under a range of fishing mortality and recruitment scenarios. Model estimates suggest that the stock entered a "low recruitment" period in 1982 which has continued to the present. Under a low recruitment scenario, fishing mortality would have to be virtually eliminated for the stock to recover. The most recent assessment of this stock (June 2001; Stansbury et al. 2001) found that there had been an increasing trend in bycatch mortality on this stock since the moratorium was imposed, and concluded that the stock would not recover, and was more likely to decline further, at current levels of bycatch fishing mortality if the low recruitment regime persists.

Summary plots indicating the change in exploitation rate over time relative to stock-recruit data for the period 1959-2000 are provided in Fig. 2.2.3.2. These plots show that more than 40% of the mature population were being harvested over the period from the mid 1960s to the mid 1970s. There was some respite at the time of extension of jurisdiction in 1977, however exploitation rate again climbed to above 40% by the early 1990s. Spawner biomass was collapsing over this period.

2.2.4. Cod in 3Ps

Stratified-random bottom trawl surveys have been conducted in Subdiv. 3Ps during the winter-spring period by Canada since 1972 and by France for the period 1978-92 (Brattey et al. 2001b). Canadian surveys were carried out with the side-trawler RV *Cameron* between 1972 and 1982 and thereafter with the RV *Templeman* and the RV *Needler*. Canadian RV data from 1983 onwards are usually considered as an index for calibrating SPA models, although the *Cameron* data have also been considered as a separate series for calibrating SPAs in some cases. In recent assessments distinction has been drawn between surveys carried out in winter and those carried out in spring. In addition, in some cases the data from the western portion of the survey (Burgeo Bank area) has been considered as a separate index because of the purported mixing of northern Gulf cod in winter into that portion of the stock area. Sentinel surveys, which commenced in 1995, provide data that have been analysed to develop an index of stock size for the inshore. Some SPAs have incorporated this index. An industry survey carried out according to the standard research stratified random design commenced in 1997 using a commercial trawler. Although this survey only covers a portion of the stock area (mainly St Pierre Bank), it has been considered as a possible tuning index in recent assessments.

Evaluation of decline

The last assessment of this stock (October 2001; Brattey et al. 2001b) examined the results from 5 SPAs constituting a variety of different models and formulations. It was considered that, while the actual size of the stock over time was uncertain, there was considerable consistency in trends. The results from two approaches, ADAPT and QLSPA, in which similar formulations are applied, is given in Fig. 2.2.4.1*a*,*b*. There was a declining trend from about 1966 to extension of jurisdiction in 1977, followed by a substantial recovery to 1984. In the QLSPA model, estimate for 1984 exceed the estimates for the start of the series, whereas in the ADAPT model, estimates suggest that the 1984 recovery level was lower than the start of the series. Both models suggest that there was a substantial decline in the population of spawners during the late 1980s. The models give different interpretations with regard to when this decline was arrested, but both suggest a rapid increase occurred from 1993 or 1994 onwards, coinciding with the implementation of the moratorium. Both models suggest that a further decline started from 1997 or 1998 onwards. The most recent assessment of this stock (Brattey et al. 2001b) predicted that the stock would decline further if the 2001/2002 TAC of 15 000 t was fished, but that improvement in recruitment was unlikely to result in the decline continuing in 2002/2003 for TACs in the range of 10 000 to 20 000 t. The TAC was eventually set at 15 000 t for this season. Although it was predicted that the stock would grow at this level, some of the model formulations applied in the assessment indicated that this TAC could result in fishing mortality levels which would have a significant risk of exceeding the $F_{0.1}$ level previously considered to be precautionary in the context of Atlantic cod management.

The age-aggregated RV index of spawner population (Fig. 2.2.4.1*c*,*d*) is not informative regarding trends. It is well know that for this stock the "signal to noise ratio" is rather low as a consequence of large year effects in the data, and that it is only by tracking cohorts across years in the age-disaggregated data that any pattern can be seen. The QLSPA model estimates of total (2+) population (Fix. 2.2.4.1*e*,*f*) do not give as optimistic a view of the population trend as that seen in the spawner population. Overall, there is a declining trend, reflecting in part the declining trend that has been observed in yearclass strength over the time period. This overall declining trend in the population, which may have only recently been arrested by good recruitment, is cause for concern. Estimates of recent year classes have large confidence intervals.

Various decline rates are computed for 3Ps cod in Table 2.2.4.1. There are clearly model differences in perceptions regarding declines. A mean of spawners of 7 years has been assumed for the whole time period based on visual inspection – values could be computed from the available data if required. ADAPT estimates indicate a decline in spawner biomass over the whole time series whereas the QLSPA estimates do not. One interpretation is that the population has gone through a number of cycles based on pulses in recruitment, and that the amplitude of these cycles has deepened as a consequence of periods of intense fishing mortality. The largest decline over the whole time series is in the 2+ population, reflecting and overall deterioration in year class strength. This trend has been pointed out in recent stock assessments is cause for concern.

Evaluation of causes of decline

The stock was heavily exploited by Spain and other non-Canadian fleets in the 1960s and early 1970s. French catches increased in the offshore throughout the 1980s. In contrast to 2J3KL and 3NO cod stocks, there was no large buildup in the Canadian dragger fleet operating in 3Ps following extension of jurisdiction and annual catches from this sector generally remained below 5000 t. A moratorium on fishing initiated in August 1993 ended in 1997 with a quota set at 10 000 t. The TAC was increased to 20 000 t for 1998 and to 30 000 t for 1999 based on DFO scientific advice. Beginning in 2000, the management year was changed to begin on 1 April. An interim quota of 6000 t was set for the first three months of 2000. The TAC for 1 April 2000 to 31 March 2001 was set at 20 000 t and for 1 April 2001 to 31 March 2002 at 15 000. The current season quota (2002/2003) remains at 15 000 t. France is currently allocated 5.6% of the TAC, most of which is fished by chartered Canadian draggers on St Pierre Bank. The reported catch by the Canadian inshore fishery over the time period prior to the moratorium has been remarkably constant at between 20 000 – 30 000 t. The accuracy of catch data for the inshore fishery is suspect. Recent efforts using dockside monitoring, while in theory an improvement over previous methods, may not be providing an accurate reflection of inshore removals.

While periods of overharvesting in the offshore, first by Spain and then by France, have undoubtedly been major factors in the fluctuations that have occurred in population size, the 3Ps cod stock has demonstrated considerable resilience and has recovered quickly each time fishing mortality has been reduced. Unlike other cod stocks in Atlantic Canada that were placed under moratorium, 3Ps cod had recovered to an extent that it could sustain a sizeable commercial fishery by the time income support to fishermen dried up and the various cod fisheries reopened. Scientific advice is currently aimed at keeping fishing mortality at sustainable levels. There is, as yet, no implementation of a precautionary approach in the management of this stock. Thus, if a series of poor year classes arise in the future, it is possible that the TAC will not be reduced quickly enough to avoid another significant cycle in the spawner population. While overall the stock appears to be in reasonably sound shape, there is some concern that local aggregations of cod in the inner part of Placentia Bay have experienced heavy fishing pressure by inshore fleets in recent years and could become depleted. Similarly, in the offshore, cod appear to be highly aggregated in a limited geographic area on St Pierre Bank during the fishing season. This makes them extremely vulnerable to excessive fishing effort should limits not be enforced. It is not known whether existing observer and DFO surveillance coverage is sufficient to prevent misreporting and overfishing occurring in this area. The overall downward trend in recruitment over the time period is cause for concern and may be indicating a gradual deterioration in the productivity of the stock.

Summary plots indicating the change in exploitation rate over time relative to stock-recruit data for the period 1959-2000 are provided in Fig. 2.2.4.2. These plots show that exploitation rate has varied between 0.2 and 0.4 over the time period. There is no clear pattern in the stock-recruit data but it is evident that spawner biomass has, in the past, responded favourable to periods of reduced exploitation.

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

As indicated above while there have been considerable fluctuations in spawner population size which may continue to persist into the future, the population has demonstrated considerable resilience and has recovered quickly in the past when fishing mortality has been reduced.

2.2.5. Cod in 4RS3Pn

Evaluation of decline

This stock is assessed annually with a sequential population analysis (SPA) that is calibrated with five indices of abundance. The longest time series is the CCGS *Alfred Needler* survey conducted annually by DFO in August (1990-2001). The four other indices come from the sentinel program that started in 1995. Two of these indices are also stratified random surveys involving nine trawlers, and these surveys are conducted in July and October. The last two indices are based on the catch rates of longlines and gillnets. The spatial, temporal coverage and size spectra encompassed by all of these indices are variable and thus present many facets of the stock.

Maturity ogives at length are derived when a survey is conducted in the appropriate time frame to evaluate maturity (winter and spring). For the remaining years, the maturity ogive is updated using commercial lengths at age. There has been a considerable shift in maturity. The biological characteristics of northern Gulf cod have varied over the years; certain changes occurred when stock abundance declined with cold oceanographic conditions that were unfavourable to the resource. Growth, condition and size and age at sexual maturity decreased through the eighties and early nineties. These changes may have had a negative impact on egg production, since a small fish in poor condition and with smaller size at maturity produce fewer eggs. In addition, natural mortality may have increased, since fish in poor condition have less chance of surviving, particularly after spawning when conditions are unfavourable. However, improvements in these biological parameters have been noted in recent years, and the biological characteristics of this stock are positive.

Cod growth increased in the second half of the nineties. Weight and size at age in the commercial fishery increased to the point that the values observed in 2000 are similar to prevailing values before the decline in abundance in the early 1980s. The mean weight of a 6-year-old cod reached a record low in 1992 and then gradually rose. The weight value in 2000 was the highest observed since 1984. Size and weight trends were the same for the other age groups, whether in the commercial fishery, the three trawl surveys (CCGS *Alfred Needler* and the sentinel surveys in July and October) or the fixed-gear sentinel fisheries (longline and gillnet). However, mean weight of a 6-year-old cod seems to be down.

The moratorium occurred between 1994 and 1996 and provided an opportunity to evaluate natural mortality. It was found to be about twice the historical value of 0.2. Potential causes suggested to explain these high values include poor fishing practices, high seal predation and bad environmental conditions. The natural mortality is thus assumed to be 0.4 since 1986.

The results of the SPA indicate that the abundance of fish aged three years and over dropped from 537 million in 1983 to 54 million in 1994, and then rose to 64 million in 2002. Abundance only increased by 1% between 2000 and 2001. Abundance of spawning stock declined from 311 million in 1982 to 23 million in 1994 (Fig. 2.2.5.1 and 2.2.5.2). It increased to 43 million in 2002, with a 10% decline between 2000 and 2001.

Since the reopening of the fishery in 1997, fishing mortality has been increasing steadily and is currently at 0.5 (Fig. 2.2.5.3). The stock recruitment relationship is quite good for this stock despite the fact that the most recent estimates are very low (Fig. 2.2.5.4). As is the case for the Southern Gulf cod, the index of recruits produced per kg of spawners was high in the mid-90's (Fig. 2.2.5.5) and thus allowed the stock to rebuild during the moratorium. From Figure 2.2.5.6, it is apparent that from 1974 to 1982, the stock essentially doubled in size for a fishing mortality that was in excess of the target fishing mortality of 0.2 and that at the same fishing pressure, the stock declined. The moratorium allowed the fish stock to rebuild slightly and since the reopening of the fishery, fishing mortalities are increasing to reach 0.5.

Various estimates of decline rate are provided in Table 2.2.5.1 based on the model estimates for spawner and 3+ population size. Mean age of spawners has varied over the time period as a consequence of both changes in the age of maturity and in the age structure of the population. Average values of about 6 for the early period and 5 for the more recent period are reasonable giving a 3 x generation time of between 15 and 18 years. Estimates of percentage decline over a period of 3 generations for alternative time periods vary but are generally around 80%.

Evaluation of causes of decline

There have been many publications on potential causes of the decline of this stock.

Fréchet (1991) examined the roles of many variables in the SPA. Three scenarios were conducted using average, maximum and minimum levels observed in the stock between 1974 and 1989. Variables examined were: perceived status of the stock, recruitment variations, target fishing mortality, changes in average weights at age, fishing limited by TAC, discards and misreporting. Each one was treated independently, however, in reality, many would have occurred simultaneously. The most influential was the perception of stock size.

Fréchet and Gagnon (1993) attempted to examine the cause for the collapse of a particular fishery: a winter longline fishery in the southwestern part of Newfoundland (3Pn). They showed that the cod had changed their migration route to deeper waters that were not fished by the fixed gear fleet. The authors did not address the cause of decline but provided an insight on many factors that can affect the fleet efficiency.

Chouinard and Fréchet (1994) investigated the various environmental factors that may have influenced the productivity of both cod stocks in the Gulf (4T,Vn and 3Pn, 4RS). Abundance changes appeared to be related more to recruitment fluctuations. An index of survival calculated as the ratio of recruitment numbers to parental biomass indicated that for both stocks, lower levels of spawning biomass in the 1970's produced good recruitment while the numbers of recruits produced from the large spawning biomass of the early 80's were low. The lower index of survival in the eighties corresponded with a period of colder conditions (greater ice extent, lower water temperatures).

Ouellet (1997) followed the idea of the index of survival presented in (Chouinard and Fréchet 1994) and showed that colder water temperatures were prevalent in early May 1993 to 1995. The poor state of the spawning stock (low abundance poor fish condition and less buoyant eggs) and harsh late winter early spring conditions in the northern Gulf limited the potential for high recruitment and rapid recovery of this stock.

Dutil and Lambert (2000) examined how the condition of individual cod was such that massive mortalities may have occurred in the wild. The extent of energy depletion was assessed in Atlantic cod (*Gadus morhua*) in spring and early summer (1993-1995) to assess relationships between poor condition and natural mortality. Several indices of condition were compared in wild fish in the northern Gulf of St. Lawrence and in fish exposed to a prolonged period of starvation in laboratory experiments. Discriminant analyses classified only a small fraction of the wild fish as similar to cod that did not survive and a much larger fraction as similar to cod that survived starvation. This percentage increased from April to May and peaked in June 1993 and 1994. Condition factor and muscle somatic index allowed a clear distinction between live and dead fish. Muscle lactate dehydrogenase activity suggested that cod had experienced a period of negative growth early in 1993, 1994, and 1995. Fish classified as similar to starved individuals were characterized by a higher gonad to liver mass ratio than others. Reproduction may have had a negative impact on survival not only in spring but also later into summer, as some individuals were found not to have recovered by late summer. This study showed that natural mortality from poor condition contributed to lower production in the early 1990s.

Finally, Stenson et al. (1997) examined consumption of cod by harp seal (*Phoca groenlandica*). Abundance estimates indicated that the total population size in eastern Canada in 1994 was approximately 4.8. million animals. To estimate the consumption of important fish prey by harp seals off the coast of Newfoundland and in the Gulf of St. Lawrence, a model incorporating age-specific estimates of energy requirements, population size, seasonal distribution and diets was developed. Total annual prey consumption increased from 3.6 million to 6.9 million t between 1981 and 1994. The proportions of prey obtained in the Arctic and eastern Newfoundland and/southern Labrador areas were 46% and 40%, respectively, while 14% was consumed in the Gulf of St. Lawrence. Arctic cod (*Boreogadus saida*) and capelin (*Mallotus villosus*) were the major prey off eastern Newfoundland while capelin was the most important in the Gulf. Based on an average diet, harp seals consumed an estimated total of 2.8 million t, including 1.2 million t of Arctic cod, 620 000 t of capelin and 88 000 t of Atlantic cod off the eastern coast of Newfoundland in 1994. In the Gulf, harp seals consumed an estimated 445 000 t of capelin, 20 000 t of Arctic cod, and 54 000 t of Atlantic cod out of a total of 961 000 t of prey. Incorporating seasonal, geographic and annual variations in the diet provided additional information on trends in consumption. Basic assumptions of the model were varied to assess its sensitivity. Changes in the energetic costs of activity and growth were found to affect significantly estimates of total consumption.

The most recent assessment of this stock (DFO 2002b) indicated that additional sources of mortality that are in excess of the TAC are adding an extra pressure to the stock. It was estimated that 886 t of cod were caught by the pilot recreational fishery in 2001. Also, an unknown amount of Gulf cod may have been caught in the 3Ps fishery. A cod stock mixing workshop concluded that 75% of the cod caught in 3Psa and 3Psd between November 1st to April 30th may be of Gulf origin. Work is still ongoing in this area. Again, from the most recent assessment of this stock it is noted that a catch of 7 000 t (the TAC for 2001) could cause a decline of at least 5% in the spawning biomass. Despite this, the FRCC has recommended that the TAC of 7 000 t be maintained in 2002 and it is currently the quota.

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

According to the most recent assessment of this stock (DFO 2000b), the smallest stock size was reached in 1994, the first year of the moratorium. Over the three years of the moratorium, the stock virtually doubled in size; it increased from 23 million mature individuals in 1994 to 52 million individuals in 1997. However, since the reopening of the commercial fishery, the mature population numbers have remained stable at around 50 million individuals. The maximum mature population number of 300 million individuals was reached in the early1980s.

2.2.6. Cod in 4TVn (Nov-Apr)

Evaluation of decline

Survey data and Sequential Population Analysis (SPA) estimates of abundance to evaluate population declines. Survey data are from the bottom-trawl survey of the southern Gulf conducted each September since 1971. The survey follows a stratified random design, with stratification based on depth and geographic region. Data was obtained from the 24 strata fished since 1971, which cover over 95% of the southern Gulf. Three survey vessels have been used: the *E. E. Prince* from 1971-1985, the *Lady Hammond* from 1985-1991, and the *Alfred Needler* from 1992 to the present. The *E. E. Prince* fished 12-hour days and used a Yankee 36 trawl, while the other two vessels fished 24-hour days and used a Western IIA trawl. Comparative fishing experiments were conducted each time the vessel changed and conversion factors have been applied where necessary (Nielsen 1989; Nielsen 1994; Swain et al. 1995). Catches by the *E. E. Prince* were multiplied by 1.3 to make them comparable to the rest of the time series and there was a depth-dependent correction applied to the results of the *Lady Hammond* missions. In addition, a series of 13 fixed stations were occupied between 1971 and 1987. These have been incorporated into the time series, along with the comparative fishing stations occupied during the 1985 survey (Nielsen 1995). When the survey was conducted aboard the *E.E. Prince*, 61 to 70 stations were occupied each year. Now, with 24-hour fishing operations, between 180 to 230 fishing sets can be made. The stratified mean catch rate of cod aged 5 years and older was used as an index of abundance. Because the annual abundance survey is conducted after the spawning season, Trippel et al. (1997) found that there were difficulties in distinguishing resting spawners from immature fish at that time of year. However, Sinclair et al. (1998) were able to calculate a maturity ogive for this stock based on surveys conducted at the end of the spawning season (July) from 1990 to 1995. The analysis indicated that 12% of southern Gulf cod are mature at age 3, 37% at age 4, 72% at age 5, 91% at age 6, 97% at age 7 and 100% at older ages. Thus, the index of abundance age range corresponds roughly to the spawning stock.

The SPA used in these analyses is described in Chouinard et al. (2002). There is strong evidence that *M*, the instantaneous rate of natural mortality, is currently near 0.4 for adult cod in this stock (Sinclair 2001), twice the value assumed in the past. Sinclair (2001) suggested that *M* may have increased from the lower value in the early 1980s, and the SPAs used in recent assessments of this stock, including Chouinard et al. (2002), assume that *M* increased from 0.2 to 0.4 in 1986. The SPA was calibrated using research survey abundance indices (ages 2-10, 1971-2001), a commercial catch rate index for otter trawls (ages 5-12, 1982-1993) assuming a trend in catchability, and five sentinel survey indices (1995-2001). In addition to the catchability coefficients for the indices, parameters to be estimated were abundance in 2002 for ages 3 to 15 yr and abundance at age 15 in 1999, 2000 and 2001. F on the oldest age was assumed to equal the weighted average of F at ages 13 and 14 (or 12 and 13 when there was no catch at age 15). A retrospective analysis indicated that there were no tendencies to over- or under-estimate population size, and there was no retrospective pattern in terms of spawning biomass. Bias in the parameter estimates was small and coefficients of variation relatively low (Table 2.2.6.1)

To obtain a longer term view of this stock, the SPA calibrated over the 1971-2001 period (Chouinard et al. 2002) is extended back to 1950 using the catch-at-age given in Maguire et al. (1983) and assuming an *M* of 0.2 for the early time period. Estimates of the spawning population were obtained by applying the maturity ogive described above to the estimated population numbers at age.

Estimates of generation time were based on mean age of spawners. Between 1950 and 2002, the estimated mean age of spawners has varied from 4.7 to 6.6 yr, with an average of 5.9 yr (Fig. 2.2.6.1). Mean age of spawners was at a minimum in the mid to late 1970s, and is now currently 6.46 yr, near the highest value in the 52-yr time series. This gives estimates for the three-generation period ranging from 14 to 20 yr, with an average of about 18 yr and a current value near 19.5 yr. The generation time that would occur in an unfished population can be estimated as age at first maturity plus $1/M$. Age at 50% maturity is about 4.5 yr for the southern Gulf population. This gives a generation time of 9.5 yr assuming M=0.2, and 28.5 yr for the three-generation period. Given this range of estimated generation times, we estimated the rate of decline (or increase) over a range of time periods, namely the last 15, 20 and 30 yr, as well as the entire 52-yr time series and the time period giving the steepest decline (the last 17 yr). We estimated the rate of decline as the slope of the linear regression of $\log_e$ abundance versus time (yr).

The SPA indicated a decline in the abundance of the spawning stock from the early 1950s to the mid-1970s (Fig. 2.2.6.2*a*). The spawning stock then increased very rapidly in abundance, reaching a peak in the mid -1980s that was nearly twice as high as the earlier peak abundance in the 1950s. A precipitous decline in abundance occurred in the late 1980s and early 1990s, to a value near the minimum abundance of the mid -1970s. Spawning stock abundance has remained fairly stable, near this low value, since 1993. Survey catch rates indicate a similar pattern, with low abundance in the mid 1970s, a rapid increase in abundance to high values throughout the 1980s, a precipitous decline in abundance in the early 1990s, and stability at a low level since 1992 (Fig. 2.2.6.2*c*). The low spawning stock abundance that has persisted over the past decade is about 50% higher than the minimum abundance in the mid 1970s according to the SPA, and about twice the earlier low abundance level according to the survey catch rates.

Because recent changes in abundance are in both directions (i.e., a rapid increase in the late 1970s and a decrease in the early 1990s), estimated rates of decline depend strongly on the period used (Table 2.2.6.2, Fig. 2.2.6.2). Estimated percent declines, using either the SPA estimates or the survey catch rates, range between about 70 and 85% over the last 15-20 yr. However, estimated percent declines are much less over longer periods. Estimated percent declines are only about 35% over the past 30 or 52 years, using the SPA estimates. Using the survey catch rates, there is an estimated 27% *increase* over the past 30 yr.

Evaluation of causes of decline

The population has been exploited since at least the 16th century. Landings varied between 20 000–40 000 t annually during 1917-1940, and then increased to a peak of over 100 000 t in 1958. The fishery was primarily prosecuted with hook and line until the late 1940s, when a ban on otter trawling was lifted (Chouinard and Fréchet 1994). Landings remained relatively high in the 1960s and early 1970s, in the range of 45 000 to 60 000 t. TACs were first imposed in 1974, and these became restrictive as the stock declined in the mid-1970s. The stock recovered somewhat and landings averaged about 60 000 t during the 1980s. During the 1980s, the fixed gear fishery declined drastically and the fishery was mainly prosecuted by mobile gear until it was closed in September 1993, due to low abundance. From 1994 to 1997, removals from the stock (sentinel surveys, recreational fishery and by-catch in other fisheries) amounted to less than 1 500 t annually. In 1998, an 'index' fishery of 3 000 t was allowed and in 1999, the commercial directed fishery re-opened with a TAC of 6 000 t. This TAC level remained in effect for 2000 and 2001.

Population abundance (Fig. 2.2.6.3) declined from the mid-1950s to the mid-1970s. Following strong recruitment in the late seventies and early eighties, population abundance increased to the highest levels in the 50-year time series. For each unit of spawning biomass, the production of recruits was much higher from the mid-1970s to the early 1980s than in any other period in the time series (Fig. 2.2.6.4). This promoted the rapid recovery of the stock observed in that period. Analyses indicated that spawning stock characteristics (e.g. mean age, diversity of age structure, growth rates of spawners, etc) did not explain the observed variability in recruitment rate (Swain and Chouinard 2000). Swain and Sinclair (2000) presented evidence suggesting an inverse relationship between recruitment rate of cod and pelagic fish biomass. The exceptionally high recruitment rates in the mid 1970s to early 1980s coincided with unprecedented collapses in herring and mackerel, the main pelagic fishes in the southern Gulf. In the late 1980s and early 1990s, population abundance declined rapidly due to high levels of both natural and fishing mortality, and lower recruitment. The current abundance of the stock is estimated to be near the 1993 level when the fishery was closed.

As indicated above, for the southern Gulf of St. Lawrence cod stock, it appears that the decline over the last 15-20 years (which occurred primarily in the period 1986-1992), can be attributed to two main causes: an increase in both fishing and natural mortality.

<u>Increase in fishing mortality</u>

An important contributor to the rapid decline in population abundance starting in the mid-1980s was the increase in fishing mortality (Fig. 2.2.6.5). For example, nominal effort (days) for mobile gear nearly doubled between 1987 and the early 1990s (Sinclair et al. 1994). In the period 1990-1992, it is estimated that the fishery removed about 50% of the fishable stock biomass annually compared to between 20-30% prior to 1988 (Chouinard et al. 2002).

The reasons for the increase in fishing effort during that time are numerous. Following the extension of jurisdiction in 1977 foreign fishing capacity was quickly replaced by domestic fleets. For the southern Gulf of St. Lawrence stock, foreign fishing took place in NAFO 4Vn. In the early to mid 1980s, vessel replacement subventions were widely available for Maritime Provinces fishers and this led to an increase in fishing capacity of the fleet.

At the time, the management strategy was to fish at $F_{0.1} = 0.2$, a constant fishing mortality rate. Retrospective patterns in the stock assessments of the late 1980s resulted in the under-estimation of fishing mortality and over-estimation of $F_{0.1}$ catch levels. In addition, the multi-year plans, which were implemented in the early 1990s, also led to increase in fishing effort by keeping TACs higher than annual estimates were suggesting.

Increase in natural mortality

With the closure of the fishery in 1993, natural mortality rates could be calculated from survey estimates of relative abundance in successive years (Sinclair 2001). Estimates of total mortality (Z) for the period of fishery closure were about 0.4 (Fig. 2.2.6.6), indicating that natural mortality in the mid-1990s was about twice the previously assumed level of 0.2. Furthermore, other analyses suggested that the increase in natural mortality had likely occurred in the early to mid 1980s (Sinclair 2001). Causes for the increase in natural mortality remain unclear but this would include all sources of unaccounted mortality such as poor environmental conditions, predation by seals, unreported catches, discarding and changes in life history characteristics. The increase in natural mortality is likely a combination of several factors. The contribution of each of the various potential causes to the recent high estimates of M has remained undetermined so far.

There is evidence for most of the factors mentioned above. For example, there are indications that significant discarding of juvenile cod occurred in the late 80s and early 90s (Sinclair et al. 1998). There were also reports of misreporting and of unreported catches (Martin 1990) during that period.

Both grey and harp seal populations in the Gulf of St. Lawrence are estimated to have increased considerably from the mid -1970s to the mid 1990s (Healy and Stenson 2000; Hammill and Stenson 2002). Estimates of the predation of cod by both grey and harp seals for this stock range from 19 000 to 39 000 t (all ages) (Hammill and Stenson 2002), depending on diet assumptions. Because seal feeding data in the southern Gulf are scarce, diets from neighboring areas were used in some of the estimates. The use of these diets produced the higher estimates. However, there is uncertainty as to the importance of the seal consumption in the increased natural mortality (including adult cod) because diet samples suggest that most cod consumed by seals appear to be less than 35 cm in length.

Finally, there is also evidence of changes in life-history characteristics. For example, individual growth (size-at-age) was high in the 1970s and declined sharply to reach a minimum in the mid-1980s (Chouinard and Fréchet 1994). It has improved somewhat since but remains low compared to the seventies. Changes in growth appear to be related to density, water temperature and size –selective fishing (Hanson and Chouinard 1992; Sinclair et al. 2001; Swain et al. 2002).

In summary, the population appears to have fluctuated due to both anthropogenic (i.e. fishing) and natural causes. Productivity of the stock was high in the seventies but has been low in the last 10 years. Because of higher productivity (high recruitment rate), the stock rebounded in the seventies in spite of continued high exploitation rates. Conversely, in the mid- to late nineties, the stock failed to recover in the absence of fishing because of low productivity (high natural mortality).

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

Although there has not been any recovery in population abundance, indicators (RV survey and SPA) suggest that there has not been any further significant decline in the population since the closure of the directed cod fishery in September 1993. The fishery was re-opened partially in 1998 (3 000 t). The TAC was set at 6 000 t annually during 1999-2001. However, the most recent assessment of the resource (Chouinard et al. 2002) suggests that spawning population abundance is likely to decline in the short-term (2-3 years), even with reduced catches, because of incoming low recruitment. A decline of 6% is predicted if there is no catch in 2002 and catches of 6 000 t would result in an 11% decline in spawning stock biomass. This prediction assumes that natural mortality will remain high.

The stock declined to similarly low levels around 1975 and recovered, suggesting that the current decline is reversible. However, it should be noted that the productivity of the stock (lower natural mortality and high recruitment rate) was higher during that period than it is presently. The time-scale for reversibility is highly dependent on productivity; the stock recovered very quickly in the mid-seventies but would likely take several generations given the lower productivity in recent years.

Summary:

1. The stock steadily declined from the early 1950s to the mid 1970s, probably due to high fishing mortality
2. The stock rapidly recovered in the late 1970s and early 1980s.
    - The mid to late 1970s were a period of high productivity. Growth was high and the rate of recruitment was exceptional.
    - Recovery occurred even though the fishery was not closed
    - The rapid recovery was due to the very high recruitment rates. These may be attributed to the collapse of pelagic fish stocks (possible predators or competitors of early life history stages of cod) and compensatory effects of low SSB.
3. Peak abundance in the mid 1980s was considerably higher than the previous peak in the early 1950s.
    - Density-dependent declines in growth and changes in distribution suggest that food was limiting at these very high abundance levels.
4. The stock declined rapidly in the late 1980s and early 1990s
    - Fishing mortality was high and increasing
    - Productivity had declined
        - Natural mortality (of adults) increased
        - Size-at-age was low

        - Recruitment rate had declined (pelagic fish biomass had recovered, SSB had increased)
5. Abundance has been stable since 1993
    - The decline stopped when the fishery was closed
    - No recovery has occurred
        - Adult natural mortality is high. Possible causes include unreported catch, seal predation and changes in life history characteristics.
        - Recent recruitment rate appears to be moderate (increased slightly as SSB declined, but not to the exceptional levels of the late 1970s)
            - Herring biomass is high
            - Mackerel biomass was high in the late 1980s and early 1990s but declined in the late 1990s. It is expected to increase dramatically, as a result of the 1999 year-class, which appears to be the largest observed.
            - Seal abundance is high
6. A slight decline in the spawning stock is predicted in the short term, due to the very weak 1999 year-class.

2.2.7. Cod in 4Vn (May-Oct)

Evaluation of decline

Survey data and Sequential Population Analysis (SPA) estimates of abundance were used to evaluate population declines. Survey data are from the bottom-trawl RV survey of the Bay of Fundy, Scotian Shelf and Sidney Bight undertaken during summer (July). The survey follows a stratified random design, with stratification based on depth and geographic region. The RV survey has been undertaken by three different vessels: the *AT Cameron* (1970-1981), the *Lady Hammond* (1982), and *Alfred Needler* (1983-present). Surveys using the first two vessels have been converted into *Needler* equivalents using a conversion factor of 1.70 (Mohn et al. 1998). The most recent stock assessment information for cod in this region of the Eastern Scotian Shelf is presented in Mohn et al. (2001). Information on stock status was derived from the July groundfish survey and a Sentinel Survey conducted by commercial fishing vessels. Additional data include an inshore survey of the western area of Sydney Bight and port sampling. Total mortality rates, as estimated from the July survey, remained relatively high following the fishery closure in 1993. This was contrary to expectation, and suggested that mortality due to causes other than reported fishing has been higher that the level of 0.2 regularly used in previous abundance assessments. As a result, a time and age varying natural mortality was assumed in the most recent assessment (Mohn et al. 2001). The SPA was calibrated using the July RV survey (ages 3-10, 1981-2000), and the Sentinel Survey (ages 5-10, 1994-2000). Error in catch was assumed to be negligible. Partial recruitment to the fishery was fixed for ages 11-12 in the terminal year. Fishing mortality on the oldest age (12) was set to the average F for ages 9 and 10.

Generation time was estimated using the mean age of spawners. The timing of the summer survey excluded the use of survey data in the estimation of maturity and reproductive stage. As a result, a maturity ogive was not been constructed for this stock. The assumption of 100% (knife-edge) maturity at age 5 was used in the assessments of this stock (Mohn et al.

2001). This assumption was used in the calculation of the mean age of the spawning stock. Between 1981 and 1998, the estimated mean age of spawners varied from approximately 5.50 to 6.68 yr, with an average of 6.11 yr (Fig. 2.2.7.1). While no strong trend is apparent, mean age was slightly higher in the first half of the time series than in the latter half of the series. The most recent value (1998) is 5.83 yr. As a result, estimates of the 3-generation period range from 16.50 to 20.04 yr, with an average of 18.33 yr and a most recent value of 17.49 yr. Given the lack of a maturity ogive, it is difficult to estimate the generation time in the absence of fishing mortality. Usually, the generation time under such conditions would be estimated as the age at first maturity plus 1/M (where M=0.2). In the Sydney Bight stock, 100% (knife-edge) maturity is assumed at age 5. The use of age 5 provides a generation time of 10 yr, and thus 30 yr for the 3-generation period. Given this range of estimated generation times, rate of decline (or increase) in the SPA abundance estimates was estimated over time periods of 15, 18, and 20 yr (the time series encompasses 20 yr). A fourth period of 32 yr was added for the RV survey data, which included span of the time series. Rate of decline was estimated as the slope of the linear regression of $\log_e$ abundance versus time (yr).

Estimates derived from SPA indicated a decline in abundance of the spawning stock from the early 1980s to 1994, the year following the moratorium (Fig. 2.2.7.2*a*). Spawning stock abundance has yet to rebound from that low level, and has shown little change since 1995. The RV survey showed a much different pattern, with large peaks in 1985 and 1988-1989 (Fig. 2.2.7.2*c*). Current stock abundance (year 2000) is approximately 9.4% of the maximum observed in 1985. Estimated percent declines depended upon the period used (Table 2.2.7.1, Fig. 2.2.7.2*b*,*d*). Over the past 15 to 20 years, percent decline has ranged from about 89 to 85% for both SPA and RV survey stratified abundance. Over the course of the entire RV time series, the percent decline lessens to approximately 20%.

Evaluation of causes of decline

Annual landings of cod in the Sydney Bight area were relatively high during the 1970s (>8000 t), but declined sharply to a low of about 2000 t in 1977 with the extension of Canadian jurisdiction to 200 n miles. Landings increased again during the early 1980s and varied around relatively high levels, with peak landings of approximately 10 600 t in 1981 and again in 1986 (Mohn et al. 2001). Landings declined sharply from the late 1980s until the declaration of the moratorium in 1993. After 1990, the commercial catch was substantially lower than the Total Allowable Catch allowed for this management unit (Mohn et al. 2001).

Both mature and total population abundance, as estimated with SPA, has declined from 1985 to current low levels (Fig. 2.2.7.3). Recruitment (age 1-4) declined through to the early 1990s, and has exhibited some recent signs of improvement (Fig. 2.2.7.3; Mohn et al. 2001). The condition factor for mature fish peaked during the late 1970s, then fell to the long-term mean in 1982 (Mohn et al. 2001). Since that time, condition factor has continued to decline, and current levels are the lowest on record (Mohn et al. 2001). The size at age of older fish declined during the mid-1980s and has remained relatively low (Mohn et al. 2001). Total mortality of the age group 7-9 has not decreased with the institution of the fishery moratorium. Additionally, the age group 2-3 has exhibited a recent increase in total mortality (Mohn et al. 2001). This increase corresponds to recent growth in grey seal abundance. The most recent stock assessment (Mohn et al. 2001) included increased in natural mortality to account for recent increases in total mortality.

Overexploitation was likely an important factor in the decline in abundance of Sydney Bight cod. Since 1981 fishing mortality on the spawning stock has regularly exceeded 0.5, and peaked in 1991 at nearly 1.4 prior to declining to near zero following fishery closure (Fig. 2.2.7.4; Mohn et al. 2001). There is little evidence to suggest that Sydney Bight cod experienced a relatively large increase in natural mortality prior to the observed decline in abundance and institution of the moratorium in 1993.

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

While there is little evidence of recovery in abundance in Sydney Bight cod in spite of the moratorium, neither is there evidence of further decline. Stock production in recent years has been low, and spawning biomass has increased only slightly since fishery closure in 1993 (Fig. 2.2.7.2). Mohn et al. (2001) have attributed the failure of the stock to recover to two factors: weak year-classes and relatively high natural mortality in recent years. Rapid recovery would require a substantial increase in productivity and recruitment to the spawning stock.

2.2.8. Cod in 4VsW

Evaluation of decline

Survey data and Sequential Population Analysis (SPA) estimates of abundance were used to evaluate population declines. Survey data are from the bottom-trawl RV survey of the Bay of Fundy, Scotian Shelf and Sidney Bight undertaken during summer (July). The survey follows a stratified random design, with stratification based on depth and geographic region. The RV survey has been undertaken by three different vessels: the *AT Cameron* (1970-1981), the *Lady Hammond* (1982), and *Alfred Needler* (1983-present). Surveys using the first two vessels have been converted into *Needler* equivalents using a conversion factor of 1.70 (Mohn et al. 1998). The most recent stock assessment information for cod in this region of the Eastern Scotian Shelf is presented in Fanning et al. (1996) and Mohn et al. (1998). Information on stock status was derived from the both the March and July groundfish surveys, and a Sentinel Survey conducted by commercial fishing vessels since 1995. The age-based population analysis was calibrated using the July RV survey (ages 3-8, 1970-1997), the March RV survey (ages 3-9, 1979-1997, excluding 1985, 1996, and 1997), and the Sentinel Survey (ages 5-10, 1994-2000). Seal predation removals were treated as an additional source of fishing mortality, by addition of the seal catch at age to the commercial catch at age (Mohn et al. 1998). Three different scenarios including seal predation were investigated (see Mohn and Bowen 1996; Mohn et al. 1998 for details). The analyses in this paper used abundance estimates from the third model presented by Mohn et al. (1998), wherein the proportion of cod in the seal diet was related to the abundance of cod, with an upper bound of 20% cod in the diet. Structure imposed on the model included: error in catch was assumed to be negligible, partial recruitment to the fishery was fixed for ages 1, 2 and 11+ in 1997, and fishing mortality on the oldest age (15) was set to the average F for ages 9 and 10. In addition, natural mortality was set to 0.2 for years up to 1985, and to 0.4 for all subsequent years.

Generation time was estimated using the mean age of spawners. Maturity at age is derived from analysis of the spring RV survey on the Scotian Shelf, and is available for the years 1979-1995, excluding 1985 and 1991 (see Trippel et al. 1997). Proportion of males and females mature at age was estimated separately by Trippel et al. (1997) and averaged in the calculation of generation time presented here. Generation time was also estimated using the assumption of knife-edge maturity at age 5, as commonly assumed in stock assessments. Between 1970 and 1997, the mean age of spawners estimated from maturity data varied from approximately 4.37 to 5.81 yr, with an average of 5.30 yr (Fig. 2.2.8.1). Using age 5+ as mature, the mean age of spawners varied from approximately 5.65 to 7.16 yr, with an average of 6.13 yr (Fig. 2.2.8.1). The mean age estimated from maturity data appeared to be slightly higher in the late 1980s and 1990s relative to earlier in the series. The most recent value in this series (1995) is 5.60 yr. Thus when using the RV series, estimates of the 3-generation period range from 13.11 to 17.43 yr, with an average of 15.90 yr, and a most recent value of 16.80 yr. Generation time, if a population has not exploited, is estimated as the age at first maturity plus 1/M (where M=0.2). Estimates of age at first maturity are not available for this stock prior to fishing. Age at 50% maturity is about 3.82 yr in the Eastern Scotian Shelf stock (average 1979-1995; Trippel et al. 1997). This provides a generation time of 8.82 yr, and thus 24.5 yr for the 3-generation period. Given this range of estimated generation times, rate of decline (or increase) in the SPA abundance estimates was calculated over time periods of 13, 16, 18, and 25 yr. Two further periods of 28 and 31 yr were added, corresponding to the lengths of the SPA and the RV survey time series, respectively. Rate of decline was estimated as the slope of the linear regression of $\log_e$ abundance versus time (yr). Since some years exhibited no mature fish at various ages (0 values), natural logarithms were taken of 1 + the year-age number ($\log_e(n_{ij} + 1)$).

Population estimates (Fig. 2.2.8.2*a*) indicated a decline in abundance during the 1970s, until the extension of Canadian jurisdiction to 200 miles in 1977. Spawning stock abundance then underwent a substantial recovery, to peak in 1985-1986. The stock then experienced a severe decline until 1993. Spawning stock abundance has yet to rebound from that low level, and has shown a slight decline up to 1997 (Fig. 2.2.8.2a). Research vessel catches show a similar pattern, with a relatively small peak in 1973, low values from 1974-1980, a peak in catches in 1984, and a decline to very low levels in the most recent years (Fig. 2.2.8.2c). Estimated stock abundance in 1997 was approximately 4.6% of the maximum observed in 1986. Estimated percent declines depended upon the period used (Table 2.2.8.1, Fig. 2.2.8.2*b*,*d*). Over the past 13 to 25 years, percent decline has ranged from about 82 to 98% for both SPA and RV survey stratified abundance, with the SPA estimates exhibiting a greater range. Over the course of both time series, the estimated percent decline was 81% in the SPA estimates, and 69% in the RV survey stratified abundance.

Evaluation of causes of decline

The Eastern Scotian Shelf cod stock was once the largest in the Scotia-Fundy region. During the period of 1958 to 1974, total landings ranged from 40 000 to 80 000 t, then declined precipitously to a low of 10 000 t in 1977. Canada extended fishery jurisdiction to 200 miles in 1977, and landings returned to relatively high levels during the mid-1980s. Catches subsequently underwent a dramatic decline into the early 1990's to historically low levels. A fishing moratorium was instituted in 1993. There has been no sign of a recovery in abundance since 1993, and current estimates of both total and spawning stock biomass are among the lowest on record. Mohn et al. (1998) predicted a further decline in spawning stock biomass, given particular assumptions concerning seal predation.

Both mature and total population abundance, as estimated through population reconstruction, peaked in 1985-1986 and has since declined low levels in recent years (Fig. 2.2.8.3). Recruitment (age 1) has been below average since the late 1980s (Mohn et al. 1998); however recruitment estimates are dependent upon assumptions of seal predation. Prior to 1990, patterns in condition factor over time suggested that condition was reduced in periods of high abundance (Mohn et al. 1998). However, condition factor continued to decline through the early 1990s despite the rapid reduction in population size, only to increase in recent years. Some investigations into causes for poor condition in cod have suggested that low temperatures can induce poor condition, leading to increased mortality and depressed reproductive success (e.g. Lambert and Dutil 1997; Dutil and Lambert 2000). These effects are consistent with lower ocean temperatures on the eastern Scotian Shelf since 1986.

The decline in abundance of Eastern Scotian Shelf cod is usually attributed to overexploitation of the population. Frank et al. (1994) concluded that high estimated fishing mortalities, which ranged from 0.22 to 1.56 and rose steadily from the mid-1980s onward, contributed to the observed reduction in spawning stock biomass (Fig. 2.2.8.4). Similarly, Myers et al. (1996) concluded that increased fishing mortality caused the decline in a number of cod populations, including Eastern Scotian Shelf cod.

Causes for the decline of cod in 4VsW, and the lack of subsequent recovery, were investigated in a modeling study by Fu et al. (2001). The authors constructed a population dynamics model that included interactions among cod vital rates, harvest, and the resident grey seal population. Mortality incorporated three components: fishing mortality, seal predation, and all other sources of natural mortality. Based on the parameter estimates from the various mortality components, Fu et al. (2001) concluded that overfishing was the primary cause of stock decline, and that it was unlikely that the collapse of the stock was due to a sudden increase in natural mortality.

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

The moratorium imposed in 1993 may have halted the decline in spawner and total biomass (Fanning et al. 1996; Mohn et al. 1998), but as of the last assessment the population has yet to exhibit a recovery in abundance. Recruitment was relatively low during the 1990s (Mohn et al. 1998). Gross production declined sharply in 1985-1986, and has remained very low (Mohn et al. 1998). Net production has been near zero since closure of the fishery in 1993, despite little change in gross production, which lead Mohn et al. (1998) to conclude that decline in stock biomass has halted. An additional reason for lack of recovery may have been an increase in natural mortality for this population. Fu et al. (2001) reported that the mortality due to seal predation in their population model became an important influence on the survival of immature cod during the 1990s. A greater proportion of immature cod died than survived to maturity during this period. Moreover, model results led Fu et al. (2001) to suggest that mature cod may also have experienced increased natural mortality since the mid-1990s.

A recovery in abundance in Eastern Scotian Shelf cod over the next few years appears unlikely (Mohn et al. 1998). Both recruitment and survivorship must increase for this population to rebound to pre-collapse abundance levels.

2.2.9. Cod in 4X/5Y

Evaluation of decline

Survey data and Virtual Population Analysis (VPA) estimates of abundance were used to evaluate population declines. Survey data are from the bottom-trawl RV survey of the Bay of Fundy, Scotian Shelf and Sidney Bight undertaken during summer (July) since 1970. The survey follows a stratified random design, with stratification based on depth and geographic region. The RV survey has been undertaken by three different vessels: the *AT Cameron* (1970-1981), the *Lady Hammond* (1982), and *Alfred Needler* (1983-present). Surveys using the first two vessels have been converted into *Needler* equivalents using a conversion factor of 1.70 (Mohn et al. 1998). The most recent stock assessment information for cod in this region of the Western Scotian Shelf and Bay of Fundy is presented in Clark et al. (2000). Information on stock status was derived from the July groundfish survey, an Individual Transferable Quota (ITQ) survey conducted by commercial fishing vessels since 1995. The sequential population analysis presented by Clark et al. (2000) was calibrated using the July RV survey (ages 2-8, 1983.5-2000.5), and the ITQ Survey (ages 2-8, 1996.5-2000.5). A more recent population reconstruction including the period 1948-2001.5 (S. Gavaris, pers. comm.) was used in the evaluation of cod in 4X/5Y presented in this paper. This reconstruction used the same indices as the VPA undertaken by Clark et al. (2000). There are some caveats associated with this longer population analysis (S. Gavaris, Fisheries and Oceans Canada, pers. comm.). Aging appears to have shifted for the period 1957-1965, in that ages may be elevated by 1 year. Sampling effort was relatively low prior to 1980, particularly in the late 1960s and through the 1970s, which may increase variance around the estimates. Exact year-class strengths may be smoothed through sampling variability.

Generation time was estimated using the mean age of spawners. Maturity at age is derived from analysis of the spring RV survey on the Western Scotian Shelf (in NAFO Subdivision 4X), and is available for the years 1979-1985 (see Trippel et al. 1997). Proportion of males and females mature at age was estimated separately by Trippel et al. (1997) and averaged in the calculation of generation time presented here. Generation time was also estimated using the assumption of knife-edge maturity at age 4, as commonly assumed in assessments of this stock. The mean age estimated from maturity data exhibited a slight declining trend from 1948 to the mid-1990s, and has increased since. This recent increase in mean age of spawners is not evident in the age 4+ population. Between 1948 and 2001.5, the mean age of spawners estimated from maturity data varied from approximately 3.71 to 4.89 yr, with an average of 4.28 yr (Fig. 2.2.9.1). The most recent value in this series (2001.5) is 3.97 yr. Using age 4+ as mature, the mean age of spawners varied from approximately 4.60 to 6.02 yr, with an average of 5.25 yr (Fig. 2.2.9.1). Thus when using the RV series, estimates of the 3-generation period range from 11.13 to 14.67 yr, with an average of 12.84 yr, and a most recent value of 11.91 yr. Generation time, if a population has not exploited, is estimated as the age at first maturity plus 1/M (where M=0.2). Estimates of age at first maturity are not available for this stock prior to fishing. Age at 50% maturity of males and females combined is about 2.63 yr in the Scotian Shelf/Bay of Fundy stock (average 1979-1985; Trippel et al. 1997). This provides a generation time of 7.63 yr, and thus 23 yr for the 3-generation period. Given this range of estimated generation times, rate of decline (or increase) in the VPA abundance estimates was estimated over time periods of 11, 13, 15, and 23 yr. Two further periods of 55 and 32 yr were added, corresponding to the lengths of the VPA and the RV survey time series, respectively. Each interval listed above was extended by 0.5 yr to accommodate the most recent abundance estimate calculated for year 2000.5. Rate of decline was estimated as the slope of the linear regression of $\log_e$ abundance versus time (yr). Since some years exhibited no mature fish at various ages (0 values), natural logarithms were taken of 1 + the year-age number ($\log_e(n_{ij} + 1)$).

Population estimates indicated a peak in abundance during the mid 1960s, and a general decline with variation ever since (Fig. 2.2.9.2a). Spawning stock abundance underwent a rapid decline from 1966-1970, but recovered to relatively high levels around 1980. The ensuing decline resulted in the minimum recorded biomass in 1999. Present mature biomass levels are still very low relative to estimated abundance in the 1960s (Fig. 2.2.9.2*a*). The Research vessel series indicated a different pattern (Fig. 2.2.9.2*c*). Annual values are highly variable, and the time series is dominated by two relatively high sample catches in 1970 and 1996. Despite this variability, there appeared to be an overall declining trend in the data (Fig. 2.2.9.2*d*). Estimated percent declines depended upon the period used (Table 2.2.9.1, Fig. 2.2.9.2*b*, *d*). Over the past 11 to 55 years, percent decline has ranged from about 35 to 75% in the population estimates from VPA. RV survey stratified abundance has shown declines ranging from 36-50% over periods of 11 to 32 yr.

Evaluation of causes of decline

The most recent stock assessment information for cod found on the Western Scotian Shelf and in the Bay of Fundy is presented in Clark et al. (2000). This is the only cod stock in Canadian waters that was not placed under a fishing moratorium or had harvest limited to by-catch only. Declines in abundance may have begun during the 1950s for this stock, with landings decreasing from 20 000 t to 12 000 t by 1958 (Clark et al. 2000). With the introduction of otter trawlers to offshore areas in 1962, landings increased rapidly, and reached a peak of 35 500 t in 1968 (Clark et al. 2000). Landings ranged between 20 000 and 31 000 t throughout the 1970s. A TAC of 30 000 t was set for the period of 1980-1983, but landings declined to 21 000 t by 1985. Landings climbed again in the late 1980s and early 1990s, then large reductions in TAC limited the catch (Clark et al. 2000).

Both mature and total population abundance, as estimated with VPA, have declined from the mid-1960s to current low levels (Fig. 2.2.9.3). Recruitment (age 1) has been variable, but has generally declined from the late-1980s to the mid-1990s, although it has exhibited some recent signs of improvement (Fig. 2.2.9.3). The condition factor for fish 50 cm in length has exhibited little variation during the last 30 years, and current levels are close to the long-term mean (Clark et al. 2000).

The decline in abundance for cod found along Western Scotian Shelf and the Bay of Fundy appears due mainly to overfishing (Myers et al. 1996; Clark et al. 2000). Fully recruited fishing mortality was relatively high throughout the late 1980s, but rose sharply to peak in 1992 (Fig. 2.2.9.4). This peak corresponded to the rapid decline observed in biomass and abundance estimates (Fig. 2.2.9.2), and led to the depletion of all cohorts prior to 1990 (Clark et al. 2000). Fishing mortality was reduced in the late 1990s, allowing the more recent cohorts to fill out the older ages in the population age structure. Increased natural mortality due to decreases in condition was unlikely to have been a factor in the decline. Cod condition, measured as predicted weight at 50 cm, has exhibited low variability, and condition values during the decline were about average during the time series (Clark et al. 2000). Similarly, no evidence has been presented to suggest an increase in predation during the same period.

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

Population abundance estimates for cod in 4X have remained relatively stable since 1996, with a slight decrease in numbers in the late 1990s. Biomass estimates indicate that stock biomass has been low but stable over the same period (Fig. 2.2.9.3; Clark et al. 2000). The 1992 year class was relatively large, and the maturation of this cohort led to a relatively large increase in spawning stock size in 1996. SSB has remained around this level since. The estimate of age 1+ biomass was still very low as of year 2000, and was just beginning to improve with the addition of the 1998 yearclass (Clark et al. 2000). The age structure of this population has improved with the increase in abundance of older fish. The incoming 1998 yearclass was considered the largest since 1992, with an abundance estimate of 12 300 000 individuals (Clark et al. 2000). The 1999 yearclass may be of similar strength. However, recruitment has been poor for most of the 1990s, resulting in low production. Ages 8+ are estimated at or above average.

Clark et al. (2000) reported that given a harvest of 6 000 t in 2000, there was a 50% chance that the biomass of 4X cod would increase by 20%. Risk evaluation indicated that substantial changes in yield would be required to influence the probability of not exceeding growth in 4+ biomass. Clark et al. (2000) concluded that biomass increases over the next several years (2001-2003) would be largely dependent upon incoming recruitment.

2.2.10. Cod in 5Zej and 5Zem

Evaluation of decline

Survey data and Sequential Population Analysis (SPA) estimates of abundance were used to evaluate population declines. The most recent stock assessment information for cod in this region of Georges Bank is presented in Hunt and Hatt (2001). Three separate research vessel surveys are used in the assessment of cod on the portion of Georges Bank under Canadian jurisdiction. The US National Marine Fishery Service (NMFS) undertakes both a spring and a fall survey on Georges Bank. DFO also conducts a spring survey. These surveys follow a stratified random design, with stratification based on depth and geographic region. In addition, a longline research survey on Georges Bank using commercial vessels was instituted in 1995.

Information on stock status was derived from the two US RV surveys and the DFO RV survey. The sequential population analysis presented by Hunt and Hatt (2001) was calibrated using the US fall survey (ages 0-5, 1977-2000; ages 1-6, 1978-2001), US spring survey (age 1-8, 1978-2000), and the Canadian spring survey (ages 1-8, 1986-2001). The US spring survey was partitioned into two indices to account for a change in the survey trawl. The spring survey results were compared to the beginning of year population abundance. Ages 0-5 from the fall survey were lagged one year and compared to year t+1. Fishing mortality for the oldest age group was estimated as the average of ages 5-9. Errors in catch-at-age were assumed negligible relative to those for the abundance indices. Error for the log–transformed abundance index were assumed to be independent and identically distributed (Hunt and Hatt 2001).

Generation time was estimated using the mean age of spawners. Maturity at age is derived from analysis of the Canadian spring RV survey on Georges Bank (in NAFO Subdivision 5Z), and is available for the years 1978-2001 (Hunt 1995; Hunt and Hatt 2001). Males and females were pooled in the estimation of proportion mature at age. Generation time was also estimated using the assumption of knife-edge maturity at age 3, as commonly assumed in assessments of this stock. The mean age estimated from maturity data showed little variation from 1978 to 1998, but has increased in recent years (Fig. 2.2.10.1). This recent increase in mean age of spawners is also evident in the age 3+ population. Between 1978 and 2001, the mean age of spawners estimated from maturity data varied from approximately 3.09 to 5.07 yr, with an average of 3.62 yr (Fig. 2.2.10.1). The most recent value in this series (2001) is 5.07 yr. Using age 3+ as mature, the mean age of spawners varied from approximately 3.51 to 5.28 yr, with an average of 4.06 yr (Fig. 2.2.10.1). Thus when using the RV series, estimates of the 3-generation period range from 9.28 to 15.21 yr, with an average of 10.87 yr, and a most recent value of 15.21 yr. Generation time if a population has not exploited is estimated as the age at first maturity plus 1/M (where M=0.2). Estimates of age at first maturity are not available for this stock prior to fishing. Age at 50% maturity is about 2.09 yr in Georges Bank stock (average 1986-1995; Trippel et al. 1997). This provides a generation time of 7.09 yr, and thus 21 yr for the 3-generation period. Given this range of estimated generation times, rate of decline (or increase) in the SPA abundance estimates was estimated over time periods of 9, 11, 15, and 21 yr. Two further periods of 16 and 24 yr were added, corresponding to the lengths of the Canadian spring RV survey and SPA series, respectively. Rate of decline was estimated as the slope of the linear regression of $\log_e$ abundance versus time (yr). Since some years exhibited no mature fish at various ages (0 values), natural logarithms were taken of 1 + the year-age number ($\log_e(n_{ij} + 1)$).

Population estimates displayed no trend until a decline became evident subsequent to 1990 (Fig. 2.2.10.2*a*). The minimum biomass estimate was recorded in 1995. Present mature biomass levels are still very low, and have declined slightly since 1999 (Fig. 2.2.10.2*a*; Hunt and Hatt 2001). Research vessel catches are highly variable and show little pattern (Fig. 2.2.10.2*c*). There is some evidence for a slight increase in the RV series since 1998 (Table 2.2.10.1, Fig. 2.2.10.2*c*). Overall, there appears to be little trend in the RV data (Fig. 2.2.10.2*d*). Estimated percent declines depended upon the period used (Table 2.2.10.1, Fig. 2.2.10.2*b*, *d*). Over the past 9 to 24 years, changes in population estimates from SPA have ranged from a 73% decline to a 38% increase. RV survey stratified abundance has shown changes ranging from a 29% decline to an 81% increase over periods of 9 to 16 yr.

Evaluation of causes of decline

Cod have been harvested over Georges Bank since the 1700s, but Canada's role in the fishery was unimportant until the development of a Canadian fishery on the Bank in the 1960s. Total cod landings in the region around Georges Bank (US, Canadian, and distant water fleets) increased from 14 000 t in 1960 to 58 000 t in 1966, but subsequently declined rapidly to 30 000 t in 1976 (Serchuk et al. 1994). In 1977, the US and Canada extended fishery jurisdiction, and thus became the only fleets involved in the Georges Bank fishery. Total cod landings rose from 30 000 t in 1977 to a peak of 71 000 t in 1982. In 1985 the World Court decision regarding delineation of the maritime international boundary in the Georges Bank area constrained Canadian and US fisheries to their respective sides of the boundary. In the following years Canadian catches on the northern section of Georges Bank reached 14 000 t in 1990, but then declined to a low of 1100 t in 1995 (Hunt and Hatt 2001). Since 1995, fishing has been restricted to by-catch only. Industry also imposed self-regulation to avoid overrunning allocations, including directing for haddock in early June and late fall when cod by-catch was low. Also, the Canadian fishery in 5Zej-5Zem has been closed to all vessels from 1 January to mid-June since 1994. US landings showed a similar, if more severe, decline and have been affected by implementation of a closed area in 1993 (Hunt and Hatt 2001).

Estimates of adult (age 3+) biomass changed relatively little from 1978 through the 1980s, and reached a peak of about 45 000 t in 1990 (Hunt and Hatt 2001). Estimates of abundance exhibited more variation, but attained relatively high levels in 1990 (Fig. 2.2.10.2*a*, Fig. 2.2.10.3). Both abundance and biomass declined sharply to reach record lows in the mid-1990s (Fig. 2.2.10.2*a*; Hunt and Hatt 2001). Over the period of 1990 to 1995, abundance of the mature portion of the stock declined by approximately 79%, and mature biomass decreased by about 85%. Recruitment (age 1) has been variable, but has generally declined from 1986 to the present (Fig. 2.2.10.3). The 1997-2000 year-classes appear very weak.

Since the extension of fishery jurisdiction and until the last few years, fishing mortality has been relatively high in both the Canadian section (Hunt and Hatt 2001), and the total area of Georges Bank (e.g. Serchuk et al. 1994). On the Canadian side of the boundary, fishing mortality peaked during the early 1990s, coinciding with the period exhibiting the greatest rate of decline (Hunt and Hatt 2001). Fishing mortality (Fig. 2.2.10.4) increased rapidly between 1989 and 1993, such that the exploitation rate rose to 65%, three and a half times the $F_{0.1}$ reference level (Hunt and Hatt 2001). In 1995, it declined to near the $F_{0.1}$ level, and has remained near $F_{0.1}$ since 1995. The 1998 and 1999 exploitation rates were less than $F_{0.1}$. Thus, fishing mortality was likely an important factor in the decline of this stock.

There is less evidence for the hypothesis of abundance decline caused by an increase in natural mortality. Growth is relatively rapid for cod associated with Georges Bank when compared to other cod populations in the Northwest Atlantic (e.g. Serchuk et al. 1994). Weight at age (a proxy for condition) has shown only slight if any decrease during the period of stock decline. Weights-at-ages for ages 4 and younger in the Canadian RV survey exhibited no trend, but a slight decline in weight-at-age for some older ages is evident (Hunt and Hatt 2001). There is no evidence for an increase in predation.

Evaluation of whether decline has ceased, is reversible, and likely time scales for reversibility

Mature population abundance has increased somewhat from the record lows estimated in the mid-1990s, but is still at a very low level (Fig. 2.2.10.2*a*, Fig. 2.2.10.3). Additionally, substantial errors are associated with the estimates of population abundance at age. Recruitment was poor during the mid-1990s, and very weak from 1997 to 2000 (Hunt and Hatt 2001). The population decline may have halted over the last several years, but it is difficult to determine given the level of uncertainty surrounding abundance estimates. Recovery in abundance by this population in the short-term is highly dependent upon reductions in fishing effort and higher recruitment (Hunt and Hatt 2001).

ToR 3: Area of occupancy and change or fluctuation in spatial distribution

3.1. Introduction/methods applied to all stocks

The objective of this section is to provide information on the geographic distribution of cod stocks in Atlantic Canada, including their current area of occupancy, changes in this area over as long a time as possible, and any evidence that there have been changes in the degree of fragmentation of these populations, or a reduction in the number of meta-population units. The indices of geographic distribution presented here are based on annual bottom-trawl surveys conducted by DFO (Doubleday and Rivard 1981). These surveys follow a stratified-random design, and the indices are constructed based on this design.

Area of occupancy (A_t) was calculated for year t as follows:

$$A_t = \sum_{i=1}^{n} a_i I \quad \text{where } I = \begin{cases} 1 \text{ if } Y_i > 0 \\ 0 \ \text{ otherwise} \end{cases}$$

where n is the number of tows in the survey in year t, Y_i is the number of cod caught in tow i, and a_i is the area of the stratum fished by tow i divided by the number of sites fished in that stratum. In some surveys, repeat tows were made at the same sites. In these cases, a_i is the above quantity divided by the number of tows at the site fished by tow i.

A number of studies have reported relationships between abundance and the distribution of marine fishes. On the basis of optimal foraging considerations, habitat selection has been predicted to be density-dependent , with selectivity declining as density and competition for resources increase (Fretwell and Lucas 1970). Consequently, distribution is expected to expand into marginal habitat as abundance increases, and contract into optimal habitat as abundance decreases (MacCall 1990). This prediction that geographic range will contract as abundance declines has important consequences for species at risk. Vulnerability to exploitation increases as geographic range declines (Paloheimo and Dickie 1964). For example, Rose and Kulka (1999) reported that catch rates for northern cod remained high (or in some fisheries, even increased) as the stock collapsed. This resulted from increasing geographic concentration as the stock declined.

Area of occupancy (as defined above) will decrease as population size decreases even if there is no increase in geographic concentration (Swain and Sinclair 1994). In order to describe changes in geographic concentration, we calculated two additional indices: D_{95}, the minimum area containing 95% of cod (Swain and Sinclair 1994), and the Gini index (Myers and Cadigan 1995).

To calculate D_{95}, we first calculated catch-weighted cumulative distribution functions (cdf) of cod catch:

$$F(c) = \sum_{i=1}^{n} w_i \frac{Y_i}{\overline{Y}} I \text{ where } I = \begin{cases} 1 \text{ if } Y_i \le c \\ 0 \text{ otherwise} \end{cases}$$

where $\overline{Y}$ is the stratified mean catch rate of cod, and w_i is the proportion of the survey area in the stratum fished by tow i divided by the number of sites fished in that stratum. In surveys with repeat sets at the same sites, w_i is the above quantity divided by the number of tows at the site fished by tow i. $F(c)$ provides an estimate of the proportion of cod that occur at a local density of c or less. We evaluated F at intervals of 0.01 and calculated the density c_{05} corresponding to F=0.05. This is the density at or below which the most sparsely distributed 5% of cod are estimated to occur. We estimated the area containing the most sparsely distributed 5% of cod (including areas where no cod were caught) as follows:

$$G(c_{05}) = \sum_{i=1}^{n} a_i I \text{ where } I = \begin{cases} 1 \text{ if } Y_i \le c_{05} \\ 0 \text{ otherwise} \end{cases}$$

Thus, the minimum area containing 95% of cod (D_{95}) is given by

$$D_{95} = a_T - G(c_{05})$$

where a_T is the total survey area.

The Gini index is calculated using Lorenz curves. To construct these curves we calculated the estimated proportion of the population associated with each tow i ($N_i = w_i Y_i / \overline{Y}$) and the proportion of the area associated with each tow (w_i). We sorted the tows by N_i, and accumulated area along the abscissa and abundance along the ordinate. The resulting Lorenz curve becomes more concave as fish distribution becomes more aggregated or concentrated. The Gini index is defined as twice the area between the Lorenz curve and the identity function.

Cod undertake seasonal migrations between spawning, feeding and overwintering grounds. The extent of these migrations varies between stocks. For example, the Gulf of St. Lawrence stocks undertake extensive migrations between summer feeding grounds inside the Gulf and overwintering grounds outside the Gulf, while the Scotian Shelf stocks show less extensive seasonal movements between areas on the Shelf. The indices of distribution described here may not be representative of distributions in seasons not covered by surveys. For example, the southern Gulf is surveyed each September; this survey provides estimates of the area occupied by southern Gulf cod in summer and early fall, but an entirely different area is occupied by these cod in winter. Results may also not be comparable between stocks because of seasonal differences between the surveys. For example, cod are often more aggregated or concentrated during the overwintering period than during the summer feeding season (e.g. Swain et al. 1998). Thus, a stock surveyed in winter may appear to be more concentrated than one surveyed in summer. Similarly, density-dependent changes in distribution might be expected to occur only when cod compete for density-dependent resources like food. In some populations, cod show strong seasonal cycles in feeding, with little feeding occurring over winter (e.g. Schwalme and Chouinard 1999). In such cases, density-dependent range contractions and expansions may be observed if the stock is surveyed in summer but not if it is surveyed in winter.

3.2. Results

3.2.1. Cod in 2GH

Line transect surveys were conducted in 2G and 2H in 1978, 1979 and 1981 (Murphy et al. 1992). Random stratified groundfish surveys were started in 1986. The pre-1986 line transect survey data have subsequently been post-stratified (Murphy et al. 1992) so that some comparisons can be drawn. The survey coverage from 1986 onwards has been very varied, both in terms of years in which there is survey coverage, the time of year in which the survey was carried out (between August and December), and the strata sampled in years when there was a survey. In most years cod has not been the main species of concern and strata have been selected with the objective of providing an index for Greenland halibut.

The coverage is such that the calculation of spatial statistics for 2GH cod surveys are not considered to be valid. Distribution data are plotted for 1981, the year with the highest survey estimate, and for 1996, the highest estimate the Campelen series of data from 1996-99 (Fig. 3.2.1.1). In the 1981 survey cod were quite widely distributed throughout 2GH, with highest densities and biomass in the Makkovik Bank area but also significant quantities in the Hopedale Saddle area, the perimeter of Nain Bank, parts of Okak Bank and across Saglek Bank. In 1996, with the exception of some small fish on the northeastern tip of Saglek Bank and a few small fish in the Hopedale Saddle area, there were very few fish and large areas where no fish at all were encountered.

3.2.2. Cod in 2J3KL

Stratified random bottom trawl survey data are available from fall surveys from 1978 onwards in 2J and 3K and from 1981 onwards in 3L. Spring surveys in 3L are available from 1978 onwards. Surveys in 3L were carried out by a side trawler, RV *A.T. Cameron* between 1971 and 1982. No conversion factors have been developed for these data, consequently the survey series is usually only considered from 1983 onwards. The Campelen Shrimp trawl has been used in all fall surveys from 1995 and in all spring surveys from 1996, replacing the Engel trawl used previously. Engel data have been converted to Campelen equivalent units (Stansbury 1997) to allow comparisons to be made across the time series. While converted data may be reasonably coherent for SPA model calibration in which only the converted mean number per tow is used, some of the spatial distribution statistics discussed below appear to be sensitive to the gear change.

The area survey between 1983 and 2001 has been relatively constant at slightly less than 90 000 square nautical miles or 300 000 km^2. Over this period the design-weighted area of occupancy (DWAO) declined at an increasing rate to a minimum of 82 000 km^2 by 1994 (Fig. 3.2.2.1, top panel), coinciding with the lowest observed population size. This extreme aggregation of the remaining cod during the collapse is clearly shown in Shelton and Lilly (2000) and in the sections describing the RV results in the annual stock assessments available in

DFO research documents. Events thereafter are less clear because of the gear change in 1995. Despite the fact that the new gear is more effective at catching fish than the old gear, the area of occupancy has not returned to 1980s levels.

D_{95} (area over which 95% of the total population by number is distributed) was highest at the start of the series, comprising roughly half the survey area, declined fairly steadily from 1984 to 1991, and then fluctuated with a general increasing trend to the present (Fig. 3.2.2.1, middle panel). It should be noted that this apparent increase represents very few fish. There is no abrupt change in the index coincidental with the change in survey gear in 1995.

The Gini index for 2J3KL cod shows an increasing concentration of fish from 1986 to 1992, followed by an decreasing trend to 1998 (Fig. 3.2.2.1, bottom panel). Subsequently the index has varied without trend. Again, there is no strong indication of a discontinuity caused by the survey change in 1995.

3.2.3. Cod in 3NO

Stratified-random bottom trawl surveys (Stansbury et al. 2001) have been carried out in spring in 3N and 3O since 1971 and 1973 respectively, with the exceptions of 1983 in 3N and 1974 and 1983 in 3O. Surveys from 1971 to 1982 were carried out with the RV *A.T. Cameron* and since 1984 with the RV *Alfred Needler* and the RV *Wilfred Templeman*. Usually only data from 1984 onwards are used as a spring index for this stock due to the lack of conversion data for the *A.T. Cameron*, a side-trawler. Fall surveys have been carried out in 3NO from 1990 onwards using the RV *Templeman* for shallow water sets and the RV *Teleost* for deeper water sets in recent years. Since the fall of 1995 the survey gear changed from the Engel trawl to the Campelen trawl but data collected with the Engel gear have been converted to Campelen units (Stansbury 1997).

The spring survey area has remained almost constant between 1984 and 2000 at about 35 000 square nautical miles or 120 000 km^2. The DWAO for the spring RV survey (Fig. 3.2.3.1, top panel) shows an overall similar pattern to that obtained for 2J3KL cod. There is a steady decline in the index from the start of the series to 1994, followed by a generally increasing trend. The change to the Campelen trawl in the spring of 1996 coincides with rapid increase in the index. The D_{95} index also shows and overall decline from the start of the series to a minimum in 1994, after which it fluctuated with a somewhat increasing trend (middle panel). The Gini index shows roughly the reverse trends seen in the other two indices (bottom panel). Fish became substantially more concentrated from 1990 onwards and although there is some fluctuation in the more recent part of the time series, the concentration has remained comparatively high.

3.2.4. Cod in 3Ps

Stratified-random bottom trawl surveys have been conducted in Subdiv. 3Ps during the winter-spring period by Canada since 1972 and by France for the period 1978-92 (Brattey et al. 2001b). Canadian surveys were carried out with the side-trawler RV *Cameron* between 1972 and 1982 and thereafter with the RV *Templeman* and the RV *Needler*. Canadian RV data from

1983 onwards are usually considered as an index with Engel data converted to Campelen equivalent units (Stansbury 1997).

The survey area has fluctuated somewhat over the time series as a consequence of strata not sampled, but has generally been in the range of 16 500 to 17 500 square nautical miles or 55 000 – 60 000 km^2. The trends in the spatial indices for 3Ps cod are less clear than they are for 2J3KL or 3NO cod and are smaller in amplitude. The area of occupancy reached a minimum of 21 000 km^2 in 1995, approximately 1/3 of the survey area (Fig. 3.2.4.1, top panel). The 1996 value indicates a rapid increase but is suspect because of the change to the Campelen trawl in that year. The D_{95} index shows a variable but declining trend to 1995 and has subsequently been quite variable with no trend (middle panel). There is comparatively little variation in the Gini index compared to 2J3KL and 3NO cod stocks, but there is a gradual rise to a peak in 1994 after which it declines somewhat (bottom panel).

Fish distribution plots from RV survey data for 3Ps cod are provided in the stock assessment research documents (e.g. Brattey et al. 2001b). These plots show that in the spring cod are often quite highly aggregated in a restricted portion of St Pierre Bank and on Burgeo Bank. The fall-winter dragger fishery on St Pierre Bank routinely locates very dense aggregations of cod and has little difficulty filling the quota in a short period of time. The tendency for cod to aggregate, even under declining or low stock size conditions, makes them very vulnerable to fishing mortality.

3.2.5. Cod in 4RS3Pn

The time series used to evaluate the spatial coverage of the stock is based on the August stratified groundfish survey conducted each year since 1990 on the CCGS *Alfred Needler*. A URI shrimp net is used with a 19 mm liner in the cod-end. This is a small time series (11 years). The survey spatial coverage is 94 460 km^2. The stock had already declined significantly prior to the onset of this survey. Previous stock analyses were based on the *Gadus* time series (1978 to 1994, except 1982). This survey was conducted in January and showed wide variations in spatial coverage due to ice cover.

Despite these caveats, there is still a noticeable decline in the area of occupancy (Figure 3.2.5.1). As is the case for other cod stocks, the geographic range (D_{95}, in 1000 km^2) shows a slight decline (Fig. 3.2.5.2). Finally, the Gini index shows a slight increase in concentration for the time period (Fig. 3.2.5.3).

3.2.6. Cod in 4TVn (Nov-Apr)

Indices of geographic distribution for the southern Gulf stock were calculated from data obtained during the September bottom-trawl survey, conducted each year since 1971. Indices were based on the 24 strata (415-439) that have been fished since 1971. These strata cover an area of 70 075 km^2, extending from depths as shallow as 20 m along the coasts of New Brunswick and PEI to depths of 350-400 m along the slope of the Laurentian Channel. Three inshore strata (401-403), fished only since 1984, were not included in these analyses. These strata cover an additional 3124 km^2, though cod are absent from half of this area (stratum 402, in the Northumberland Strait). Virtually the entire southern Gulf stock appears to be contained within the survey area in September. Two very large catches of small cod, set 127 in 1995 and set 126 in 2001, are considered anomalous and have been omitted in these analyses.

The area occupied by southern Gulf cod in September ranged from 53-56 000 km^2 in the mid-1970s to 65-68 000 km^2 in the 1980s (Fig. 3.2.6.1). Area of occupancy declined steadily throughout the 1990s, with values in recent years comparable to the low values in the mid-1970s. The index of geographic range, D_{95}, showed a similar pattern. Geographic range was low in the mid-1970s and expanded as abundance increased in the late 1970s and early 1980s, reaching high values in the early to mid-1980s. Range contracted as abundance declined in the late 1980s and early 1990s. It continued to contract throughout the 1990s even though abundance has changed little since the early 1990s. In recent years, range has contracted to the smallest areas seen in the 31-yr time-series, considerably smaller than even those observed in the mid-1970s in the case of older cod (5$^+$ years). The Gini index indicates a similar pattern, with September distribution least concentrated in the early to mid 1980s and most concentrated in recent years.

Changes in the September distribution of southern Gulf cod conform to the prediction that geographic range should expand as abundance increases and contract as it declines (e.g., MacCall 1990). However, the continued contraction of range in recent years when abundance has remained stable is surprising. Like a number of other fish species (Swain and Benoît 2001), cod have also exhibited an eastward shift in their September distribution in the 1990s (Fig. 3.2.6.2). The fall migration of cod out of the southern Gulf occurs earlier now than in the 1970s, peaking near the end of November in the 1970s and near the beginning of November in recent years (Comeau et al. 2002). Although the entire population appears to be still within the survey area in September, the eastward shift in distribution and increased concentration in recent years could be associated with earlier pre-migratory changes in distribution. On the other hand, the eastward shift in distribution could be related to environmental changes in the 1990s, such as delayed spring migrations due to late ice cover (Sinclair and Currie 1994) or unusually cold bottom waters in western regions of the southern Gulf (Swain 1999). In this case, the earlier migration could be a consequence rather than a cause of these changes in distribution. If the increased concentration of cod in September reflects a change in distribution throughout the summer and early fall feeding season (as opposed to an earlier fall migration), it would indicate that the stock is becoming increasingly vulnerable to exploitation, with an increasing proportion of the stock removed by a unit of fishing effort. Rose and Kulka (1999) suggest that the high catch rates maintained in fisheries for northern cod as the stock collapsed in the early 1990s resulted from a similar “hyperaggregation”.

There is no evidence that there have been changes in the degree of fragmentation of this population, or recent losses in population components. There have been suggestions that there may be western and eastern subcomponents to the southern Gulf stock (Templeman 1962), but there is no strong evidence to support this view. Adaptive phenotypic traits that distinguish southern Gulf cod from other neighbouring cod stocks (e.g. vertebral number, length-at-age) do not differ between eastern and western regions of the southern Gulf (Swain et al. 2001; Sinclair and Fanning 1995). Relatively small but significant differences in otolith elemental composition do occur between cod caught in eastern versus western regions of the southern Gulf (Campana et al. 2000). However, these are environmentally-induced differences and may simply reflect a tendency for individual cod to return to the same grounds in the southern Gulf each year during the feeding season. Nonetheless, the eastward ‘shift’ in cod distribution in the southern Gulf in September in recent years may reflect a change in the relative importance of eastern versus western stock components rather than an eastward shift in the distribution of a homogeneous stock. Fine-scale bathymetric trends in vertebral number and length-at-age of cod in the southern Gulf in September do suggest a surprising degree of spatial structure to this population during the feeding season on the Magdalen Shallows (Swain and Frank 2000; Chouinard and Swain 2001).

3.2.7. Cod in 4Vn (May-Oct)

Indices of geographic distribution for the cod stock in Sydney Bight (NAFO Subdivision 4Vn; Fig. 1.1) were calculated from data obtained during the Canadian research vessel survey conducted in July, and including the years 1970-2001. Indices were based on three strata (440, 441, and 442) that encompass an area of approximately 11 500 km^2. These strata include depths ranging from 20 m to 183 m. The low number of strata and rare catches in one stratum (440) lead to complications in the calculation of the indices. D_{95} values exhibited high variation, and in some years it was not possible to calculate the area occupied by 95 percent of the stock (too few non-zero sets), therefore D_{95} was excluded from the spatial analysis of 4Vn cod. The years 1981 and 1985 were dominated by large, single sets.

The area occupied by all ages of Sydney Bight cod in July ranged from around 4100 to 11 400 km^2, and adult (age 5+) cod covered a range of 3900 to 11 400 km^2 (Fig. 3.2.7.1). Except for a few years, area occupied was fairly constant, given that most catches originated in two strata (441 and 442). No trend is evident in area occupancy for either the mature or total population. The Gini index is highly variable over the time series (Fig. 3.2.7.1). In general, the Gini index indicates that cod may have become somewhat less aggregated during the 1990s, as abundance declined. The occupancy of survey area by Sydney Bight cod is difficult to interpret due to the low number of survey strata. In general, there appears to be little change in area occupancy over the course of the 32 yr time series. Maps of the geographic distribution of survey catches for the first and most recent survey years are provided in Fig. 3.2.7.2*a*,*b*.

There is no evidence of a change in the degree of population fragmentation, or of recent losses of population components. Subdivision 4Vn is a known area of stock mixing. However population structure of these cod, and the degree of separation of cod in 4Vn from adjacent stocks is a focus for current research. Evidence for the existence of a local stock is derived from tagging studies, but no evidence suggests the existence of multiple population components within the management unit.

3.2.8. Cod in 4VsW

Indices of geographic distribution for Eastern Scotian Shelf cod (NAFO Subdivision 4VsW; Fig. 1.1) were calculated from data obtained during the Canadian research vessel survey conducted during July, and including the years 1970-2001. Indices were based on 27 strata (443-469) that include an area of approximately 102 000 km^2. These strata cover depths of 20 m to 275 m.

The area occupied by all ages of Eastern Scotian Shelf cod ranged from approximately 36 700 to 81 600 km^2, and the adult (age 5+) segment of the population covered an area of 30 700 to 72 700 km^2 (Fig. 3.2.8.1). Area of occupancy underwent a slight decline until around 1990, when the rate of decline increased substantially until the mid-1990s. The total population reached a minimum in area occupied in 1997, but has since shown an increase. Age 5+ cod exhibited a minimum area in 1995, and has remained low (Fig. 3.2.8.1). The index of geographic range, D_{95}, underwent a more general decline over the time series for both population segments, and does not exhibit the changes in rate of decline observed in area of occupancy (Fig. 3.2.8.1). Whether this decline has halted is not readily apparent. The Gini index indicates a general increase in concentration over time for both age 5+ cod and the total population, with the trend more apparent in 5+ cod. Maps of the geographic distribution of survey catches for the first and most recent survey years are provided in Fig. 3.2.8.2*a*,*b*.

There is no evidence of a change in the degree of population fragmentation, but evidence does exist for the recent loss of population components, as discussed in section 1.3.8. Cod in the region of the Eastern Scotian Shelf are considered a stock complex comprising several relatively large subpopulations of various sizes associated with offshore banks, together with smaller, coastal subpopulations or spawning locations (Frank et al. 1994). Ichthyoplankton surveys contained evidence of spring spawning on Sable/Western Bank in the early 1980s, but this signal was absent in later surveys conducted during the early 1990s (Frank et al. 1994). This lack of spawning has been attributed to an increase in fishing effort on this particular spawning component (Frank et al. 1994; Fanning et al. 1996; Sinclair 1997). In the mid 1980s, the fishery shifted from a pattern of exploitation that spread effort among resident subpopulations, to a concentration of effort on the Sable/Western Bank subpopulation during the spawning period (Fanning et al. 1996). Frank et al. (1994) concluded that this sharp increase in exploitation of spawning aggregations resulted in a loss of reproductive capacity, as evidenced by the ichthyoplankton surveys, and thus led to the collapse of this population spawning component.

3.2.9. Cod in 4X/5Y

Indices of geographic distribution for Western Scotian Shelf /Bay of Fundy cod (NAFO Subdivision 4X/5Y; Fig. 1.1) were calculated from data obtained during the Canadian summer research vessel survey, including the years 1970-2001. Indices were based on 21 strata (470-495) that include an area of approximately 63 600 km^2. These strata cover depths of 20 m to 275 m.

The area occupied by all ages of cod on the Western Scotian Shelf and in the Bay of Fundy ranged from approximately 36 300 to 52 500 km^2, and adult (age 4+) cod covered an area of 29 500 to 51 600 km^2 (Fig. 3.2.9.1). Area of occupancy for both the 4+ and total populations has been relatively stable from 1990 to 2000. A slight decline is indicated in the area occupied by the age 4+ component, with the lowest area in the most recent year (2000). The same general patterns are indicated in the index of geographic range, D_{95} (Fig. 3.2.7.1). D_{95} for the adult component peaked during the early 1980s, and the total population exhibited no trend. The Gini index does not indicate a trend in concentration over time for either the age 5+ cod or the total population. Annual values exhibited a fair degree of variation. It should be noted that the summer RV survey samples relatively few cod in 4X compared the Eastern Scotian Shelf

(4VsW) (Fig. 2.2.8.2*c*, Fig. 2.2.9.2*c*). Maps of the geographic distribution of survey catches for the first and most recent survey years are provided in Fig. 3.2.9.2*a*,*b*.

There is no evidence of a change in the degree of population fragmentation, or of recent losses of population components. Aggregations associated with spawning areas may have declined in abundance, but no evidence exists for the extirpation of such spawning components. For instance, cod that aggregated in the vicinity of Sambro Head, near Halifax Harbour, were targeted by both a gillnet and trawl fishery (Clark et al. 2000). Catches began to decline in the early 1980s, and the fishery in this area has been almost completely abandoned. However, in recent years fish in spawning condition have been caught in this area. (Clark et al. 2000).

3.2.10. Cod in 5Zej and 5Zem

Indices of geographic distribution for the stock on Georges Bank in 5Zej and 5Zem were calculated from data obtained during the Canadian spring bottom-trawl survey, including the years 1987-2001. Indices were based on 4 strata (5Z1, 5Z2, 5Z3, and 5Z4). Details of survey design and estimation of catch per tow are provided in Hunt et al. (1991), and Hunt and Hatt (2001). These strata cover an area of approximately 16 800 km^2 over the northeastern section of Georges Bank, with depths of 50–100 m.

In general, the majority of the total survey catch (biomass) is sampled from stratum 5Z2 (Hunt and Hatt 2001). The relative contribution to total survey catches in 2001 was lower in 5Z3 and higher in 5Z2 relative to their contributions in 2000. A single set of caught more than 2 t of cod in 2001, and had strong influence on average catch per tow (Hunt and Hatt 2001). In recent years, most of the cod found on Georges Bank has been concentrated in northern area under Canadian jurisdiction. However, cod are free to move across the bank and are harvested on both sides of the international boundary.

The area occupied by cod on Georges Bank in Canadian waters in the spring ranged from about 8000-16 000 km^2, and averaged 13 000 km^2 during the time series (Fig. 3.2.10.1). Since survey catches are dominated by fish aged 3 and older, indices calculated for both the mature portion and total population exhibited similar patterns. Occupancy was greatest around 1990, and while variable, has declined somewhat since then. Area occupied has rebounded recently. The areas occupied during the last two survey years were very close to the long term average. The index of geographic range, D_{95}, showed a similar variability, with a slight overall decline (Fig. 3.2.10.1). D_{95} ranged from about 4700-10 000 km^2, and averaged approximately 7700 km^2 during the time series. Again, the mature population and total population showed similar patterns. The D_{95} values for last two years of the survey are among the lowest for the time series. The Gini index indicates a concentration of catch within the survey area over time, similar to the pattern in D_{95} (Fig. 3.2.10.1). Mature population and total population again show similar patterns. Interpretation of these spatial indices is complicated by the transboundary nature of the population. Further analysis would benefit from collaboration with US fishery managers. Maps of the geographic distribution of survey catches for the first and most recent survey years are provided in Fig. 3.2.10.2*a*,*b*.

There is no evidence of a change in the degree of population fragmentation, or of recent losses of population components.

ToR 4: Small Total Population Size and Decline and Very Small and Restricted

4.1. Introduction/methods applied to all stocks

Under this term of reference the authors were asked to, "Tabulate the best scientific estimates of the number of mature individuals. If there are likely to be fewer than 10 000 mature individuals, summarize trends in numbers of mature individuals over the past 10 years or three generations, and, to the extend possible, causes for the trends." In the determination of population status, COSEWIC considers absolute population abundance against various thresholds, depending on the level of extinction risk (e.g. threatened, endangered).

The applicability of the IUCN thresholds for small population size used by COSEWIC to cod populations may be worthy of discussion. Most of the cod populations reviewed in this document have recently experienced historically low biomass levels, but still likely contain vastly more mature individuals than the limits set by COSEWIC. Secondly, there is debate concerning the dynamics of fish populations reduced to relatively small sizes. Arguments have been proposed for the presence of both compensatory and depensatory dynamics. As an example, there is some evidence to suggest that depensation may play a role in the stock-recruitment dynamics of some fish populations at low abundance, but not in the majority of populations studied (Myers et al. 1995; Liermann and Hilborn 1997). However, even in these few cases, Allee effects were detected at mature population abundances much higher than the abundance levels identified as reference points by COSEWIC. Depensation may be difficult to detect, and thus may not be as rare as previous studies suggest (Shelton and Healey 1999). Recent reviews have investigated the generality of both depensation (Liermann and Hilborn 2001) and compensation (Rose et al. 2001) in the dynamics of marine fish populations.

Given the lack of consensus as to the prevalence of depensatory dynamics, and the current abundance levels exhibited by cod populations in Canadian waters, the following section mainly contains short statements concerning the status of each stock in relation to the minimum abundance of mature individuals set by COSEWIC.

4.2. Evaluation of Small Total Population Size and Decline by management unit

4.2.1. Cod in 2GH

There is no accurate estimate of the current size of the spawner population of 2GH cod but it is thought to be very small.

4.2.2. Cod in 2J3KL

Results from the missing fish model of Shelton and Lilly (2000) extended to the present time indicate a 2J3JL cod spawner population of around 5 million fish. However, while probably providing a reasonable indication of general trends, the model is poorly calibrated in absolute terms for the recent period and this estimate is undoubtedly too low. Acoustic surveys in Smith Sound, Trinity Bay, the location of the last known overwintering aggregation of northern cod, indicate a current biomass of about 25 000 t (G. Rose, Chair of Fisheries Conservation, Memorial University, pers. comm.). Based on a modal age of 5, and a weight at age for 5 year olds of about 1.5 kg, this would indicate a population of about 16 million fish. If about half of these fish were mature, this would indicate a spawner population in Smith Sound of 8 million fish. Tagging estimates for 3K and northern 3L indicate a biomass of commercial size fish of about 40 000 t. Assuming an average weight of 2 kg, this would equate to about 20 million fish, of which perhaps 80% might be expected to be mature, giving about 16 million spawners. While more detailed calculations could be carried out using maturity ogives and length weight relationships from survey data, the above estimates provide a rough quantification for portions of the population which, in the absence of an appropriately calibrated SPA for the whole population, should suffice.

4.2.3. Cod in 3NO

For 3NO cod there is an accepted SPA which provides an estimate of the numbers of spawners. The estimate for 2001 is 1.3 million fish. This is an extremely small number, only about 1/40th of the population at the start of the time series in 1959. The CV's on the population estimates at age are in the range of 30-55%.

4.2.4. Cod in 3Ps

While no single SPA model/formulation is considered to be representative of the abundance and dynamics of 3Ps cod at the present time, it was found in the last assessment that a number of different model/formulations provided similar overall trends and gave risk estimates for a number of biological reference points which were roughly comparable (Brattey et al. 2001b). One of the model/formulations from the 2001 assessment, the "comparison run", uses the identical approach to that applied in the 2000 assessment. The spawner population estimated in the comparison run for the beginning of 2001 is approximately 30 million fish. The CV's on the population estimates at age are in the range of 30-40%.

4.2.5. Cod in 4RS3Pn

Based on the SPA in the most recent assessment of this stock (DFO 2002b), the size of the spawning stock at the beginning of 2002 was estimated as 43 million spawners, with a biomass of 54 thousand t. Based on this analysis, the average for the last decade (1993-2002) was 43 million spawners with an average biomass of 47 thousand t. The CV's on the population estimates at age are all less than 10%.

4.2.6. Cod in 4TVn (Nov-Apr)

Based on the SPA in the most recent assessment of this stock (Chouinard et al. 2002), the size of the spawning stock at the beginning of 2002 was estimated as 76.2 million spawners, with a biomass of 84 500 t. Based on this analysis, the average for the last decade (1993-2002) was

90.5 million spawners with an average biomass of 77 800 t. Coefficients of variation for the population estimates at age are about 10-15% (Table 2.2.6.1).

4.2.7. Cod in 4Vn (May-Oct)

The most recent assessment of population abundance of the 4Vn cod stock includes up to year 2000 (Mohn et al. 2001). The abundance of the total population (ages 1-12) was estimated to be 28 351 000 individuals. An estimate of 1 965 000 individuals was provided for cod aged 5 and older, which are used as a proxy for the adult population. Total and age 5+ abundance averaged 37 906 000 and 7 952 000, respectively, over the 20 year time series. The CV's on the population estimates at age range from approximately 10 to 30%.

4.2.8. Cod in 4VsW

The last regular assessment of cod abundance in this region was performed for the year 1995. Methods for abundance estimation are provided in Fanning et al. (1996). The adult portion of the population is assumed to include cod aged 6 and older. The abundance of this fraction was estimated at 11 046 000 individuals by Fanning et al. (1996). An estimate of 32 622 000 individuals was presented for the segment of the population aged 3 and older. A subsequent assessment was undertaken for the year 1998, in which additional sources of mortality (e.g. seal predation) were included in a population dynamics model (see Mohn et al. 1998). In this assessment the mature abundance was estimated at 4 304 000 individuals, and the total population abundance estimate (ages 1 to 15) of 32 622 000 individuals was presented. The 1997 estimate of mature abundance was lower than the estimate provided for 1995, but still much larger than the limit set by COSEWIC. The bootstrap CV's on the population estimates at age for the model including seal predation range from about 10 to 80% (Mohn et al. 1998).

4.2.9. Cod in 4X/5Y

The most recent assessment of cod in this region was conducted for the year 2000. At this time, population abundance (ages1+) was estimated to be 29 111 000 individuals (Clark et al. 2000). The mature population, which can be assumed conservatively to include individuals aged 4 and older, was estimated to number 7 633 000 individuals. Methods for abundance estimation are provided in Clark et al. (2000). These estimates are several orders of magnitude greater than the reference points set for minimum population size set by COSEWIC. Relative errors (estimate/standard error of estimate) of the population estimates at age range from 0.21-0.58 (Clark et al. 2000).

4.2.10. Cod in 5Zej and 5Zem

The most recent assessment of cod in this region was undertaken for the year 2000. Methods for abundance and error estimation are provided in Hunt and Hatt (2001). Adult biomass (ages 3+) has increased from 1995 to 2001 to an estimate of 19 900 t. This biomass estimate corresponds to an adult abundance of approximately 4 433 000 individuals (Hunt and Hatt 2001). An estimate of 5 767 000 individuals was provided for the total abundance of cod aged 1 and older (Hunt and Hatt 2001). Relative errors (estimate/standard error of estimate) of the population estimates at age range from 0.28-1.01. These abundance estimates are several orders of magnitude greater than the reference points set for minimum population size set by COSEWIC.

Summary

The structure, distribution, and abundance of 10 cod stocks in Atlantic Canada have been reviewed under four terms of reference. Under the first Term of Reference we were asked to evaluate population structure of Atlantic cod in Canada in the context of "evolutionarily significant units". If fish stocks within Canadian waters have been identified correctly, Canadian fishery management units are already defined on a finer scale than potential ESUs. Therefore, under the Terms of Reference for National Assessment Process on Species at Risk Issues, we have reviewed what is known of population structure within current assessment and management units. Only if this review provided evidence of evolutionarily important differences *within* stock boundaries should current stock designations be dropped in favour of new conservation units based on criteria for delineation of potential ESUs. The review did not provide evidence to indicate the existence of ESUs within current management units, therefore all subsequent analyses were undertaken at the level of current unit stocks.

The second Term of Reference examined the degree to which the 10 cod stocks have declined in abundance. Decline was evaluated using a number of analyses carried out upon (1) population abundance estimates derived from sequential population analysis, and (2) research vessel survey indices of abundance. Additional information was considered in the evaluation of the causes for decline and potential for recovery. In some cases, estimated rates of decline depended critically on the time period used in the estimation. For example, survey data on cod in 4TVn indicated an 85% decline using the 1982-2001 period but a 27% increase using the 1972-2001 period. This difference reflected the rapid increase in abundance in this stock to unprecedented levels in the mid 1980s. Several of the other cod stocks also showed substantial population growth in the late 1970s and early 1980s. However, in general all 10 stocks across Atlantic Canada exhibited some level of decline during the available time series of abundance. Populations in most management units demonstrated rapid declines in the late 1980s and early 1990s. Seven stocks underwent collapses that reached at least 90% for some portion of the time periods examined. Two stocks, in management units 4TVn and 5Zej-5Zem, exhibited both declines and increases, depending upon the time interval used in the analysis. By 1994 eight of ten stocks were under a moratorium on directed fishing, and in 1995 the cod fishery on Georges Bank (5Zej-5Zem) was reduced to by-catch only. Only the fishery exploiting the Western Scotian Shelf/Bay of Fundy stock (4X/5Y) escaped these measures.

Overexploitation is considered to be, by far, the main cause of abundance decline in all stocks, although unfavourable environmental conditions affecting recruitment, growth and condition, and increased natural mortality, have also been given consideration. Lack of recovery is variously attributed to low recruitment, high natural mortality (for example through seal predation), low growth rates or body condition, by-catch mortality, unreported fishing and, in those stocks for which the moratorium has ended, directed fishing.

Of the eight cod stocks placed under moratorium, only 3Ps showed a substantial improvement. In 1997/98 directed commercial fisheries reopened on this stock and the 2J3KL, 4Rs3Pn and 4TVn stocks which had shown little or no recovery. Although the TACs on these three stocks are small relative to those in place in the 1980s and early 1990s, the most recent assessments indicate that they are probably unsustainable and have a high risk of causing further depletion of the remaining spawner populations.

Changes in the geographic distribution of cod stocks in Atlantic Canada were examined under the third Term of Reference. Information was provided concerning current area of occupancy, changes in this area over as long a time as possible, and any evidence that there have been changes in the degree of fragmentation of these populations, or a reduction in the number of meta-population units. Indices of geographic distribution were based on annual bottom-trawl surveys conducted by DFO. Three indices were calculated: the area of occupancy, the minimum area occupied by 95% of the stock, and the Gini index of aggregation. Most importantly, cod still occurs throughout the parts of its historic range examined. Unlike the widespread trend in abundance decline, the 10 cod stocks did not exhibit a general pattern or trend in geographic distribution. Most stocks that underwent a large (at least 90%) decline in abundance, also demonstrated at least some decrease in area occupied and a corresponding increase in the degree of aggregation. Several stocks showed little change in occupancy (e.g. 4Vn, 4X/5Y). Interpretation of spatial indices for cod stocks in the Newfoundland and Labrador region (2J3KL, 3NO, 3Ps) was complicated by the change of trawl gear in the RV surveys conducted in these areas. All three stocks exhibited a decrease in area occupied and an increase in the degree of aggregation during the years prior to the gear change. Evidence exists that suggests the loss of a population (spawning) component on the Eastern Scotian Shelf (4VsW). No evidence was presented for an increase in the degree of population fragmentation within management units.

Under the fourth Term of Reference the authors were asked to tabulate the best scientific estimates of the number of mature individuals. If these estimates were less than 10 000 mature individuals, then trends in numbers of mature individuals over the past 10 years or three generations were to be summarized and, to the extent possible, causes for the trends. Population estimates of all cod stocks in Atlantic Canada were at least two orders of magnitude greater than the threshold of 10 000 mature individuals.

Acknowledgements

R.K. Smedbol would like to thank R. Mohn, P. Fanning, D. Clark, and J. Hunt for their discussions and assistance concerning cod stocks in management units 4Vn, 4VsW, 4X/5Y, and 5Zej-5Zem. Peter Shelton would like to thank Don Stansbury for developing the required computer code for calculating spatial statistics from survey data and for providing statistics for Newfoundland region cod stocks. For the section concerning the northern Gulf of St. Lawrence cod stock (3Pn, 4RS), Alain Fréchet wishes to sincerely thank Marthe Bérubé, Guy Moreault, Louis Pageau and Doug Swain for their contribution in data extraction and analysis.

References

Anderson, J.P., Brattey, J., Colbourne, E., Miller, D.S., Porter, S.R, Stevens, C.R. and Wheeler, J.P. 1998. Distribution and abundance of Atlantic cod from the 1997 Division 3KL inshore acoustic survey. DFO Can. Stock. Assess. Sec. Res. Doc. 98/49.

Baird, J.W., Bishop, C.A., Brodie, W.B., and Murphy, E.F. 1992. An assessment of the cod stock in NAFO Divisions 2J3KL. NAFO SCR Doc. 92/18.

Beacham, T.D., Brattey, J., Miller, K.M., Le, K.D., and Withler, R.E. 1999. Population structure of Atlantic cod (*Gadus morhua*) in the Newfoundland and Labrador area based on microsatellite variation. DFO Can. Stock Assess. Sec. Res. Doc. 99/35. 32 p.

Beacham, T.D., Brattey, J., Miller, K.M., Le, K.D., Schulze, A.D. and Withler, R.E. 2000. Population structure of Atlantic cod (*Gadus morhua*) in the Newfoundland and Labrador area determined from genetic variation. Can. Stock. Ass. Sec. Res. Doc. 2000/099.

Beacham, T.D., Brattey, J., Miller, K.M., Le, K.D., and Withler, R.E. 2001. Stock structure of Atlantic cod (*Gadus morhua*) off Newfoundland and Labrador determined from genetic variation. ICES CM 2001/L:17.

Beamish, R.J. 1993. Climate and exceptional fish production off the west coast of North America. Can. J. of Fish. and Aquat. Sci. **50**: 2270-2291.

Bentzen, P., Taggart, C.T., Ruzzante, D.E. and Cook, D. 1996. Microsatellite polymorphism and the population structure of Atlantic cod (*Gadus morhua*) in the northwest Atlantic. Can. J. Fish. Aquat. Sci. **53:** 2706-2721.

Bishop, C.A. and Shelton, P.A. 1997. A narrative of NAFO Div. 2J3KL cod assessments from extension of jurisdiction to moratorium. Can. Tech. Rep. Fish. Aquat. Sci. 2199, 66p.

Brattey, J. 1996. Overview of Atlantic cod (*Gadus morhua*) stock structure in NAFO Subdivision 3Ps. DFO Can. Stock Assess. Sec. Res. Doc. 96/93, 19p.

Brattey, 1999. Stock structure and seasonal migration patterns of Atlantic cod (*Gadus morhua*) based on inshore tagging experiments in Divs. 3KL during 1995-97. DFO Can. Stock. Assess. Sec. Res. Doc. 99/103.

Brattey, J. 2000. Stock structure and seasonal movements of Atlantic cod (*Gadus morhua*) in NAFO Divs. 3KL inferred from recent tagging experiments. DFO Can. Stock. Assess. Sec. Res. Doc. 2000/084.

Brattey, J., Cadigan, N.G., Lilly, G.R., Murphy, E.F., Shelton, P.A., and Stansbury, D.E. 1999a. An assessment of the cod stock in NAFO Subdivision 3Ps. DFO Can. Stock Assess. Sec. Res. Doc. 99/36, 89p.

Brattey, J., Cadigan, N.G., Lilly, G.R., Murphy, E.F., Shelton, P.A., and Stansbury, D.E. 1999b. An assessment of the cod stock in NAFO Subdivision 3Ps in October 1999. DFO Can. Stock Assess. Sec. Res. Doc. 99/161, 106p.

Brattey, J., Cadigan, N.G., Lilly, G.R., Murphy, E.F., Shelton, P.A. and Stansbury D.E. 2000. An assessment of the cod stock in NAFO Subdiv. 3Ps. in October 2000. DFO Can. Stoc. Assess. Sec. Res. Doc. 2000/134, 107p.

Brattey, J., Porter, D., and George, C. 2001a. Stock structure, movements, and exploitation of Atlantic cod (*Gadus morhua*) in NAFO Divs. 2J+3KL based on tagging experiments conducted during 1999-2000. DFO Can. Stock Assess. Sec. Res. Doc. 2001/072.

Brattey, J., Cadigan, N.G., Lilly, G.R., Murphy, E.F., Shelton, P.A., Stansbury, D.E. and Mahe, J.-C. 2001b. An assessment of the cod stock in NAFO Subdiv. 3Ps in October 2001. Can. Stock Assess. Sec. Res. Doc. 2001/099, 148 p.

Campana, S., and Simon, J. 1986. Assessment of the 4X cod fishery in 1985. CAFSAC Res. Doc. 86/35.

Campana, S.E., Chouinard, G.A., Hanson, J.M., Fréchet, A., and Brattey, J. 2000. Otolith elemental fingerprints as biological tracers of fish stocks. Fish. Res. **46**: 343-357.

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

Castonguay, M., Rollet, C., Fréchet, A., Gagnon, P., Gilbert, D., and Brêthes. J.-C. 1999. Distribution changes of Atlantic cod (*Gadus morhua*) in the northern Gulf of St. Lawrence in relation to an oceanic cooling. ICES J. Mar. Sci. **56**: 333-344.

Chouinard G.A. 2000 Report of the Cod Mixing Workshop. CSAS Proceedings series 2000/27.

Chouinard, G.A. and Fréchet, A. 1994. Fluctuations in the cod stocks of the Gulf of St. Lawrence. ICES mar Sci Symp. **198**: 121-139.

Chouinard, G.A., and Swain, D.P. 2001. Bathymetric variation in condition and length-at-age of southern Gulf of St. Lawrence cod in September. ICES CM 2001/ V:06.

Chouinard, G.A., Currie, L., Poirier, G., Swain, D.P., Rondeau, A., Benoit, H., Hurlbut, T. 2002. Assessment of Cod in the Southern Gulf of St. Lawrence, February 2002 /Évaluation du stock de morue du sud du Golfe du St-Laurent, février 2002. CSAS Res. Doc. 2002/020 (in prep).

Clark, D.S., Gavaris, S., and Paul, S.D. 2000. Assessment of cod in Division 4X in 2000. Can. Stock Ass. Sec. Res. Doc. 2000/139.

Comeau, L.A., Campana, S.E. and Chouinard, G.A. 2002. Timing of Atlantic cod (*Gadus morhua* L.) seasonal migrations in the southern Gulf of St. Lawrence: interannual variability and proximate control. ICES J. Mar. Sci. In press.

DFO 2002a. Northern (2J+3KL) cod stock status update. Stock Status Report A2-01 (2002).

DFO 2002b. Northern Gulf of St Lawrence Cod in 2001. DFO – Science, Stock Status Report A4-01 (2002).

Dimmick, W.W., Ghedotti, M.J., Grose, M.J., Maglia, A.M., Meinhardt, D.J., and Pennock, D.S. 1999. The importance of systemiatic biology in defining units of conservation. Conserv. Biol. **13**: 653-660.

Dimmick, W.W., Ghedotti, M.J., Grose, M.J., Maglia, A.M., Meinhardt, D.J., and Pennock, D.S. 2001. The evolutionarily significant unit and adaptive criteria: a response to Young. Conserv. Biol. **15**: 788-790.

Dizon, A.E., Lockyer, C., Perrin, W.F., Demaster, D.P. and Sisson, J. 1992. Rethinking the stock concept: a phylogenetic approach. Conserv. Biol. **6**: 24-36.

Doubleday, W.G. and Rivard, D. [ed.]. 1981. Bottom trawl surveys. Can. Spec. Publ. Fish. Aquat. Sci. **58**: 273 p.

Dutil, J-D., and Lambert, Y. 2000. Natural mortality from poor condition in Atlantic cod (*Gadus morhua*). Can. J. Fish. Aquat. Sci. **57**: 826 - 836

Fanning, L. P., Mohn, R. K., and MacEachern, W. J. 1996. Assessment of 4VsW cod in 1995 with consideration of ecological indicators of stock status. Can. Stock Ass. Sec. Res. Doc. 96/27.

Fleming, A.M. 1960. Age, growth and sexual maturity of cod (*Gadus morhua* L.) in the Newfoundland area, 1947-1950. J. Fish Res. Board Can. **17**: 775-809.

Frank, K.T. and Brickham, D. 2000. Allee effects and compensatory population dynamics within a stock complex. Can. J. Fish. Aquat. Sci. **57**: 513-517.

Frank, K.T., Drinkwater, K.F. and Page, F.H. 1994. Possible causes of recent trends and fluctuations in Scotian Shelf/Gulf of Maine cod stocks. ICES Mar. Sci. Symp. **198**: 110-120.
Fraser, D.J., and Bernatchez, L. 2001. Adaptive evolutionary conservation: towards a unified concept for defining conservation units. Mol. Ecol. **10**: 2741-2752.
Fréchet, A. 1991. A declining cod stock in the Gulf of St. Lawrence: How can we learn from the past? NAFO Sci. Coun. Studies. **16**: 95-102.
Fréchet, A., and P. Gagnon. 1993. Changes in distribution and Failure of the Winter Fixed Gear Cod (*Gadus morhua*) Fishery off Southwestern Newfoundland. NAFO Sci. Coun. Studies **18**: 71-77.
Fretwell, S.D., and Lucas, H.L. 1970. On territorial behavior and other factors influencing habitat distribution in birds. I. Theoretical development. Acta Biotheor. 19: 16-36.
Fu, C., Mohn, R. K., and Fanning, L. P. 2001. Why the Atlantic cod (*Gadus morhua*) stock off eastern Nova Scotia has not recovered. Can. J. Fish. Aquat. Sci. **58**: 1613-1623.
Gascon, D., Aparicio, M., and Mercille, B. 1990. Estimations du melange entre les stocks de morue du Nord du Golfe du Saint Laurent (Divisions 3Pn4RS) et les stocks adjacents (2J3KL, 3Ps, et 4TVn (janvier-avril)) a partir de resultats de marquage CAFSAC research document 90/61; CSCPCA document de recherche 90/61.
Gavaris, S. 1980. Assessment of the cod stock in Divisions 3NO. NAFO SCR Doc., 80/II/24, 6p.
Halliday, R.G. and Pinhorn, A.T. 1990. The delimination of fishing areas in the northwest Atlantic. J. Northw. Atl. Fish. Sci. **10**: 1-51.
Hammill, M.O. and Stenson, G.B. 2002. Estimated consumption of Atlantic cod (*Gadus morhua*) and some other prey by grey seals (*Halichoerus grypus*) and harp seals (*Phoca groenlandica*) in the southern Gulf of St. Lawrence (NAFO zone 4T). CSAS Res. Doc (in prep.).
Hanson, J.M. and Chouinard, G.A. 1992. Evidence that size-selectivity mortality affects growth of Atlantic cod (*Gadus morhua*) in the southern Gulf of St. Lawrence. J. Fish. Biol. **41**: 31-41.
Healey, B. and Stenson, G. 2000. Estimating pup production and population size of the Northwest Atlantic harp seal (*Phoca groenlandica*). NAFO Sci. Coun. Res. Doc. 00/55.
Hunt, J.J. 1989. Status of the Atlantic cod stock on Georges Bank in Unitareas 5Zj and 5Zm, 1978-88. Can. Atl. Fish. Sci. Adv. Com. Res. Doc. 89/47, 26p.
Hunt, J.J. 1995. Rates of sexual maturity for Atlantic cod in NAFO Division 5Ze and catches of juveniles. J. Northw. Atl. Fish. Sci. **18**: 61-75.
Hunt, J.J., Buzeta, M.-I., and Neilson, J.D. 1991. Status of the Atlantic cod stock on Georges Bank in Unit Areas 5Zj and 5Zm, 1978-90. CAFSAC Res. Doc. 91/41, 21p.
Hunt, J.J. and Hatt, B. 2001. Population status of Eastern Georges Bank cod (Unitareas 5Zj,m) for 1978-2001. Can Sci. Adv. Sect. Res. Doc. 2001/070.
Hunt, J.J. and Neilson, J.N.. 1993. Is there a separate stock of Atlantic cod in the Western side of the Bay of Fundy? N. Amer. J. Fish. Mgmt. **13**: 421-436.
Hunt, J.J., Stobo, W.T., and Almeida, F. 1999. Movement of Atlantic cod, *Gadus morhua*, tagged the Gulf of Maine area. Fish. Bull. **97**: 842-860.
Hutchings, J.A. 1994. Temporal variability in estimates of population sustainability for 3NO Atlantic cod from 1959 to 1994. NAFO SCR Doc. 94/2, 5p.
Hutchings, J.A. 2000. Collapse and recovery of marine fishes. Nature (Lond.), **406**: 882-885.

Hutchings, J. A. 2001. Conservation biology of marine fishes: perceptions and caveats regarding assignment of extinction risk. Can. J. Fish. Aquat. Sci. **58**: 108-121.

Hutchings, J.A., and Myers, R.A. 1994. What can be learned from the collapse of a renewable resource? Atlantic cod, Gadus morhua, of Newfoundland and Labrador. Can. J. Fish. Aquat. Sci. **51**: 2126-2146.

Lambert, Y., and Dutil, J-D. 1997. Condition and energy reserves of Atlantic cod (*Gadus morhua*) during the collapse of the northern Gulf of St. Lawrence stock. Can. J. Fish. Aquat. Sci. **54**: 2388-2400.

Lande, R., and Shannon, S. 1996. The role of genetic variation in adaptation and population persistence in a changing environment. Evolution **50**: 434-437.

Lear, W.H. 1986. A further discussion of the stock complex of Atlantic cod (*Gadus morhua)* in NAFO Div. 2J, 3K and 3L. NAFO SCR Doc. 86/118, Serial No. N1245. 18 p.

Liermann, M., and Hilborn, R. 1997. Depensation in fish stocks in a hierarchic Bayesian meta-analysis. Can. J. Fish. Aquatic Sci. **54**: 1976-1984.

Liermann, M. and Hilborn, R. 2001. Depensation: evidence, models and implications. Fish and Fisheries **2**: 33–58.

Lilly, G.R., Shelton, P.A., Brattey, J., Cadigan, N.G., Murphy, E.F., Stansbury, D.E., Davis, M.B and Morgan, M.J. 1998. An assessment of the cod stock in NAFO Divisions 2J+3KL. DFO Can. Stock Assess. Sec. Res. Doc. 98/15, 165 p.

Lilly, G.R., Shelton, P.A., Brattey, J., Cadigan, N.G., Murphy, E.F., and Stansbury, D.E. 1999. An assessment of the cod stock in NAFO Divisions 2J+3KL. DFO Can. Stock Assess. Sec. Res. Doc. 99/42, 165 p.

Lilly, G.R., Shelton, P.A., Brattey, J., Cadigan, N.G., Murphy, E.F., and Stansbury, D.E. 2000. An assessment of the cod stock in NAFO Divisions 2J+3KL. DFO Can. Stock Assess. Sec. Res. Doc. 2000/063, 123 p.

Lilly, G.R., Shelton, P.A., Brattey, J., Cadigan, B.P. Healey, N.G., Murphy, E.F., and Stansbury, D.E. 2001. An assessment of the cod stock in NAFO Divisions 2J+3KL. DFO Can. Stock Assess. Sec. Res. Doc. 2001/044, 148 p.

MacCall, A.D. 1990. Dynamic geography of marine fish populations. Seattle: University of Washington Press, 153p.

Maguire, J.J., Lever, D. and Waite, L. 1983. Assessment of cod in NAFO Division 4T and subdivision 4Vn (Jan.-Apr.) for 1983. CAFSAC Res. Doc. 83/51:38 p.

Martin, D. 1990. Report of the special committee on the conservation and protection of the Gulf of St. Lawrence groundfish stocks. Department of Fisheries and Oceans, Québec, Qué.

Martin, W.R., and Jean, Y. 1964. Winter cod taggings off Cape Breton and on offshore Nova Scotia banks, 1959–1962. J. Fish. Res. Board Can. **21**: 215–238.

McElhany, P., Ruckelshaus, M.H., Ford, M.J., Wainwright, T.C., and Bjorkstedt, E.P. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U.S. Department of Commerce, National Oceanic and Atmospheric Administration Technical Memorandum NMFS-NWFSC-42, 156 p.

McKenzie, R.A. 1940. Nova Scotian autumn cod spawning. J. Fish. Res. Board Can. **5**: 105-120.

McKenzie, R.A. 1956. Atlantic cod tagging off the Southern Canadian mainland. Bull. Fish. Res. Board Can. **105**: 1–93.

McQuinn I. H., Simard Y., Stroud, T.W.F, Beaulieu, J-L., McCallum, B., and Walsh, S. 1999. An adaptive integrated acoustic-trawl survey on Atlantic cod. ICES C.M. 1999/J:11.

Minet. J. P. 1977. Updated results on migrations of the northern Gulf of St. Lawrence cod stock (ICNAF Div. 4R-4S Subdiv. 3Pn) Annu. Meet. Int. Comm. North. Atlant. Fish. 1977. Res. Doc. No. 77/VI/49 Serial No. 5102.

Mohn, R.K., and Bowen, W.D. 1996. Grey seal predation on the eastern Scotian Shelf: modelling the impact on Atlantic cod. Can. J. Fish. Aquat. Sci. **53**: 2722-2738.

Mohn, R.K., Fanning, L.P., and MacEachern, W.J. 1998. Assessment of 4VsW cod in 1997 incorporating additional sources of mortality. Can. Stock Ass. Sec. Res. Doc. 98/78.

Mohn, R.K., Beanlands, D., Black, G.A.P., and Lambert, T. 2001. Assessment of the status of 4Vn cod (May to October) 2000. Can. Sci. Adv. Sec. Res. Doc. 2001/105.

Morgan, J. 2000. Estimating spawning stock biomass in 2J3KL cod using a cohort maturation model and variable sex ratio. DFO Can Stock. Assess. Sec. Res. Doc. 2000/110.

Moritz, C. 1994. Defining 'evolutionarily significant units' for conservation. Trends Ecol. Evol. **9**: 373-375.

Moritz, C., Lavery, S., and Slade, R. 1995. Using allele frequency and phylogeny to define units for conservation and management. *In* Evolution and the aquatic ecosystem: defining unique units in population conservation. *Edited by* J.L. Neilsen, American Fisheries Society Symposium 17, Bethesda, pp. 249-262.

Murphy, EOF., Bishop, C.A. and Baird, J.W. 1992. A review of stock status – 2GH cod. CAFSAC Res. Doc. 92/112, 15p.

Musick, J.A. 1999. Criteria to define extinction risk in marine fish. Fisheries **24**(12): 6-12.

Musick, J.A., Berkeley, S.A., Cailliet, G.M., Camhi, M., Hutsman, G., Nammack, M. and Warren, M.L., Jr. 2000. Protection of marine fish stocks at risk of extinction. Fisheries **25**(3): 6-8.

Myers, R.A., and Cadigan, N.G. 1995. Was an increase in natural mortality responsible for the collapse of northern cod? Can. J. Fish. Aquat. Sci. **52**: 1274-1285.

Myers, R.A., Barrowman, N.J., Hutchings, J.A. and Rosenberg, A.A. 1995. Population dynamics of exploited fish stocks at low population levels. Science **269**: 1106-1108.

Myers, R.A., Hutchings, J.A. and Barrowman, N.J. 1996. Hypotheses for the decline of cod in the North Atlantic. Mar. Ecol. Prog. Ser. **138**: 293-308.

Myers, R.A., Mertz, G. and Fowlow, P.S. 1997. Maximum population growth rates and recovery times for Atlantic cod, *Gadus morhua*. Fish. Bull. **95**: 762-772.

Neigel, J. and Avise, J.C. 1986. Phylogenetic relationships of mitochondrial DNA under various demographic models of speciation. *In* Evolutionary Processes and Theory *Edited by* Nevo, E., Larlin, S. Academic Press, New York, pp. 515-534.

Neilsen, J.L., ed. 1995. *Evolution and the aquatic ecosystem: defining unique units in population conservation*. American Fisheries Society Symposium 17, Bethesda.

Nielsen, G. 1989. An analysis of the day versus night catches of the southern Gulf of St. Lawrence groundfish cruises 1985-1988. CAFSAC Res. Doc. 89/54: 18 p.

Nielsen, G.A. 1994. Comparison of the fishing efficiency of research vessels used in the southern Gulf of St. Lawrence groundfish surveys from 1971 to 1992. Can. Tech. Rep. Fish. Aquat. Sci. 1952: 56 p.

Nielsen, G.A. 1995. Incorporating fixed and repeat sets in the stratified random survey for groundfish in the southern Gulf of St. Lawrence. Can. Tech. Rep. Fish. Aquat. Sci. 2068: 30p.

Nielsen, J.D., and Perley, P. 1996. Can ichthyoplankton data be used to describe spawning areas of marine fish? *In* Report of the second workshop on Scotia-Fundy groundfish management

Edited by Burke, D.L., O'Boyle, R.N., Partington, P., and Sinclair, M., Can. Tech. Rep. Fish. Aquat. Sci. 2100, pp. 147-156.

Ouellet, P. 1997. Characteristics and vertical distribution of Atlantic cod (*Gadus morhua*) eggs in the northern Gulf of St. Lawrence, and the possible effect of cold water temperature on recruitment. Can. J. Fish. Aquat. Sci. **54**: 210-223.

Paloheimo, J.E., and Dickie, L.M.. 1964. Abundance and fishing success. Rapp. P.-V. Reun. Cons. Int. Explor. Mer **155**: 152-163.

Pennock, D.S., and Dimmick, W.W. 1997. Critique of the evolutionarily significant unit as a definition for 'distinct population segments' under the U.S. Endangered Species Act. Conserv. Biol. **11**: 611-619.

Pepin, P., and Carr, S.M. 1993. Morphological, meristic, and genetic analysis of stock structure in juvenile Atlantic cod (*Gadus morhua*) from the Newfoundland Shelf. Can. J. Fish. Aquat. Sci. **50**: 1924-1933.

Rice, J.R. 1997. Proceedings of the workshop on cod stock components, March 3-5, 1997, St. John's, Newfoundland. DFO Can. Stock Ass. Sec. Proc. Ser. 97/05.

Ricker, W. E. 1972. Hereditary and environmental factors affecting certain salmonid populations. *In* The Stock Concept in Pacific Salmon *Edited by* Simon, R.C., and P.A. Larkin, P.A., Vancouver, B.C., University of British Columbia, p. 27-160.

Rivard, D, Shelton, P and Stansbury, S. 1999. Evaluating recovery time from long-term projections including uncertainties: an example for cod on southern Grand Banks (NAFO Divisions 3NO). NAFO SCR Doc. 99/67.

Robichaud, D. and Rose, G.A. 2001. Multiyear homing of Atlantic cod to a spawning ground. Can. J. Fish. Aquat. Sci. **58**: 2325-2329.

Rose, G.A., and Kulka, D.W. 1999. Hyperaggregation of fish and fisheries: how catch-by-unit-effort increased as the northern cod (*Gadus morhua*) declined. Can. J. Fish. Aquat. Sci. **56**(Suppl. 1): 118-127.

Rose, K.A., Cowan, J.A. Jr., Winemiller, K.O., Myers, R.A., and Hilborn, R. 2001. Compensatory density dependence in fish populations: importance, controversy, understanding and prognosis. Fish and Fisheries **2**: 293-327.

Ruzzante, D.E., Taggart, C.T. and Cook, D. 1998. A nuclear DNA basis for shelf- and bank-scale population structure in northwest Atlantic cod (*Gadus morhua*): Labrador to Georges Bank. Mol. Eco. **7**: 1663-1680.

Ruzzante, D.E., Taggart, C.T., and Cook, D. 1999. A review of the evidence for genetic structure of cod (*Gadus morhua*) populations in the NW Atlantic and population affinities of larval cod off Newfoundland and the Gulf of St. Lawrence. Fish. Res. **43**: 79-97.

Ruzzante, D.E., Taggart, C.T., Cook, D. and Goddard, S. 1996. Genetic differentiation between inshore and offshore Atlantic cod (*Gadus morhua* L.) off Newfoundland: microsatellite DNA variation and antifreeze level. Can. J. Fish. Aquat. Sci. **53**: 634-645.

Ruzzante, D.E., Taggart, C.T., Cook, D. and Goddard, S.V. 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**: 2700-2708.

Ruzzante, D.E., Taggart, C.T., Doyle, R.W. and Cook, D. 2001. Stability in the historical pattern of genetic structure of Newfoundland cod (*Gadus morhua*) despite the catastrophic decline in population size from 1964 to 1994. Conserv. Gene. **2**: 257-269.

Ruzzante, D.E., Wroblewski, J.S., Taggart, C.T., Smedbol, R.K., Cook, D. and Goddard, S.V. 2000. Bay-scale population structure in coastal Atlantic cod in Labrador and Newfoundland, Canada. J. Fish Biol. **56**: 431-447.

Ryder, O.A. 1986. Species conservation and systematics: the dilemma of subspecies. Trends Ecol. Evol. **1**: 9-10.

Schwalme, K., and Chouinard, G.A. 1999. Seasonal dynamics in feeding, organ weights, and reproductive maturation of Atlantic cod (*Gadus morhua*) in the southern Gulf of St. Lawrence. ICES J. Mar. Sci. **56**:303-319.

Serchuk, F.M., Grosslein, M.D., Lough, R.G. and Mountain, D.G. 1994. Fishery and enviromental factors affecting trends and fluctuations in the Georges Bank and Gulf of Maine Atlantic cod stocks: an overview. ICES Mar. Sci. Symp. **198**: 77-109.

Serebryakov, V.P. 1967. Cod reproduction in the Northwest Atlantic. Trudy PINRO, 20:205-242. (Fish. Res. Bd. Canada Transl. Ser., No. 1133, 1968).

Shelton, P.A. 1998. A comparison between a fixed and variable fishing mortality control rule used to manage the cod stocks off southern Labrador and the east coast of Newfoundland. Fish. Res. **37**: 275-286.

Shelton, P.A., and Healey, B.P. 1999. Should depensation be dismissed as a possible explanation for the lack of recovery of the northern cod (*Gadus morhua*) stock? Can. J. Fish. Aquat. Sci. **56**: 1521-1524.

Shelton, P.A. and Lilly, G.R. 2000. Interpreting the collapse of the northern cod stock from survey and catch data. Can. J. Fish. Aquat. Sci. **57**: 2230-2239.

Shelton, P.A. and Morgan, M.J. 1994. NAFO Divisions 3NO cod stock – spawner stock biomass and recruitment required for replacement. NAFO SCR Doc. 94/1, 9p.

Shelton P.A., Lilly, G.R. and Colbourne, E. 1999. Patterns in the annual weight increment for Div. 2J+3KL cod and possible prediction for stock projection. J. Northw. Atl. Fish. Sci., **25**: 151-159.

Shelton, P.A., Stansbury, D.E., Murphy, E.F., Brattey, J., and Lilly, G.R. 1996. An assessment of the cod stock in NAFO Subdivision 3Ps. DFO Atl. Fish. Res. Doc. 96/91, 82p.

Sinclair, M. 1997. Recent advances and challenges in fisheries science. *In*: Proceedings of the Gulf of Maine ecosystem dynamics scientific symposium and workshop. RARGOM Report, 97-1 *Edited by* Wallace, G.T., and Braasch, E.F., Hanover, NH. Regional Association for Research on the Gulf of Maine, pp. 193-209.

Sinclair, A.F. 2001. Natural mortality of cod (*Gadus morhua*) in the Southern Gulf of St Lawrence, ICES Journal of Marine Science, **58**:1-10.

Sinclair, A., and Currie, L. 1994. Timing of cod migrations into and out of the Gulf of St. Lawrence based on commercial fisheries, 1986-93. DFO Atl. Fish. Res. Doc. 94/47.

Sinclair, A. and Fanning, P. 1995. Lengths at age of cod in 4T, 4Vn, and 4Vs. p. 88-90 *In* Report of the 4Vn working group on the scientific value of a 4Vn cod (May-Oct) stock assessment. *Edited by* Campana, S., Fanning, P., Fowler, M., Frank, K., Halliday, R., Lambert, T., Mohn, R., Wilson, S., Stobo, W., Hanson, M., and Sinclair, A. DFO Atl. Fish. Res. Doc. 95/16.

Sinclair, A.F., Chouinard, G.A. and Currie, L.G. 1998. Assessment of cod in the southern Gulf of St. Lawrence, January 1998. CSAS Res. Doc. 98/08

Sinclair, A.F., Chouinard, G., Swain, D., Hébert, R., Nielsen, G., Hanson, M., Currie, L. and Hurlbut, T. 1994. Assessment of the fishery for southern Gulf of St. Lawrence cod, May 1994. DFO Atl. Fish. Res. Doc. 94/77, 116p.

Sinclair, A. F., Swain, D.P, and Hanson, J.M. 2001. Disentangling effects of size-selective mortality, temperature and density on length-at-age of Atlantic cod (*Gadus morhua*) in the southern Gulf of St. Lawrence. ICES C.M. 2001/V:6

Smedbol, R.K., and Stephenson, R.L. 2001. The importance of managing within-species diversity in modern fisheries, with examples from the northwestern Atlantic. J. Fish Biol. **59**(Supplement A): 109–128.

Stansbury, D.E. 1997. Conversion factors for cod from comparative fishing trials for Engel 145 otter trawl and the Campelen 1800 shrimp trawl used on research vessels. NAFO SCR Doc. 97/73, 10p.

Stansbury, D.E., Shelton, P.A., Brattey, J., Murphy, E.F., Lilly, G.R., Cadigan, N.G. and Morgan, M.J. 1998. An assessment of the cod stock in NAFO Subdivision 3Ps. Can. Stock Assess. Sec. Res. Doc. 98/19, 92p.

Stansbury, D.E, Shelton, P.A., Murphy, E.F., Healey, B.P. and Brattey, J. 2001. An assessment of the cod stock in NAFO Divisions 3NO. NAFO SCR Doc. 01/72.

Stenson, G.B., M.O. Hammill, and J.W. Lawson, 1997. Predation by harp seals in Atlantic Canada : preliminary consumption estimates for Arctic cod, capelin and Atlantic cod. J. Northwest Atl. Fish. Sci. **22**: 137-154.

Swain, D.P. 1999. Changes in the distribution of Atlantic cod (*Gadus morhua*) in the southern Gulf of St Lawrence -- effects of environmental change or change in environmental preferences? Fish. Oceanogr. **8**: 1-17.

Swain, D.P. and Benoît, H. 2001. Geographic distribution of selected marine fish in September in the southern Gulf of St. Lawrence based on annual bottom-trawl surveys. CSAS Res. Doc. 2001/118.

Swain, D.P. and Chouinard, G.A. 2000. Spawning stock characteristics and cod recruitment success in the southern Gulf of St. Lawrence. CSAS Res. Doc. 2000/148: 14 p.

Swain, D.P., and Frank, K.T. 2000. Depth-dependent vertebral number of Atlantic cod (*Gadus morhua*) on the Magdalen Shallows and Scotian Shelf: stock mixing or microgeographic trends within populations? Can. J. Fish. Aquat. Sci. **57**: 2393-2401.

Swain, D.P., and Sinclair, A.F. 1994. Fish distribution and catchability: what is the appropriate measure of distribution? Can. J. Fish. Aquat. Sci. **51**: 1046-1054.

Swain, D.P. and Sinclair, A.F. 2000. Pelagic fishes and the cod recruitment dilemma in the Northwest Atlantic. Can. J. Fish. Aquat. Sci. **57**: 1321-1325.

Swain, D.P., Chouinard, G.A., Morin, R., and Drinkwater, K.F. 1998. Seasonal variation in the habitat associations of Atlantic cod (*Gadus morhua)* and American plaice (*Hippoglossoides platessoides*) from the southern Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. **55**: 2548-2461.

Swain, D.P., Frank, K.T., and Maillet, G. 2001. Delineating stocks of Atlantic cod (*Gadus morhua*) in the Gulf of St. Lawrence and Cabot Strait areas using vertebral number. ICES J. Mar. Sci. **58**: 253-269.

Swain, D. P., Nielsen, G.A., and McKay, D.E.. 1995. Incorporating depth-dependent differences in fishing efficiency among vessels in the research survey time series for Atlantic cod (*Gadus morhua*) in the southern Gulf of St. Lawrence. Can. MS Rept. Fish. Aquat. Sci. 2317: 20 p.

Swain, D.P., Sinclair, A.F., Castonguay, M., Chouinard, G.A., Drinkwater, K.F., Fanning, L.P., and Clark, D.S. 2002. Density- versus temperature-dependent growth of Atlantic cod (*Gadus morhua*) in the Gulf of St. Lawrence and on the Scotian Shelf. Fish. Res. (in press).

Templeman, W. 1962. Divisions of cod stocks in the Northwest Atlantic. ICNAF redbook III: 79-123.
Templeman, W. 1974. Migration and intermingling of Atlantic cod (*Gadus morhua*) stocks of the Newfoundland area. J. Fish. Res. Board. Can. **31**: 1073-1092.
Templeman, W. 1979. Migration and intermingling of stocks of Atlantic cod, *Gadus morhua*, of the Newfoundland and adjacent areas from tagging in 1962-66. ICNAF Res. Bull. **14**: 5-50.
Templeman, W. 1981. Vertebral Numbers in Atlantic Cod *Gadus morhua*, of the Newfoundland and Adjacent Areas, 1947-71, and their use for delineating cod stocks. J. Northw. Atl. Fish. Sci. **2**: 21-45.
Trippel, E.A., Morgan, M.J., Fréchet, A., Rollet, C., Sinclair, A., Annand, C., Beanlands, D., and Brown, L. 1997. Changes in age and length at sexual maturity of Northwest Atlantic cod, haddock, and pollock stocks, 1972-1995. Can. Tech. Rep. Fish. Aquat. Sci. No. 2157, 120p.
Waples, R.S. 1991. Pacific salmon, *Oncorhynchus* spp., and the definition of "species" under the Endangered Species Act. U.S. Nat. Mar. Fish. Serv. Mar. Fish. Rev. **53**: 11-22.
Waples, R.S. 1995. Evolutionarily significant units and the conservation of biological diversity under the Endangered Species Act. *In* Evolution and the aquatic ecosystem: defining unique units in population conservation. *Edited by* J.L. Neilsen, American Fisheries Society Symposium 17, Bethesda, pp. 8-27.
Waples, R. 1998. Separating the wheat from the chaff: patterns of genetic differentiation in high gene flow species. J. Hered. **89**: 438-450.
Ward, R.D., Woodwark, M. and Skibinski, D.O.F. 1994. A comparison of genetic diversity levels in marine, freshwater and anadromous fishes. J. Fish Biol. **44**: 213-232.
Wise, J.P. 1963. Cod groups in the New England area. U.S. Fish. Wild. Serv. Fish. Bull. **63**: 189-203.
Young, K.A. 2001. Defining units of conservation for intraspecific biodiversity: reply to Dimmick et al. Conserv. Biol. **15**: 784-787.
Younger, A., Healey, K., Sinclair, M., and Trippel, E. 1996. Fisheries knowledge of spawning locations on the Scotian Shelf. *In* Report of the second workshop on Scotia-Fundy groundfish management. *Edited by* Burke, D.L., O'Boyle, R.N., Partington, P., and Sinclair, M., Can. Tech. Rep. Fish. Aquat. Sci. 2100, pp. 147-156.

Table 2.2.2.1. Calculation of a range of decline rates for 2J3KL cod. Mean age refers to mean age of spawners. Years refers to the number of years for which data are available. The %Rate is computed over all the years indicated under the Period column and %Rate 3x is the equivalent decline rate over 3 generations. SPA S and RV S refer to the spawner population, whereas 2+ refers to the total population aged 2 years and older.

Percentage decline rates - 2J3KL Cod

Data	Period	Mean age	Years	% Rate	% Rate3x
SPA 2+	1962-2001	7	39	99.45	93.92
SPA 2+	1962-1977	7	15	79.36	89.03
SPA S	1962-2001	7	39	99.30	93.06
SPA S	1962-1977	7	15	87.10	94.32
SPA S	1977-1994	6	17	64.61	66.71
SPA S	1992-2001	6	9	88.41	98.66
RV S	1983-2001	6	18	99.73	99.73

Table 2.2.3.1. Calculation of a range of decline rates for 3NO cod. Mean age refers to mean age of spawners. Years refers to the number of years for which data are available. The %Rate is computed over all the years indicated under the Period column and %Rate 3x is the equivalent decline rate over 3 generations. SPA S and RV S refer to the spawner population, whereas 2+ refers to the total population aged 2 years and older.

Percentage decline rates - 3NO cod

Data	Period	Mean Age	Years	% Rate	% Rate 3x
SPA 2+	1959-2001	7	42	98.91	89.54
SPA S	1959-2001	7	42	95.02	77.67
SPA S	1965-1977	7	12	89.29	98.00
SPA S	1981-2001	6	20	96.62	97.15
RV S	1984-2001	6	17	90.46	91.69

Table 2.2.4.1. Calculation of a range of decline rates for 3Ps cod. Mean age refers to mean age of spawners. Years refers to the number of years for which data are available. The %Rate is computed over all the years indicated under the Period column and %Rate 3x is the equivalent decline rate over 3 generations. Analysis of spawner population is based on both the QLSPA and the ADAPT model approaches. SPA S and RV S refer to the spawner population, whereas 2+ refers to the total population aged 2 years and older.

Percentage decline rates - 3Ps cod

Model	Data	Period	Mean Age	Years	% Rate	%Rate 3x
QLSPA	SPA 2+	1959-1998	7	39	64.65	42.88
QLSPA	SPA S	1959-2001	7	42	0.00	0.00
ADAPT	SPA S	1959-2001	7	42	47.24	27.37
	RV S	1983-2001	7	18	-15.44	-18.24

Table 2.2.5.1. Calculation of a range of decline rates for 3Pn, 4RS cod. Mean age refers to mean age of spawners. Years refers to the number of years for which data are available. The %Rate is computed over all the years indicated under the Period column and %Rate 3x is the equivalent decline rate over 3 generations. SPA S and RV S refer to the spawner population, whereas 3+ refers to the total population aged 3 years and older.

Percentage decline rates - 3Pn, 4RS Cod

Data	Period	Mean age	Years	% Rate	% Rate3x
SPA 3+	1974-2002	6	29	92.47	81.04
SPA 3+	1974-1994	6	20	81.53	78.13
SPA S	1974-2002	6	28	89.78	76.92
SPA S	1974-1994	6	20	85.47	82.38
RV 3+	1990-2001	5	12	49.02	56.93

Table 2.2.6.1. Abundance estimates (thousands) from the SPA given in Chouinard et al. (2002). Further details are given in their Table 20. (Codes: e.g. Pop 2002 = population estimates at the beginning of the year 2002).

Parameter	Age	Estimate	Standard Error	Relative Error	Bias	Relative Bias
Pop 1999	15	121	23	0.19	2	0.02
Pop 2000	15	161	23	0.14	1	0.01
Pop 2001	15	287	36	0.13	2	0.01
Pop 2002	3	18200	4530	0.25	570	0.03
Pop 2002	4	28800	4810	0.17	413	0.01
Pop 2002	5	24000	3270	0.14	232	0.01
Pop 2002	6	17800	2030	0.11	121	0.01
Pop 2002	7	13000	1360	0.10	72	0.01
Pop 2002	8	6610	662	0.10	32	0.01
Pop 2002	9	3490	340	0.10	15	0.00
Pop 2002	10	2850	286	0.10	12	0.00
Pop 2002	11	1660	164	0.10	6	0.00
Pop 2002	12	1160	126	0.11	5	0.00
Pop 2002	13	766	85	0.11	3	0.00
Pop 2002	14	849	96	0.11	4	0.01
Pop 2002	15	510	58	0.11	3	0.01

Table 2.2.6.2. Rates of decline in spawning stock abundance for the southern Gulf of St. Lawrence cod stock (NAFO Div. 4T-Vn (Nov-Apr)). Slopes are from the linear regression of $\log_e$ abundance versus time (yr). Percent declines are for the indicated time period. Negative values indicate an increase in abundance.

	SPA			survey		
Period (yr)		slope	%decline		slope	%decline
15	1988-2002	-0.0820	70.8	1987-2001	-0.099	77.3
17	1986-2002	-0.1040	82.9	1985-2001	-0.112	85.1
20	1983-2002	-0.1000	86.5	1982-2001	-0.095	85.0
30	1973-2002	-0.0140	34.3	1972-2001	0.008	-27.1
52	1950-2002	-0.0084	35.4			

Table 2.2.7.1. Rates of decline in spawning stock abundance for the Sydney Bight cod stock (NAFO Div. 4Vn (May-Oct)). Slopes are from the linear regression of $\log_e$ abundance versus time (yr). Percent declines are for the indicated time period.

	SPA			Research vessel survey		
Period (yr)		slope	%decline		slope	%decline
15	1986-2000	-0.162	91.2	1986-2001	-0.153	89.9
18	1983-2000	-0.171	95.4	1983-2001	-0.144	92.5
20	1981-2000	-0.155	95.5	1981-2001	-0.112	89.4
32				1970-2001	-0.007	20.1

Table 2.2.8.1. Rates of decline in spawning stock abundance for the Eastern Scotian Shelf cod stock (NAFO Div. 4VsW). Slopes are from the linear regression of $\log_e$ abundance versus time (yr). Percent declines are for the indicated time period.

	SPA			Research vessel survey		
Period (yr)		slope	%decline		slope	%decline
13	1985-1997	-0.289	97.7	1988-2000	-0.194	91.9
16	1982-1997	-0.224	97.2	1985-2000	-0.191	95.3
18	1980-1997	-0.180	96.0	1983-2000	-0.187	96.5
25	1973-1997	-0.069	82.0	1976-2000	-0.086	88.3
28	1970-1997	-0.059	80.8	1973-2000	-0.053	77.6
31				1970-2000	-0.038	68.7

Table 2.2.9.1. Rates of decline in spawning stock abundance for the Scotian Shelf/Bay of Fundy cod stock (NAFO Div. 4X/5Y). Slopes are from the linear regression of $\log_e$ abundance versus time (yr). Percent declines are for the indicated time period.

	VPA			Research vessel survey		
Period (yr)		slope	%decline		slope	%decline
11	1992-2000.5	-0.040	35.7	1991-2001	-0.049	41.6
13	1990-2000.5	-0.068	58.7	1989-2001	-0.048	46.5
15	1988-2000.5	-0.071	65.5	1987-2001	-0.030	35.9
23	1980-2000.5	-0.060	74.6	1997-2001	-0.030	48.8
32	1971-2000.5	-0.039	71.0	1970-2001	-0.023	52.0
55	1948-2000.5	-0.016	59.4			

Table 2.2.10.1. Rates of decline in spawning stock abundance for the Georges Bank cod stock (NAFO Unitareas 5Zej and 5Zem). Slopes are from the linear regression of $\log_e$ abundance versus time (yr). Percent declines are for the indicated time period. Negative decline values indicate an increase in abundance.

	SPA			Research vessel survey		
Period (yr)		slope	%decline		slope	%decline
9	1993-2001	0.036	-38.3	1994-2002	0.066	-80.9
11	1991-2001	-0.029	27.4	1990-2002	-0.026	24.6
15	1987-2001	-0.077	68.4	1988-2002	-0.022	28.9
16	1986-2001	-0.082	72.9	1987-2002	0.0001	-0.20
21	1981-2001	-0.063	73.3			
24	1978-2001	-0.055	73.6			

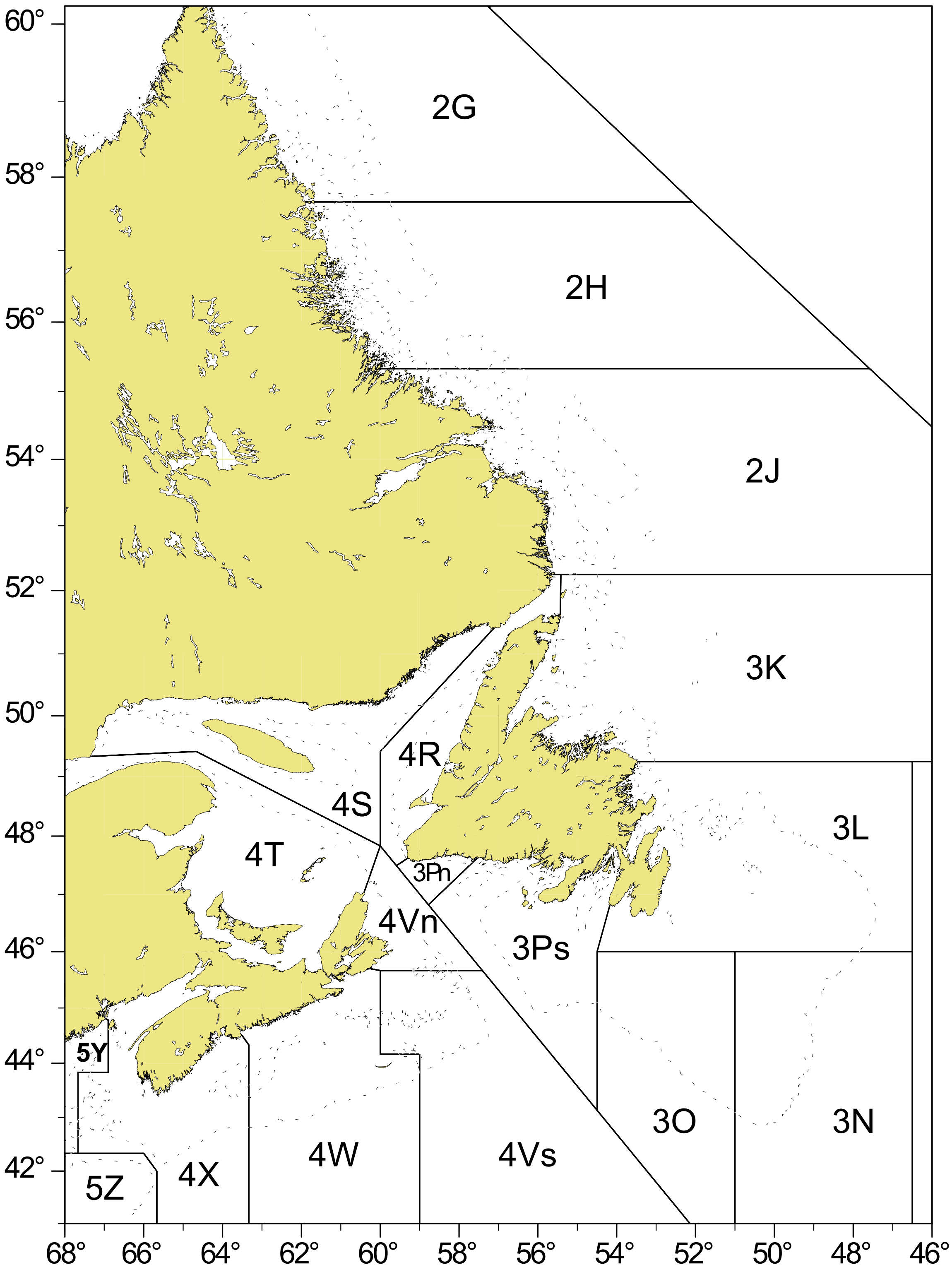


Figure 1.1. Bathymetric chart of the northwest Atlantic, presenting Northwest Atlantic Fisheries Organization (NAFO) management units along eastern Canada. Boundary of NAFO fishing areas, ——; 200 m isobath, – – –.

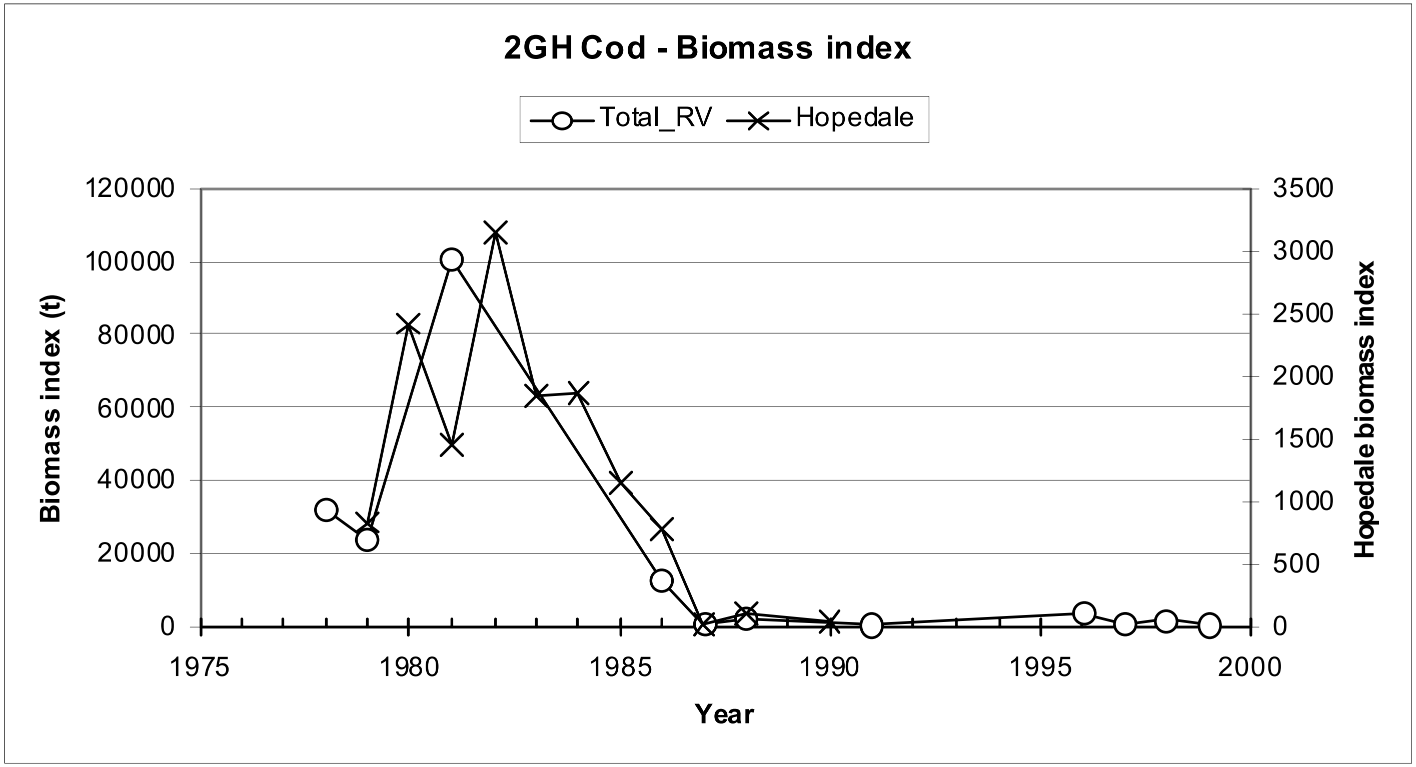


Figure 2.2.1.1. Comparison of research vessel survey biomass index and shrimp survey biomass index for 2GH cod.

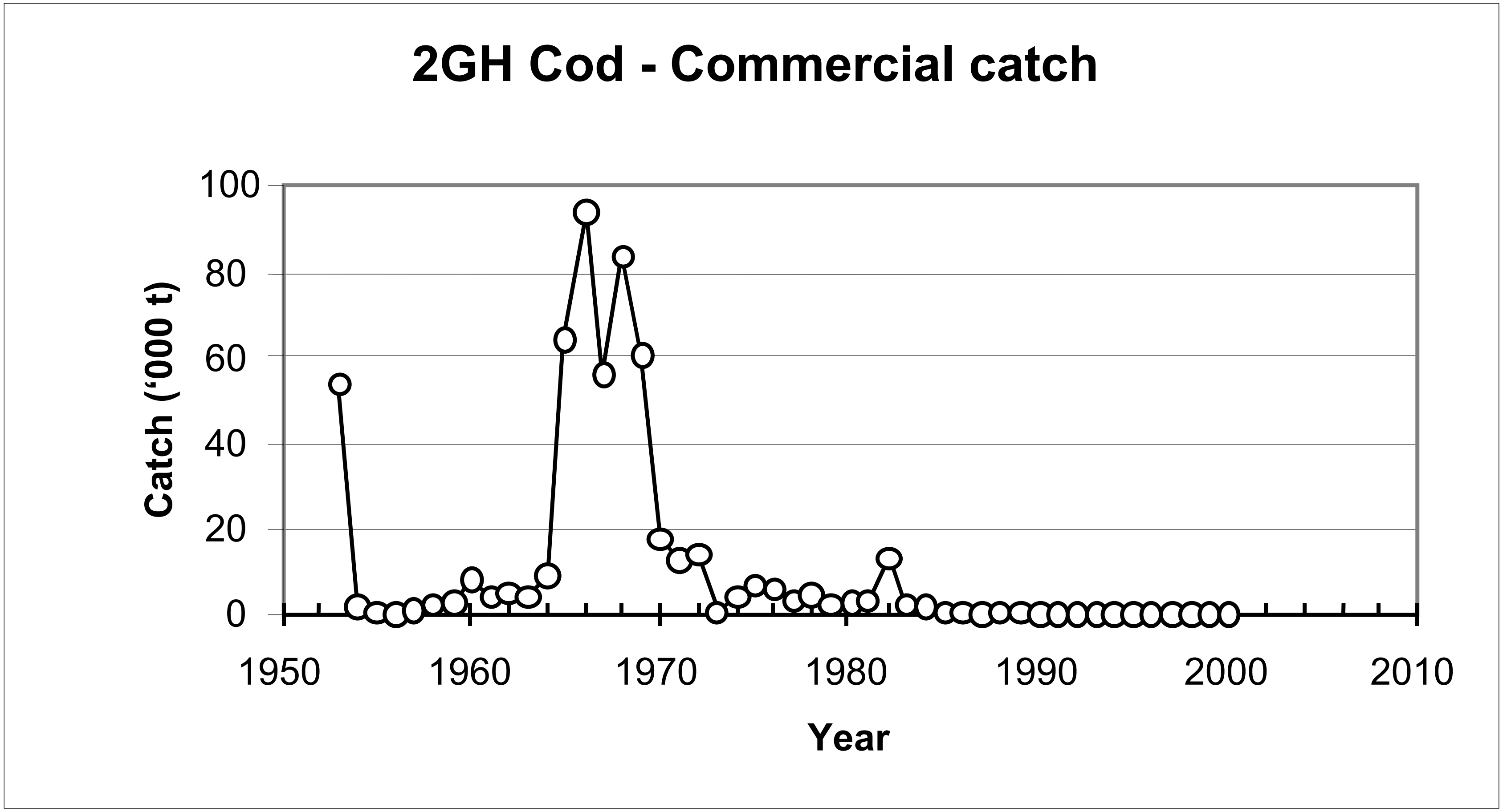


Figure 2.2.1.2. Commercial catch data for 2GH cod.

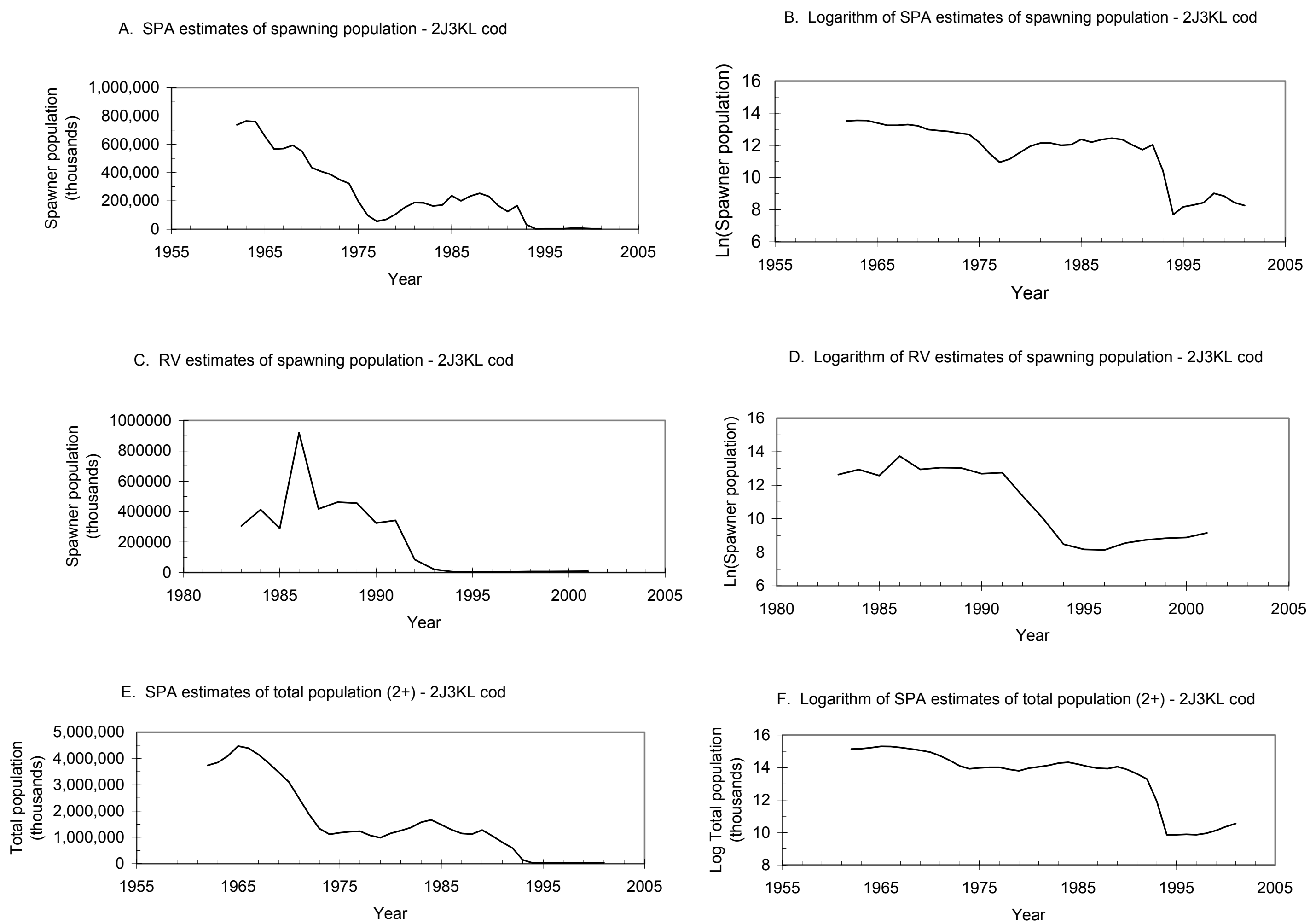


Figure 2.2.2.1. Estimates of spawner population size, mature population index and total population of 2J3KL cod.

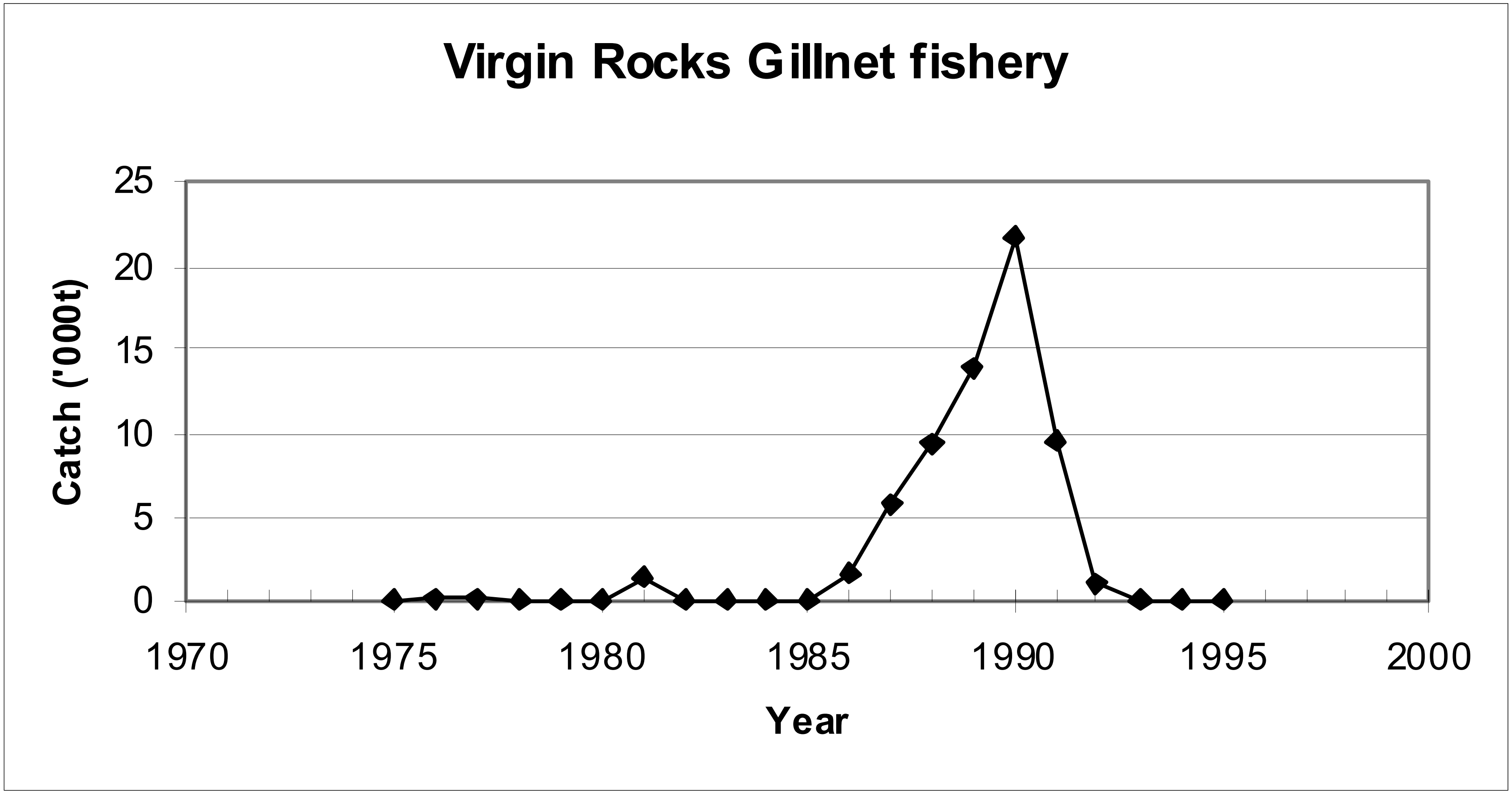
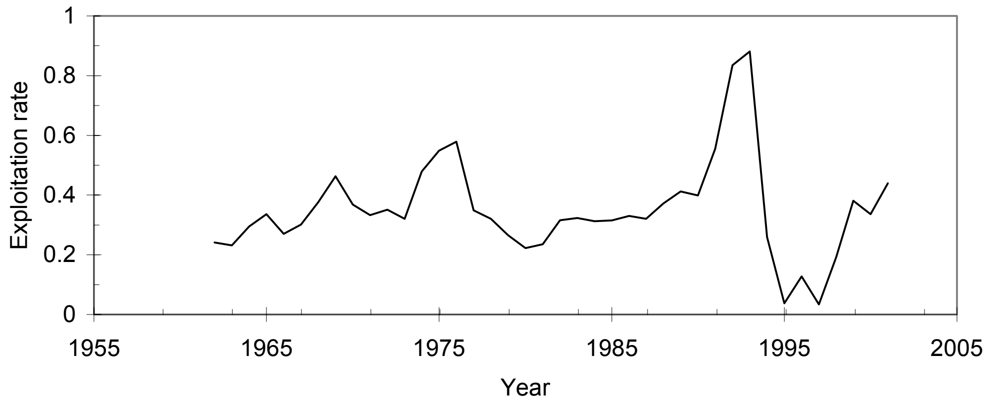
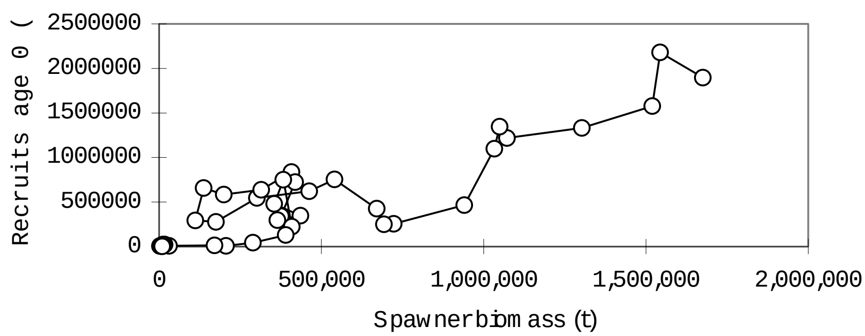


Figure 2.2.2.2. Catch data for the Virgin Rocks cod fishery in 3L.

Exploitation rate - 2J3KL Cod



Spawner-Recruit - 2J3KL Cod



Exploitation rate versus spawner biomass - 2J3KL Cod

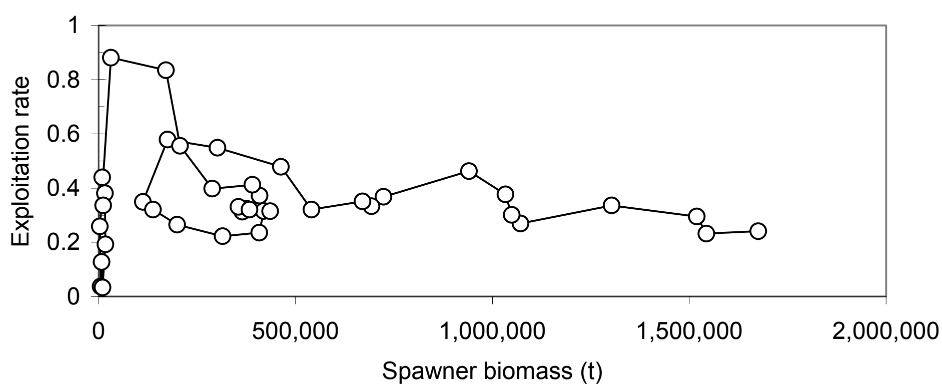


Figure 2.2.2.3. Summary graphs of the exploitation rate and stock-recruit data for 2J3KL cod over the period 1962 to 2001. Estimates are from the missing fish model.

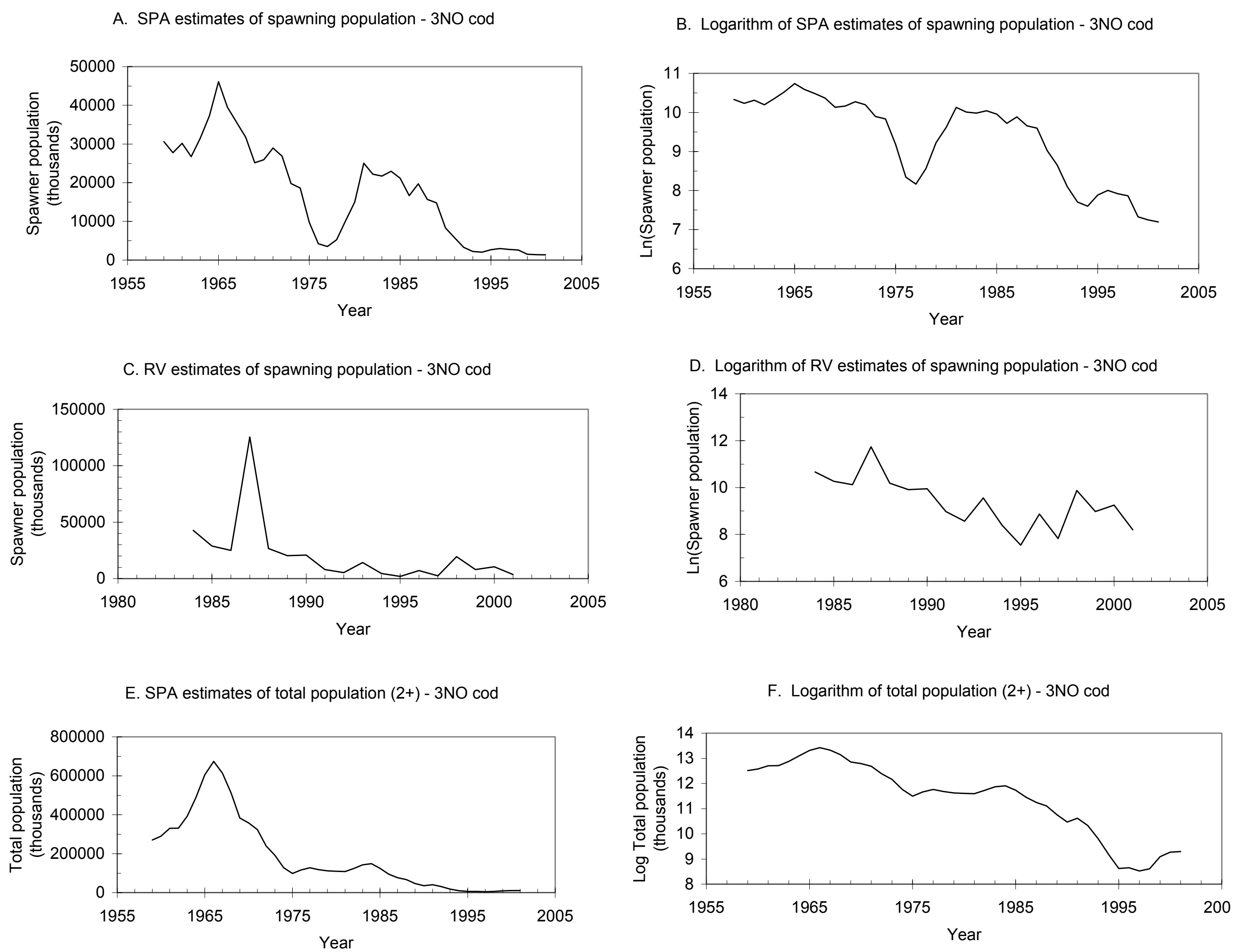


Figure 2.2.3.1. Estimates of spawner population size, mature population index and total population of 3NO cod.

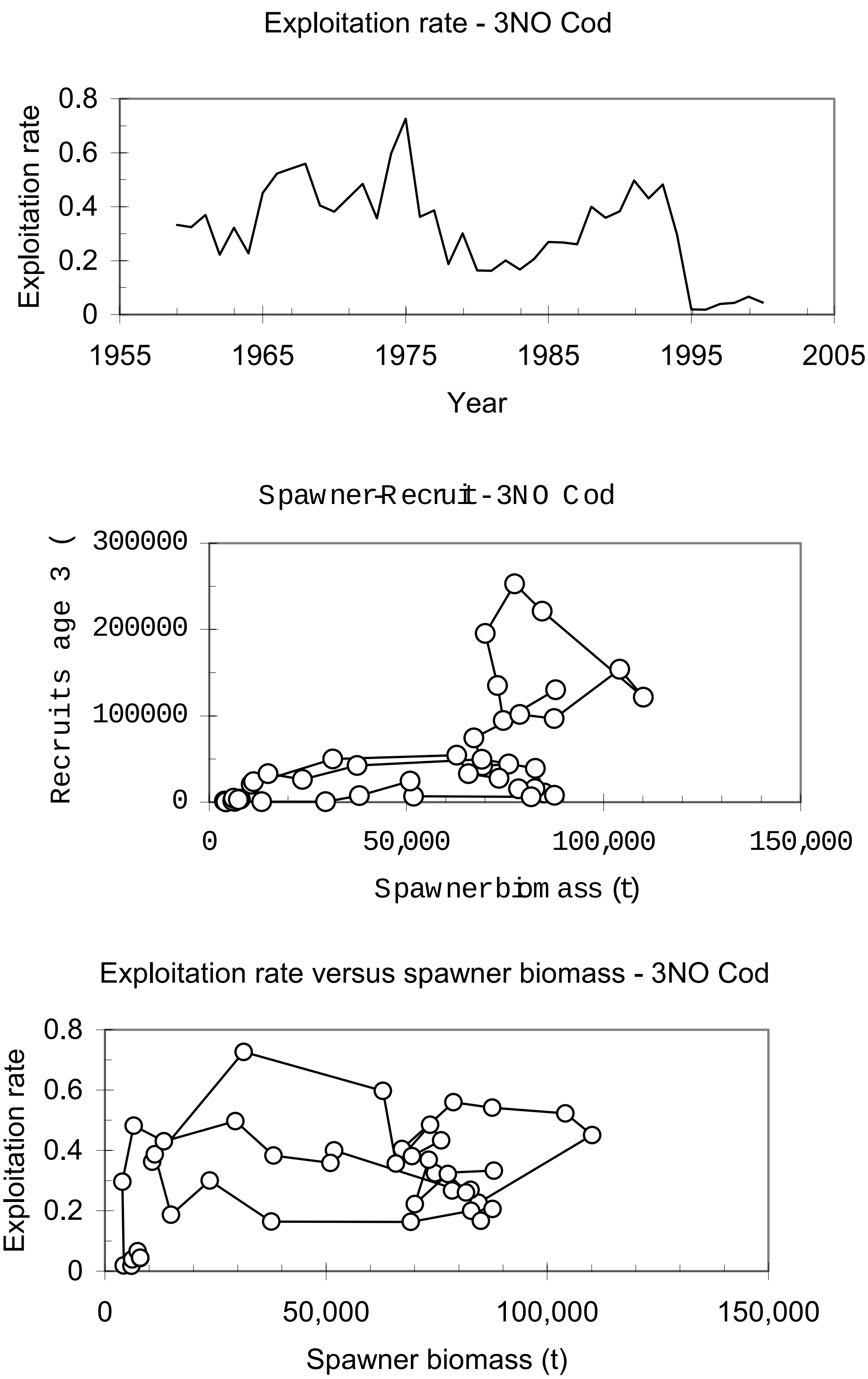


Figure 2.2.3.2. Summary graphs of the exploitation rate and stock-recruit estimates for 3NO cod over the period 1959 to 2000.

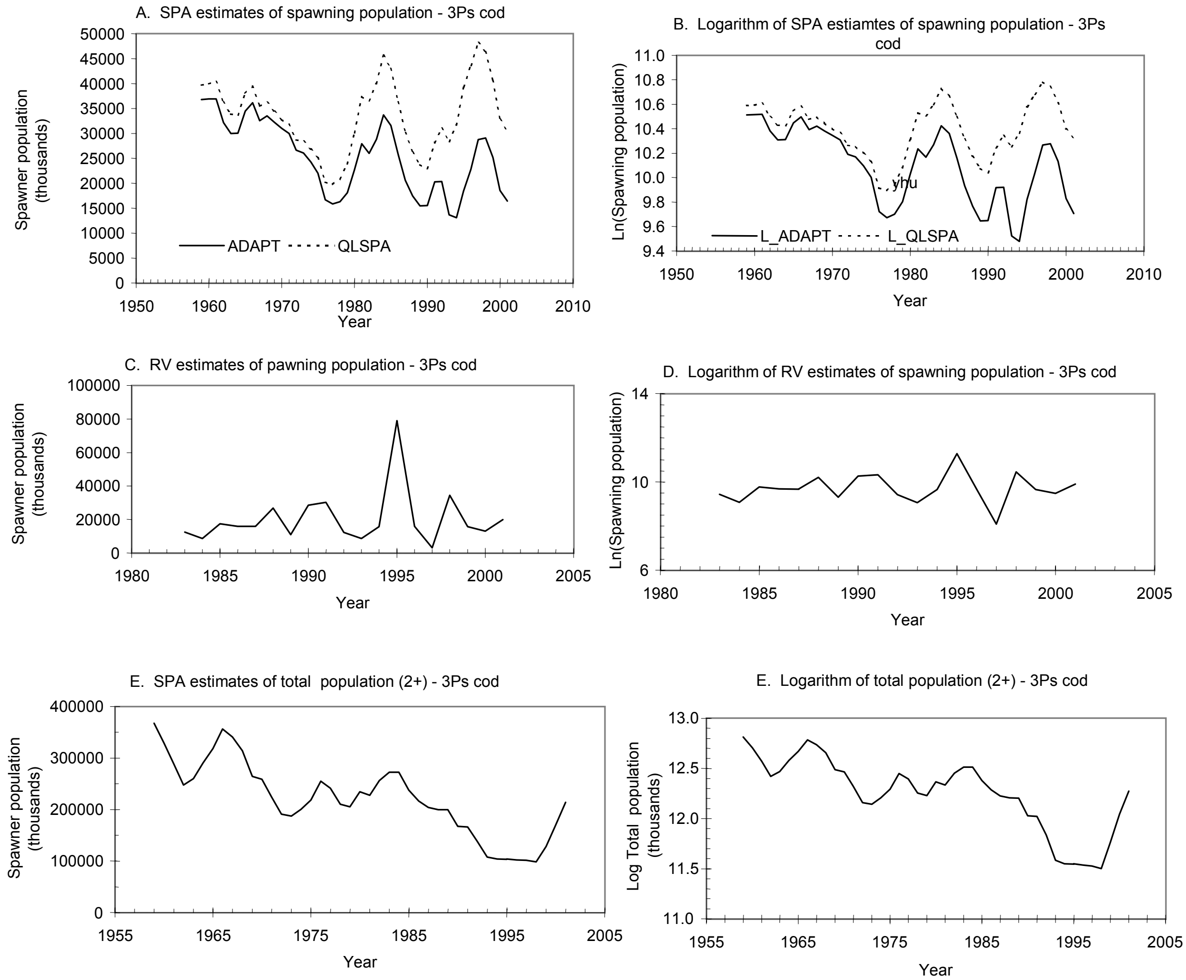


Figure 2.2.4.1. Estimates of spawner population size, mature population index and total population of 3Ps cod. Panels A and B provide estimates from both the ADAPT and QLSPA models/formulations. Panels E and F show QLSPA estimates.

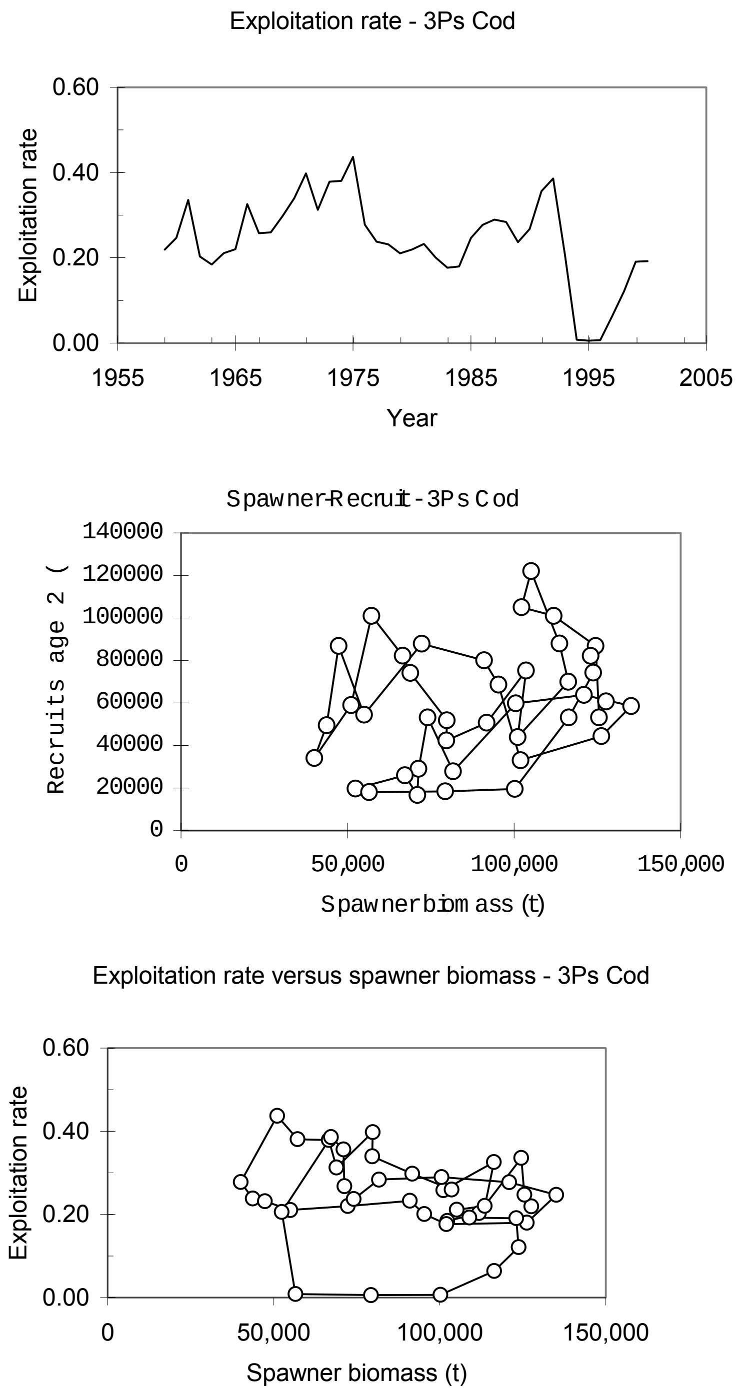


Figure 2.2.4.2. Summary plots of the exploitation rate and spawner-recruit estimates for 3Ps cod over the period 1959 to 2000.

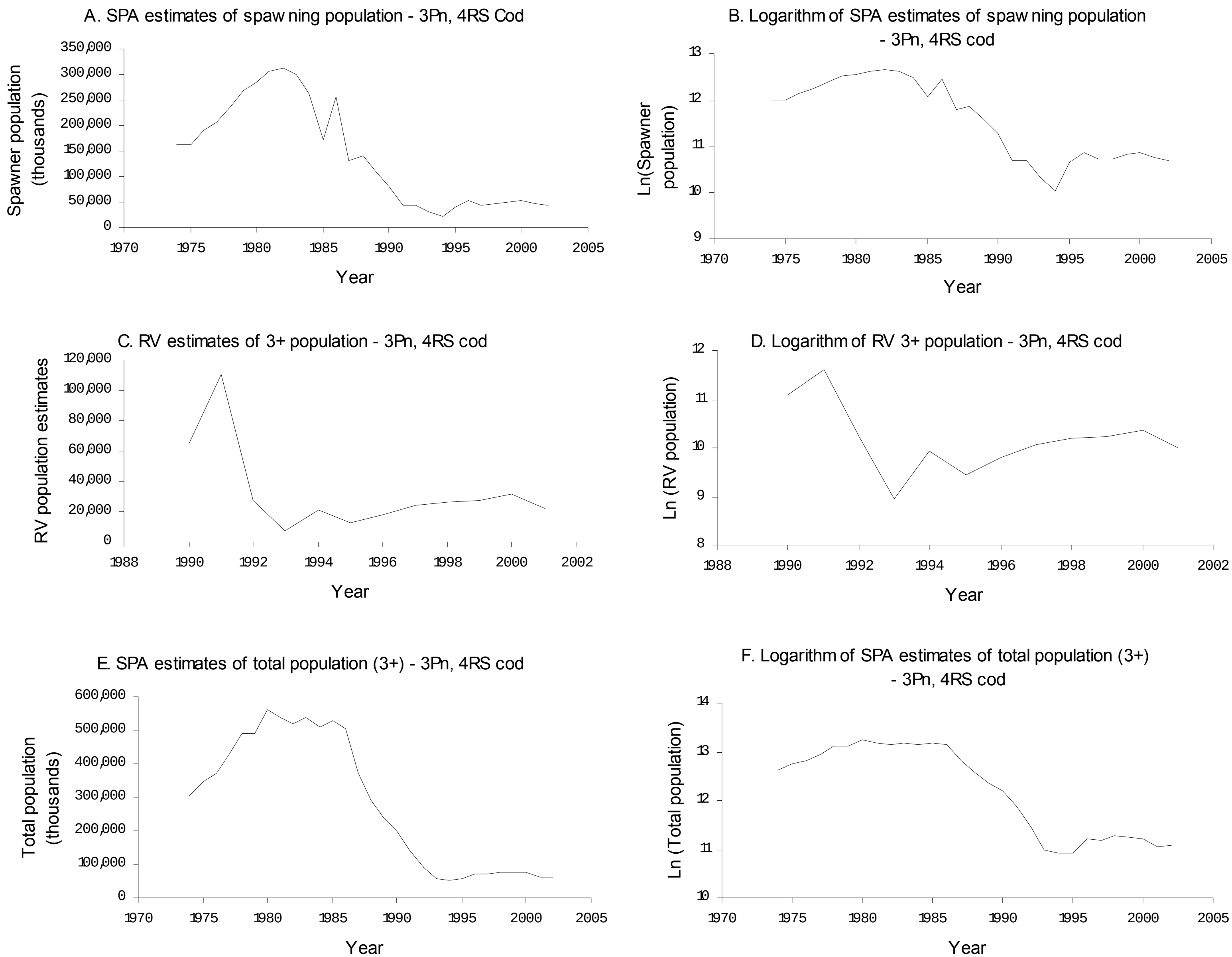


Figure 2.2.5.1. Estimates of spawner population size, 3+ population index and 3+ population of 3Pn, 4RS cod.

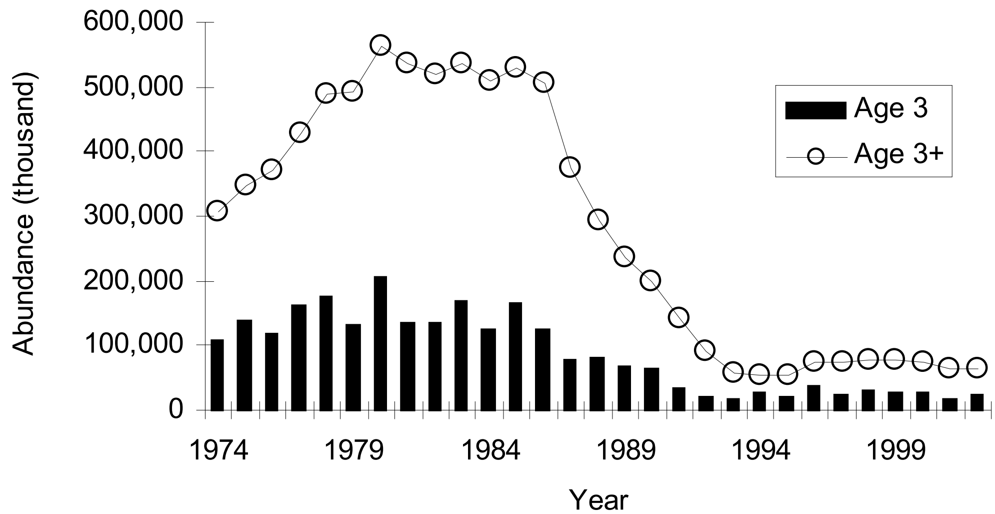


Figure 2.2.5.2. Trends in population abundance (age 3+) and recruitment (age 3) for the northern Gulf of St. Lawrence cod, based on SPA estimates.

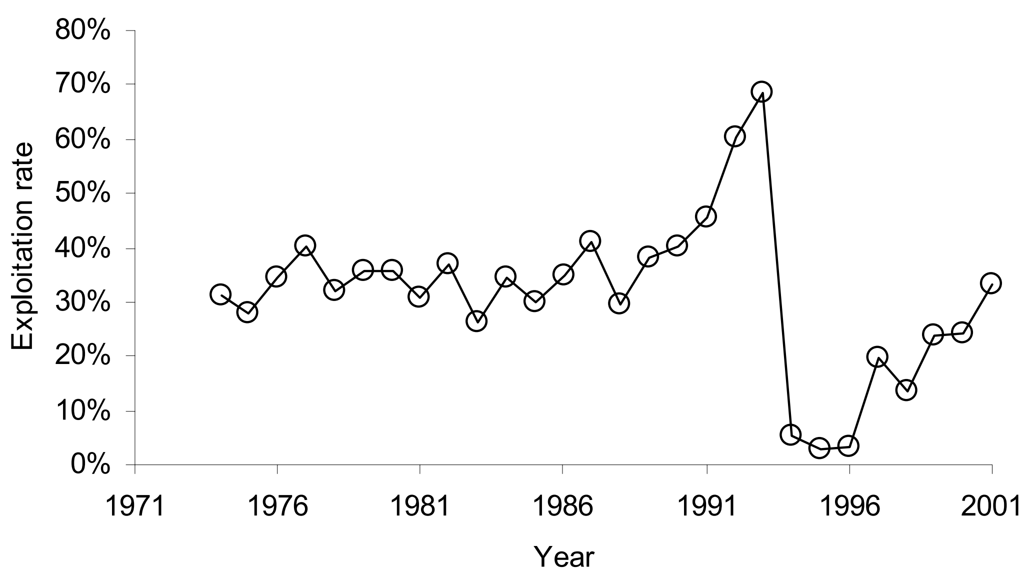


Figure 2.2.5.3. Exploitation rates of northern Gulf of St. Lawrence cod aged 7 and older based on SPA results.

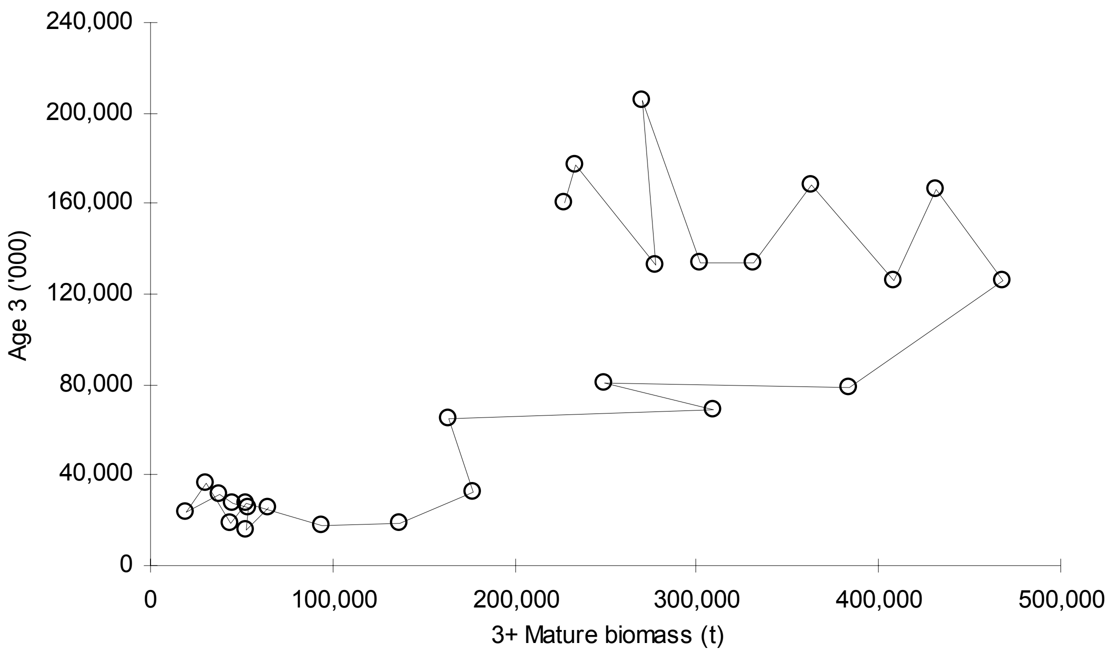


Figure 2.2.5.4. Recruits versus spawning biomass for the northern Gulf of St. Lawrence cod stock.

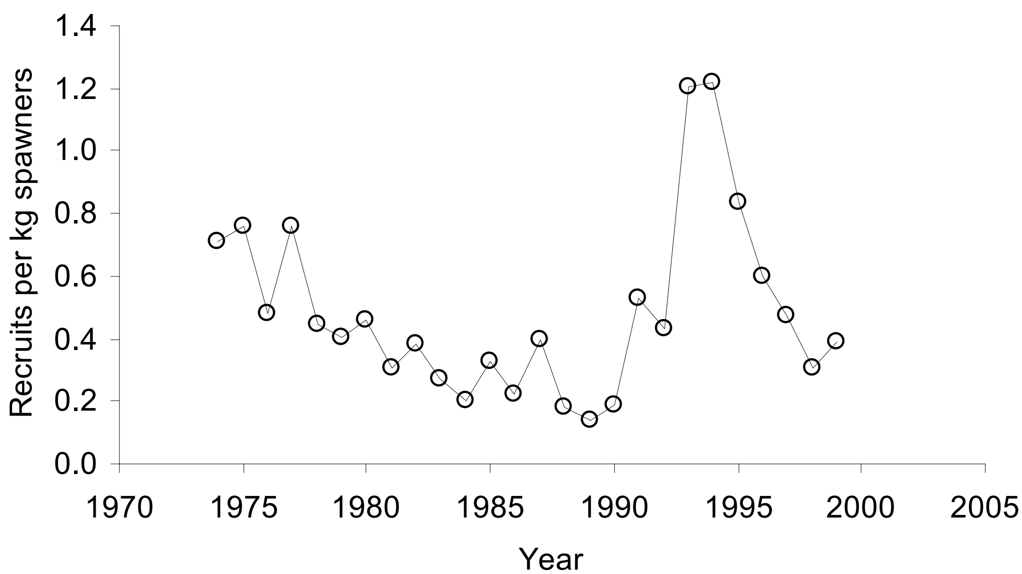


Figure 2.2.5.5. Trend in recruitment rate (# of recruits / spawning stock biomass) for the northern Gulf of St. Lawrence cod stock.

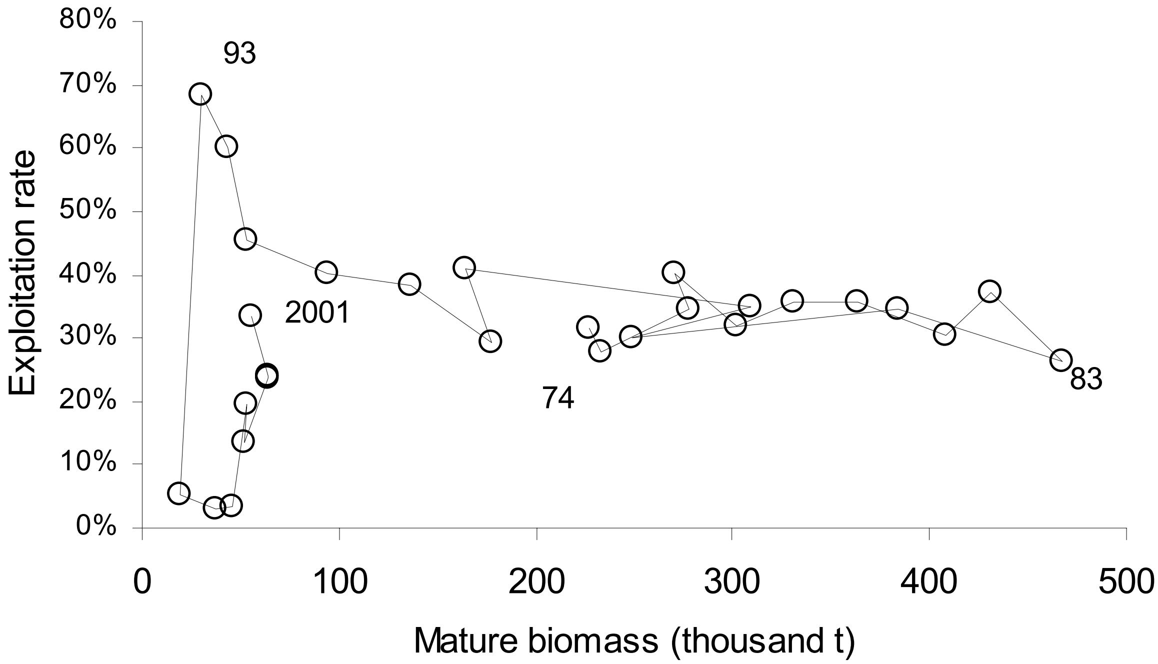


Figure 2.2.5.6. Exploitation rate versus spawning stock biomass for the northern Gulf of St. Lawrence cod stock.

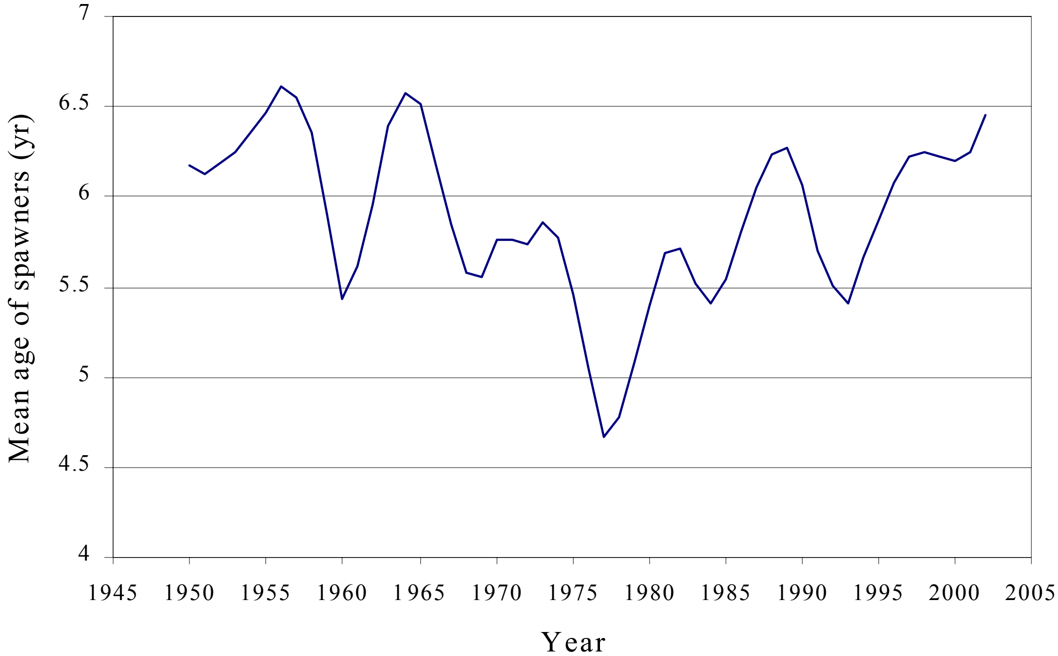


Figure 2.2.6.1. Mean age of spawners in the southern Gulf of St. Lawrence cod stock (NAFO Div. 4T-Vn (Nov-Apr)).

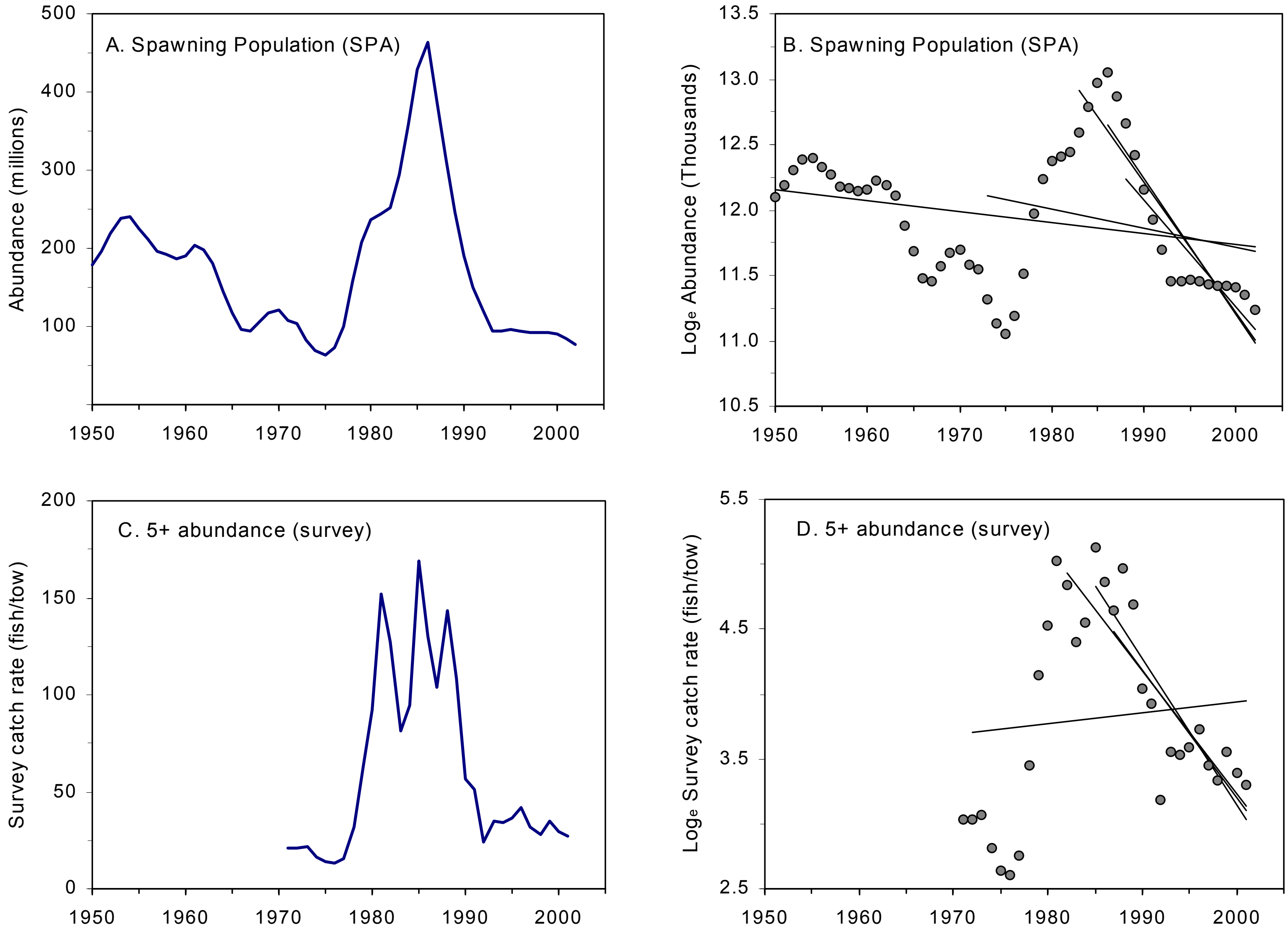


Figure 2.2.6.2. Trends in spawning stock abundance for southern Gulf of St. Lawrence cod, based on SPA estimates and survey catch rates. Lines show the regression of $\log_e$ abundance versus time over various time periods.

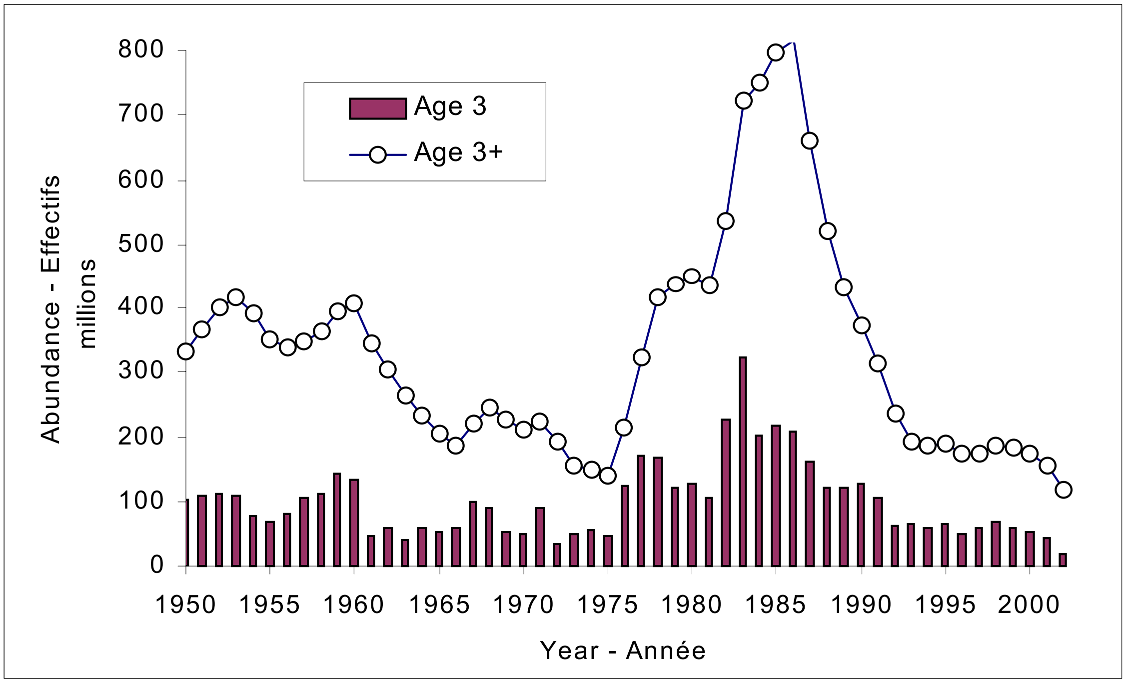
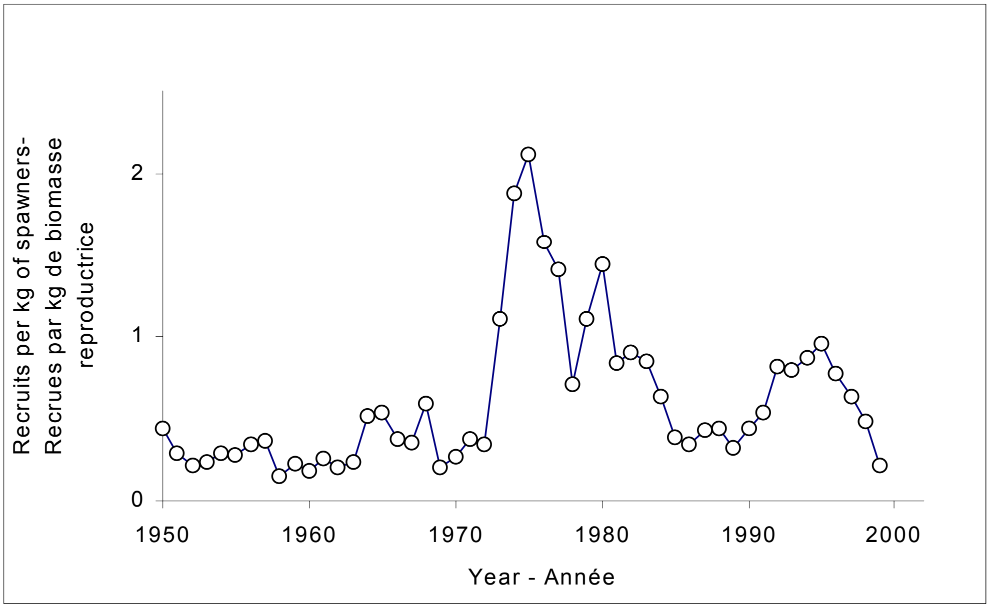


Figure 2.2.6.3. Trends in population abundance (age 3+) and recruitment (age 3) for southern Gulf of St. Lawrence cod, based on SPA estimates.

A.



B.

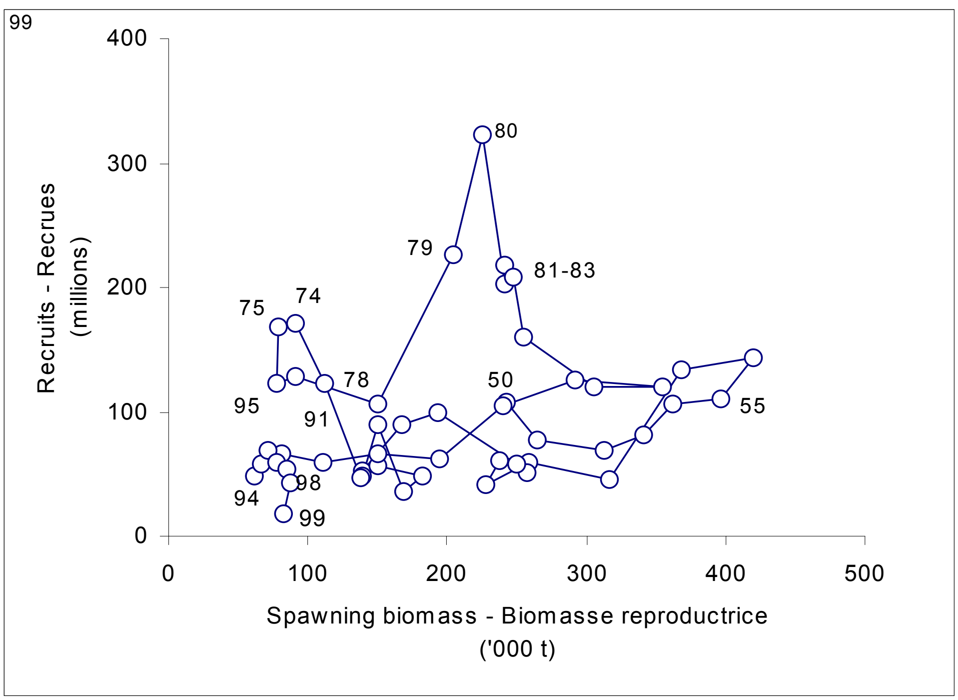
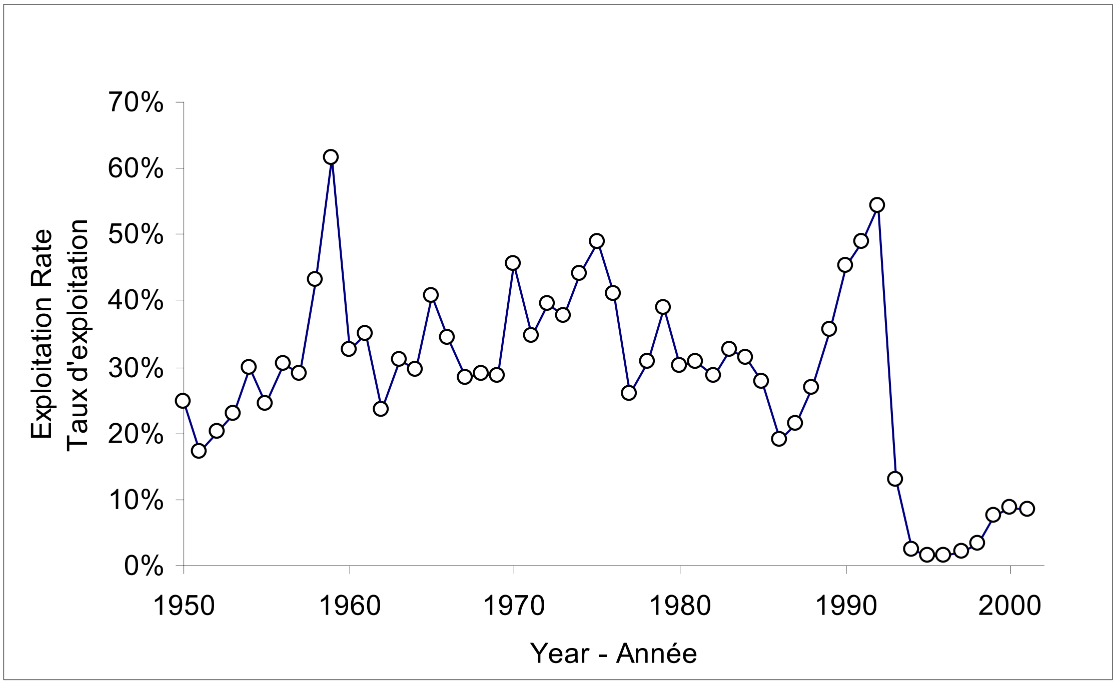


Figure 2.2.6.4. Trends in recruitment rate (# of recruits/ spawning stock biomass) for southern Gulf of St. Lawrence cod, based on SPA estimates. A. Recruitment rate time series. B. Recruits versus spawning biomass.

A.



B.

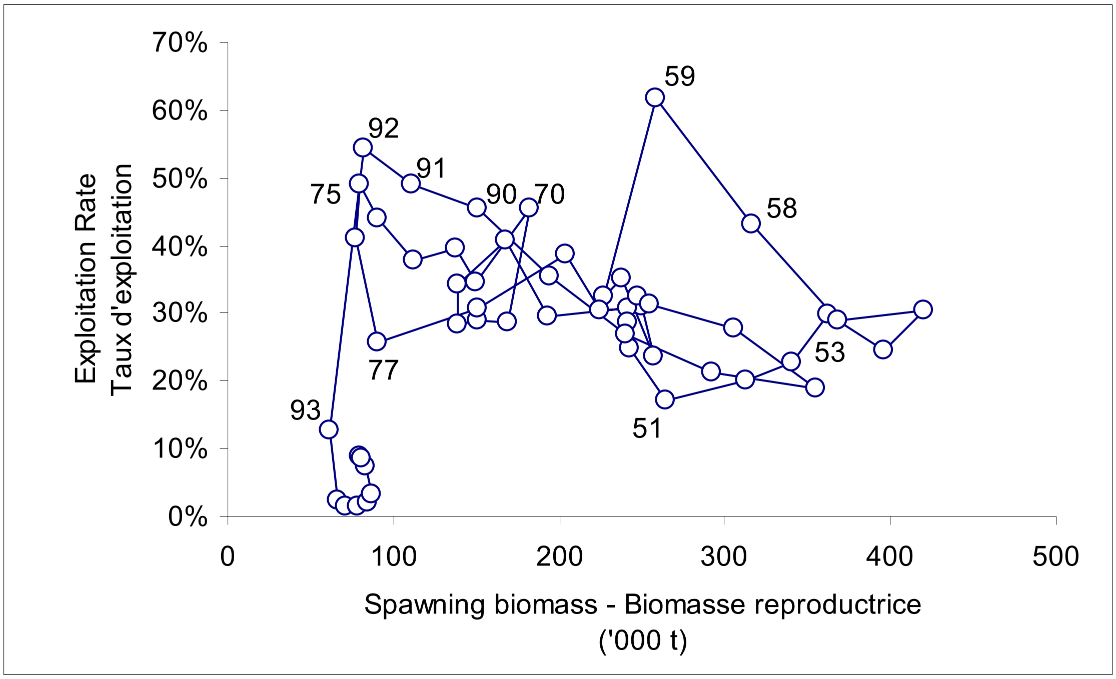


Figure 2.2.6.5. Exploitation rate of southern Gulf of St. Lawrence cod aged 7 yr and older based on SPA results from Chouinard et al. (2002). A. Exploitation rate time series. B. Exploitation rate versus spawning stock biomass.

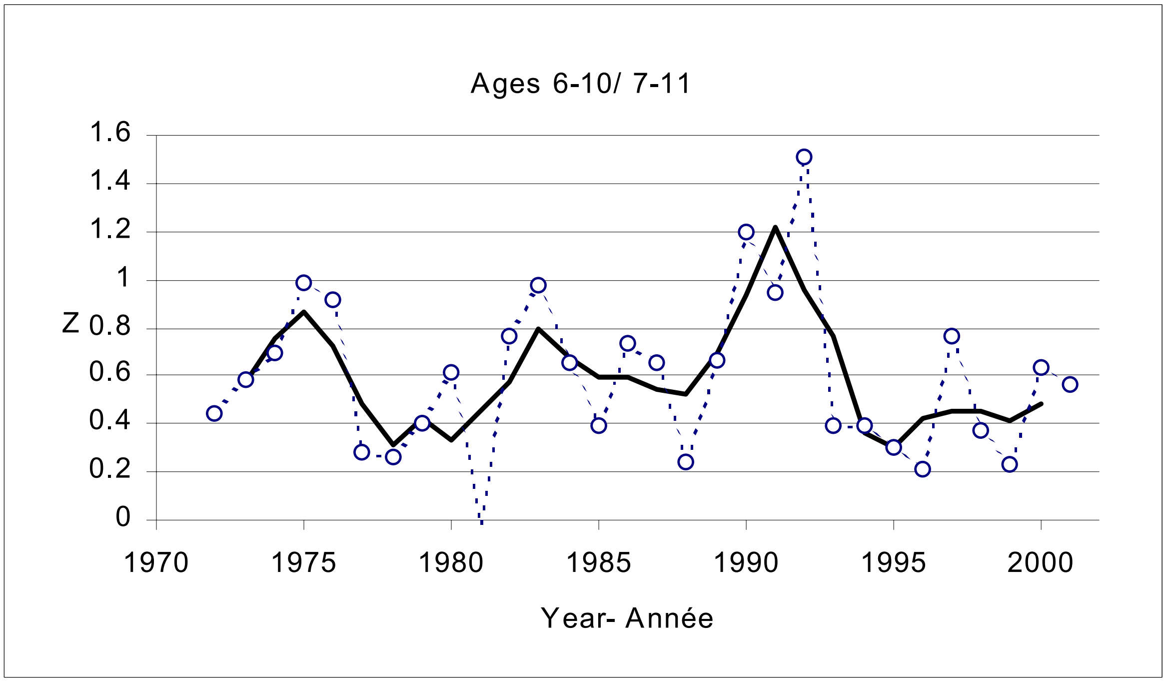


Figure 2.2.6.6. Estimates of total mortality rate (Z) of southern Gulf of St. Lawrence cod, based on survey catch rates of ages 6-10 yr in year *j* and ages 7-11 yr in year *j*+1

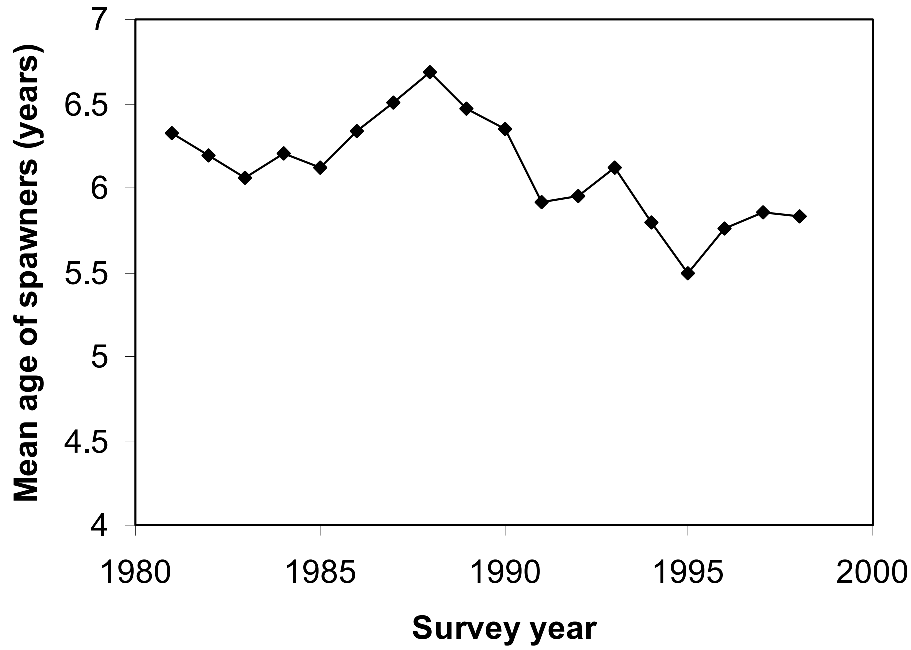


Figure 2.2.7.1. Mean age of spawners in the Sydney Bight cod stock (NAFO Div. 4Vn (May-Oct)) assuming knife-edge full maturity at age 5 (age 5+).

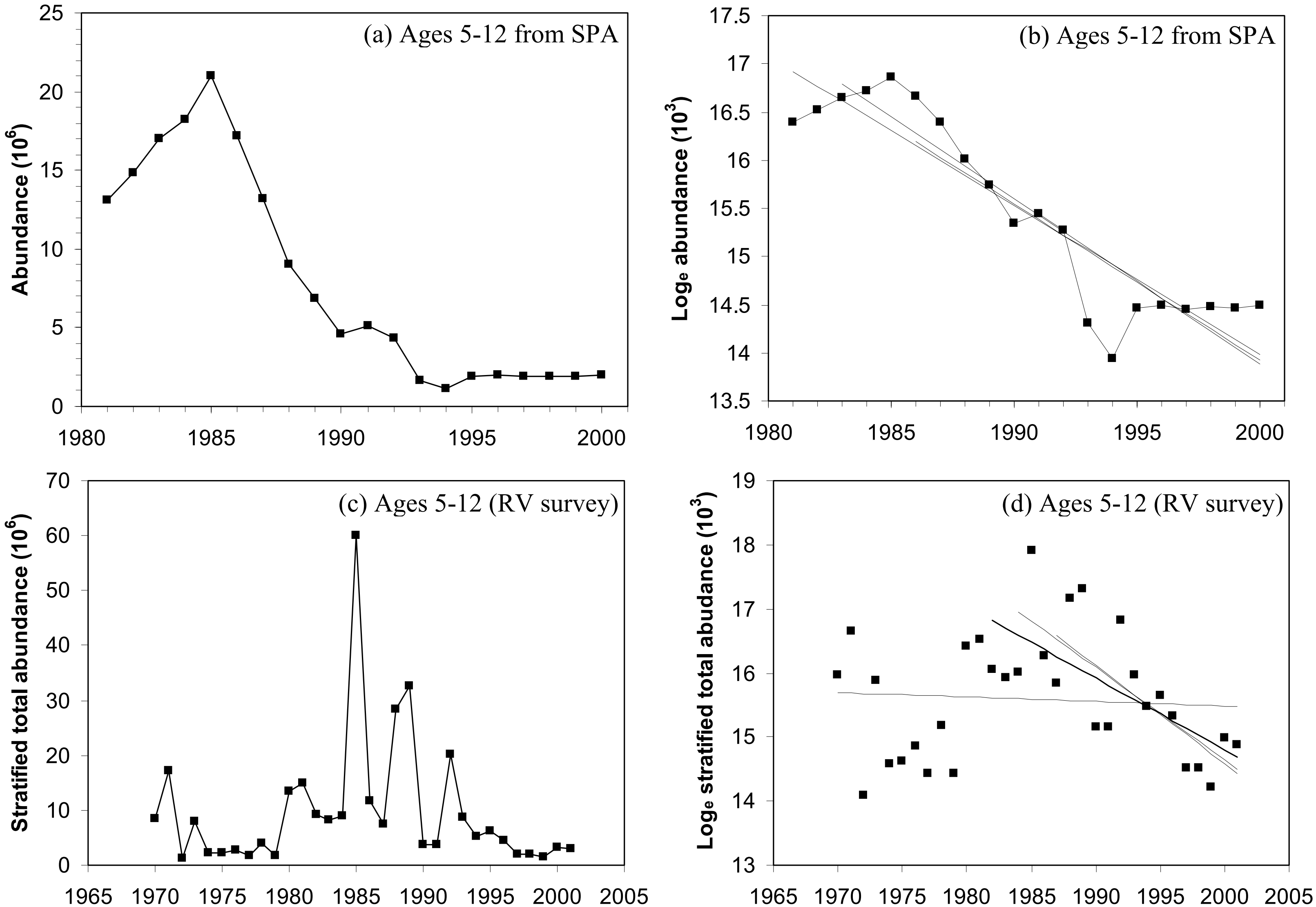


Figure 2.2.7.2. Trends in spawning stock abundance for Sydney Bight cod, based on SPA estimates (a, b) and RV survey catches (c, d). Lines in (b) and (d) represent the regression of $\log_e$ abundance versus time over various time periods.

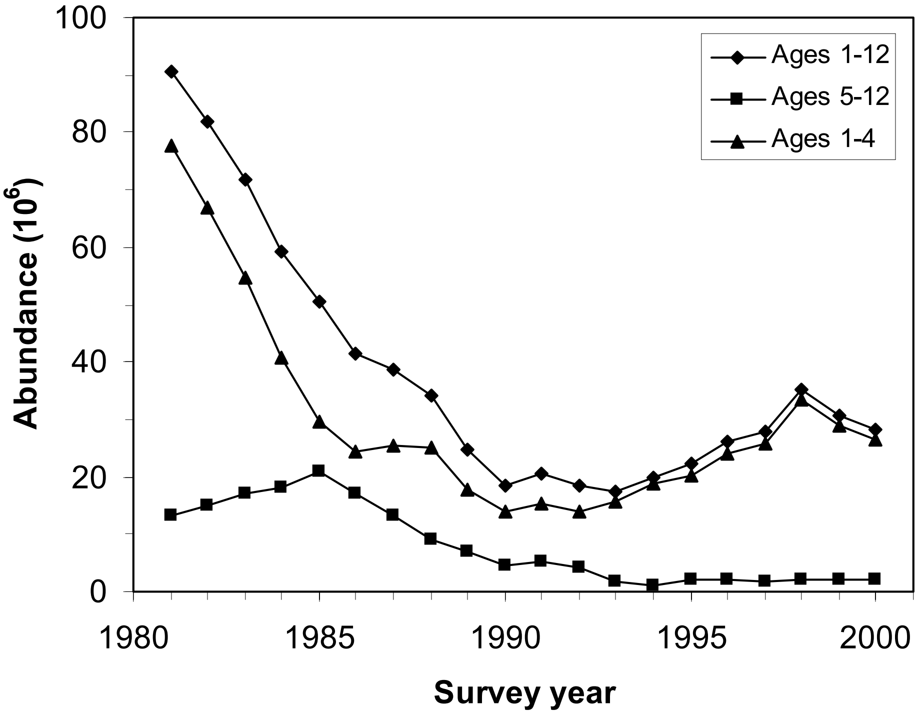


Figure 2.2.7.3. Trends in total (age 1-12), immature (age 1-4), and mature (age 5-12) population abundance for Sydney Bight cod, based on SPA estimates.

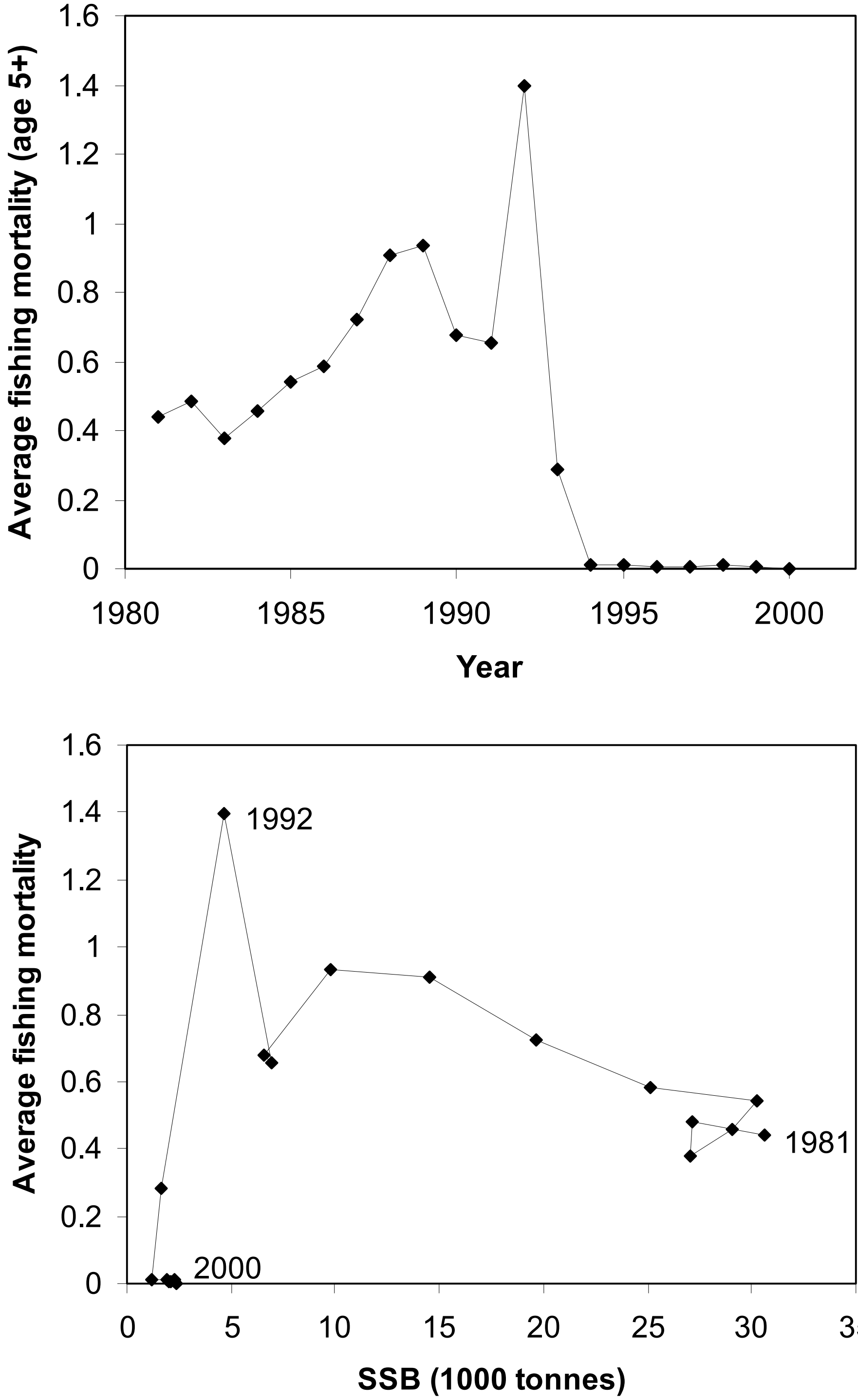


Figure 2.2.7.4. (a) Average fishing mortality (age 5+) over time, and (b) average fishing mortality (age 5+) versus spawning stock biomass (age 5+) for Sydney Bight cod.

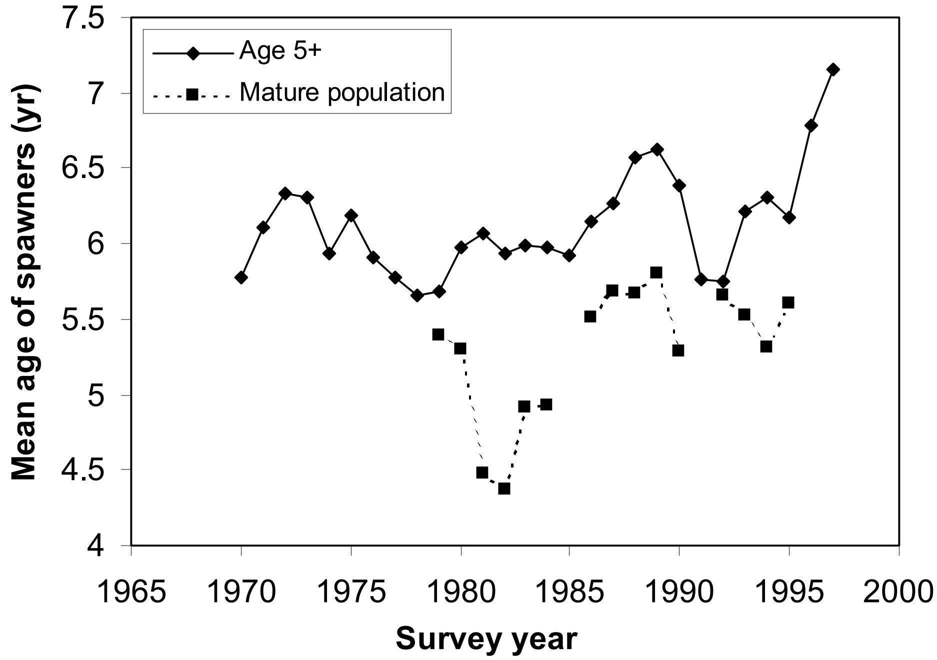


Figure 2.2.8.1. Mean age of spawners in the Eastern Scotian Shelf cod stock (NAFO Div. 4VsW), as estimated from the spring research vessel survey (mature population), and assuming knife-edge full maturity at age 5 (age 5+).

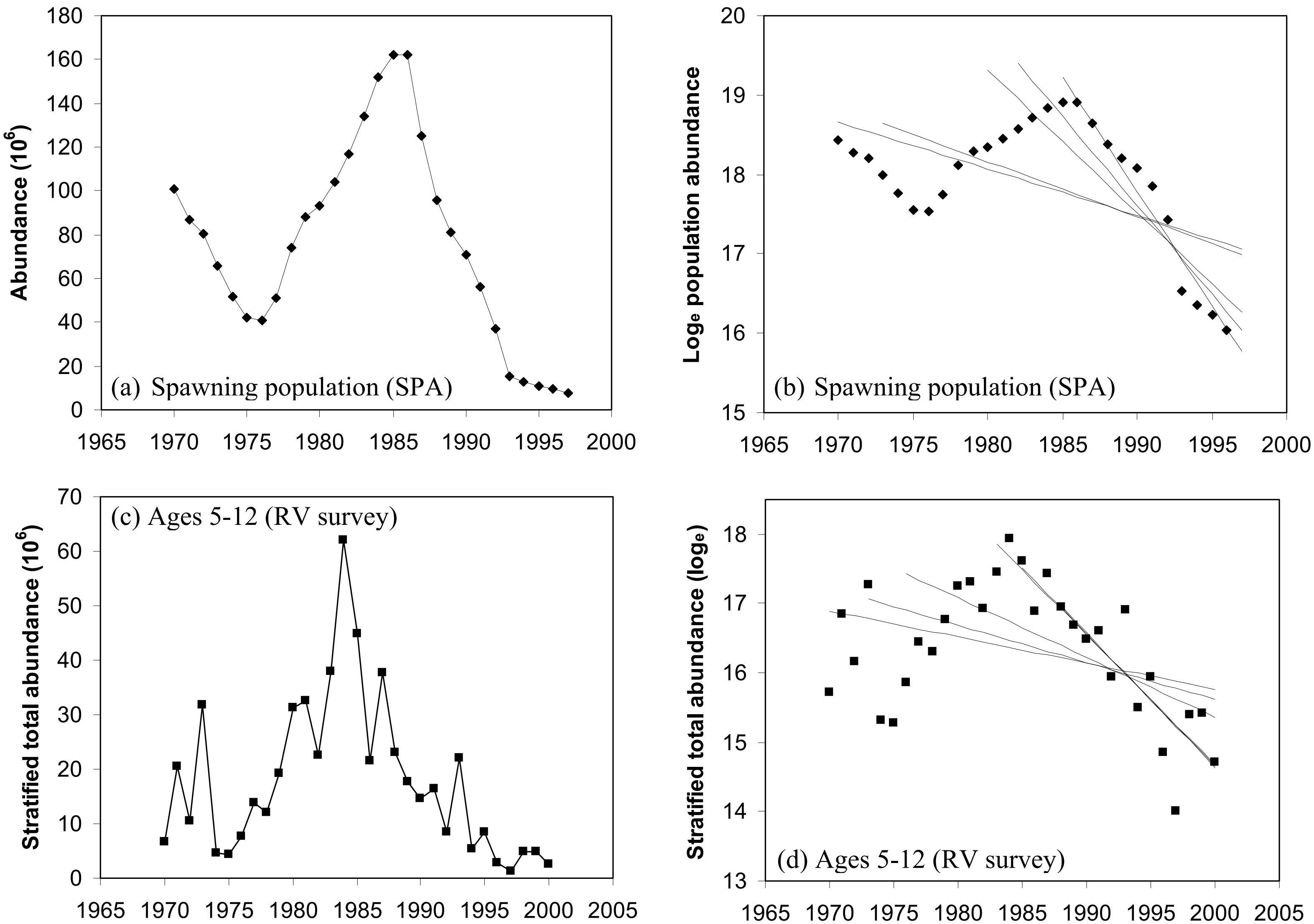


Figure 2.2.8.2. Trends in spawning stock abundance for Eastern Scotian Shelf cod, based on SPA estimates (a, b) and RV survey catches (c, d). Lines in (b) and (d) represent the regression of $\log_e$ abundance versus time over various time periods.

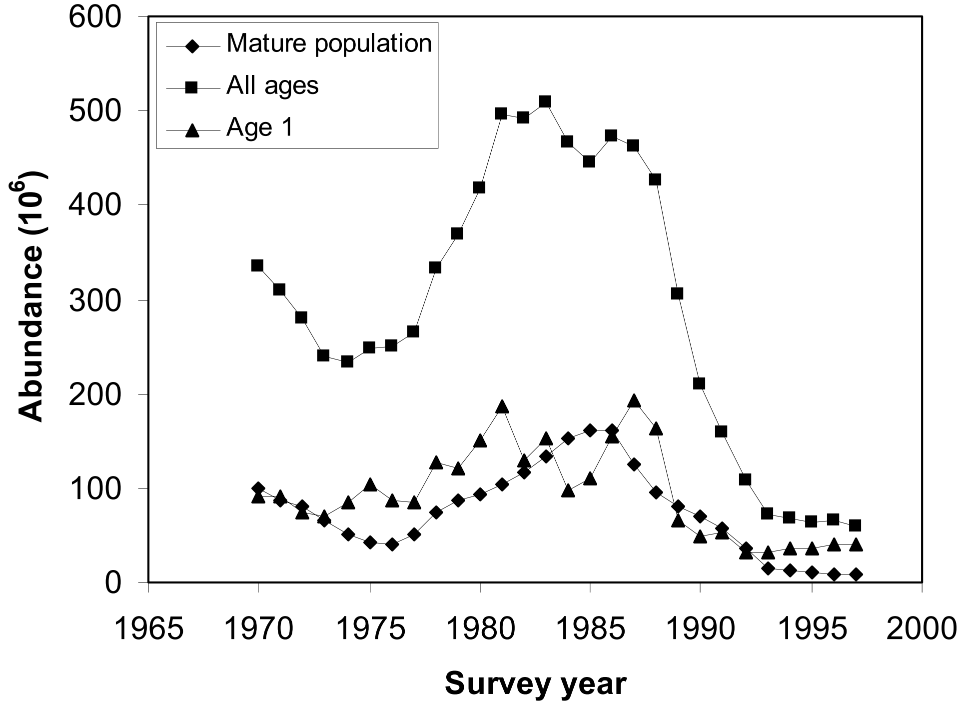


Figure 2.2.8.3. Trends in population abundance and recruitment (age 1) for Eastern Scotian Shelf cod based on SPA estimates.

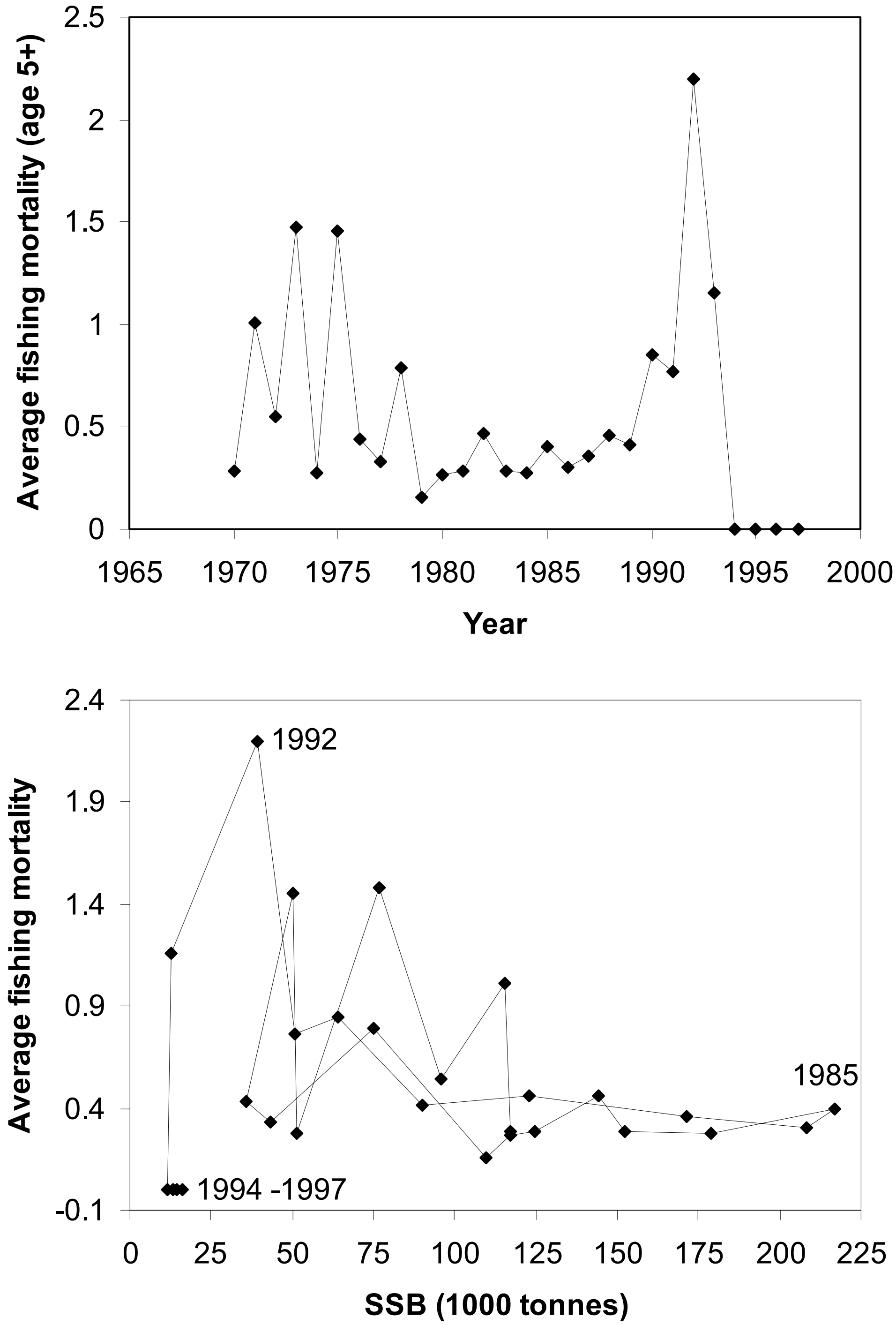


Figure 2.2.8.4. (a) Average fishing mortality (age 5+) over time, and (b) average fishing mortality (age 5+) versus spawning stock biomass (age 5+) for Eastern Scotian Shelf cod.

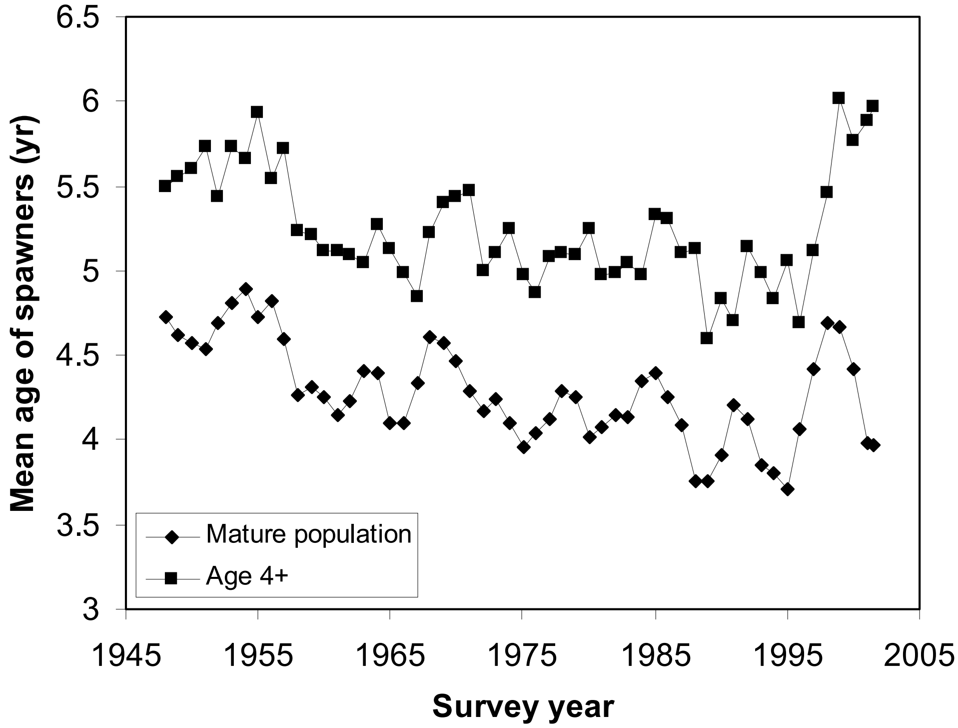


Figure 2.2.9.1. Mean age of spawners in the Western Scotian Shelf/Bay of Fundy cod stock (NAFO Div. 4X/5Y), as estimated from the spring research vessel survey (mature population), and assuming knife-edge full maturity at age 4 (age 4+).

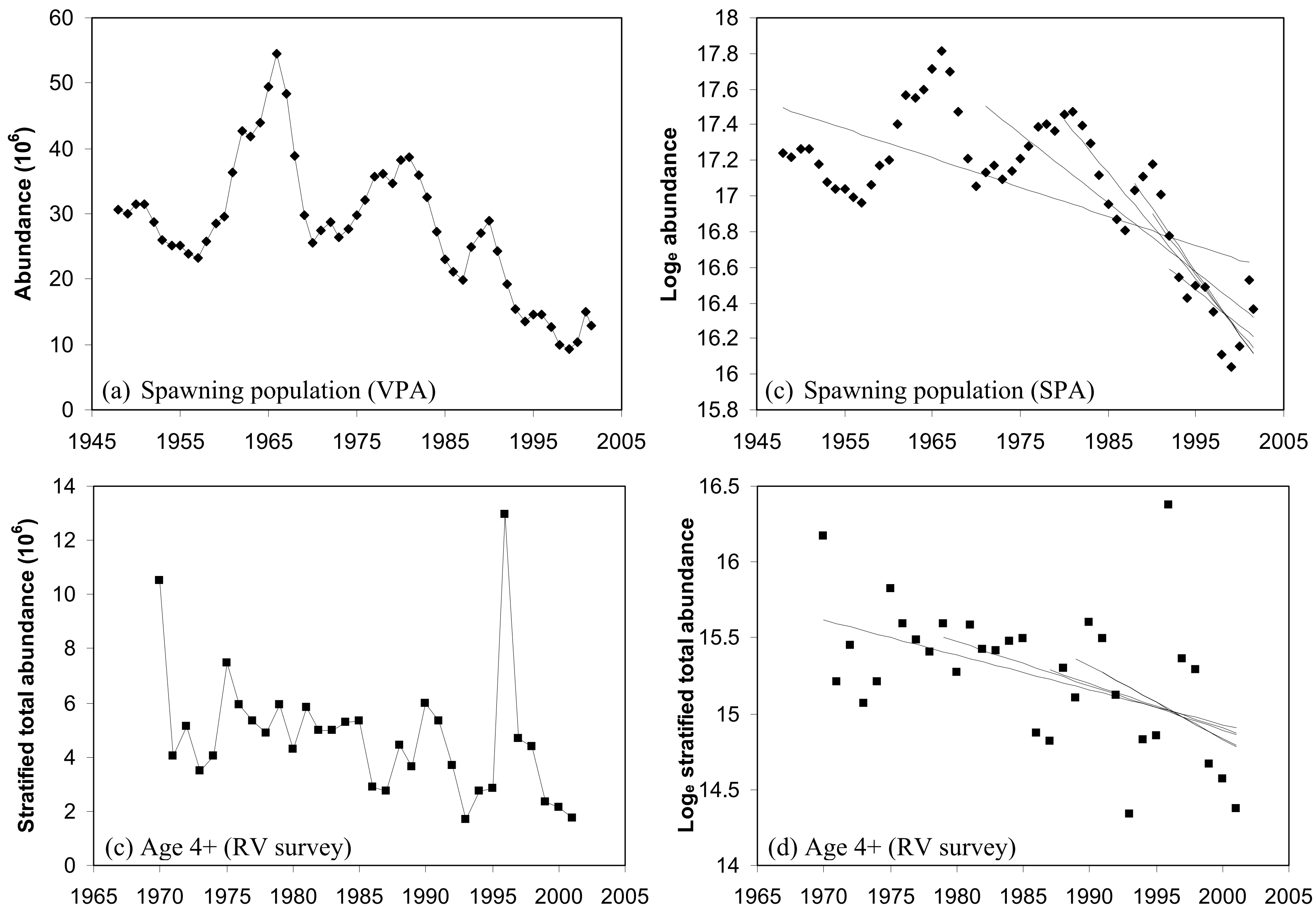


Figure 2.2.9.2. Trends in spawning stock abundance for Western Scotian Shelf/Bay of Fundy cod, based on VPA estimates (a, b) and RV survey catches (c, d). Lines in (b) and (d) represent the regression of log$_e$ abundance versus time over various time periods.

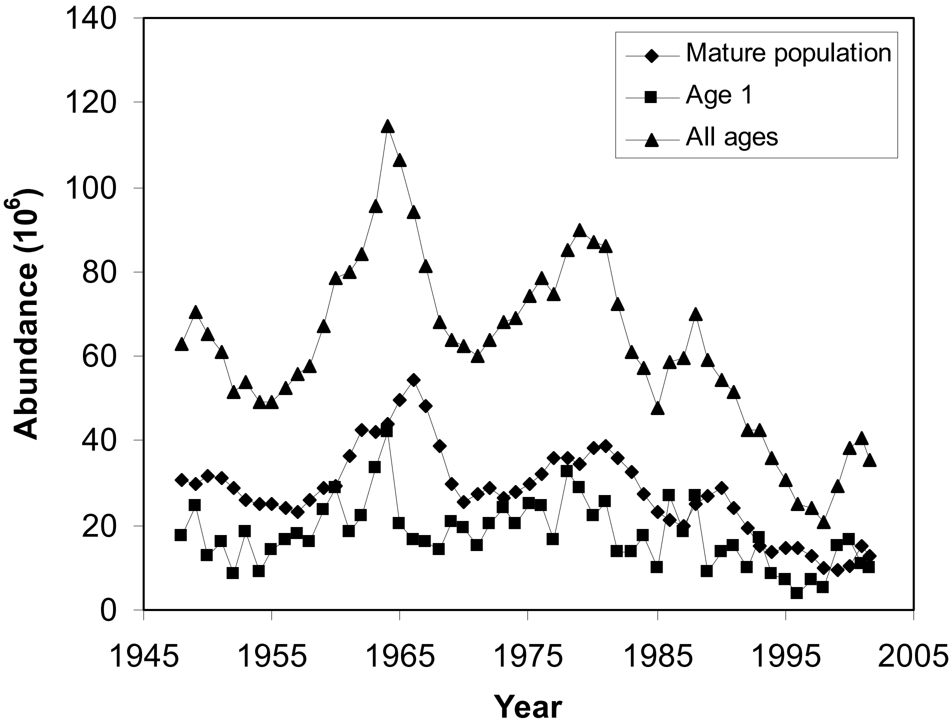


Figure 2.2.9.3. Trends in population abundance and recruitment (age 1) for Western Scotian Shelf/Bay of Fundy cod based on VPA estimates.

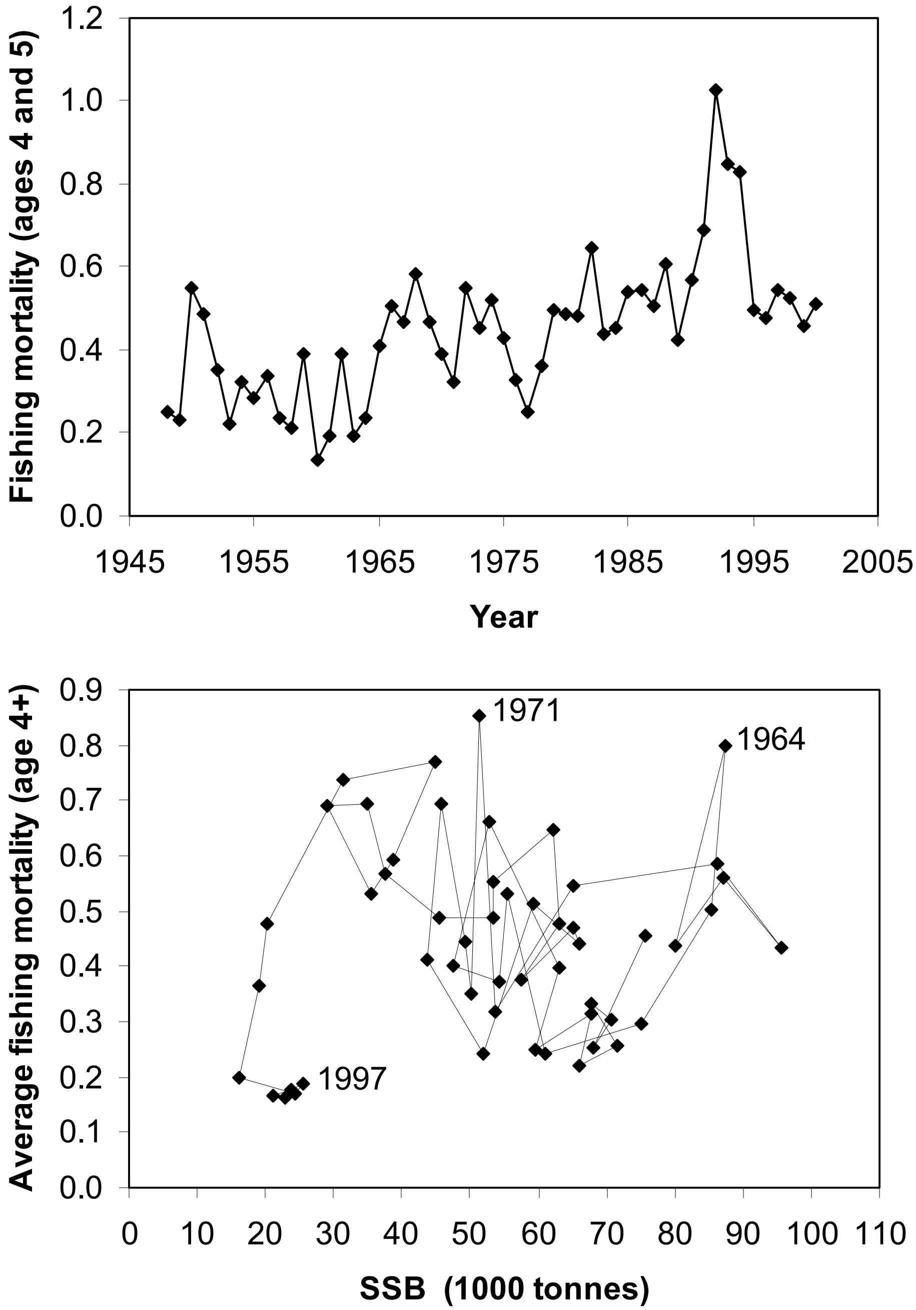


Figure 2.2.9.4. (a) Fishing mortality on fully-recruited ages (ages 4 and 5) over time, and (b) average fishing mortality (age 4+) versus spawning stock biomass (age 4+) for Western Scotian Shelf/Bay of Fundy cod.

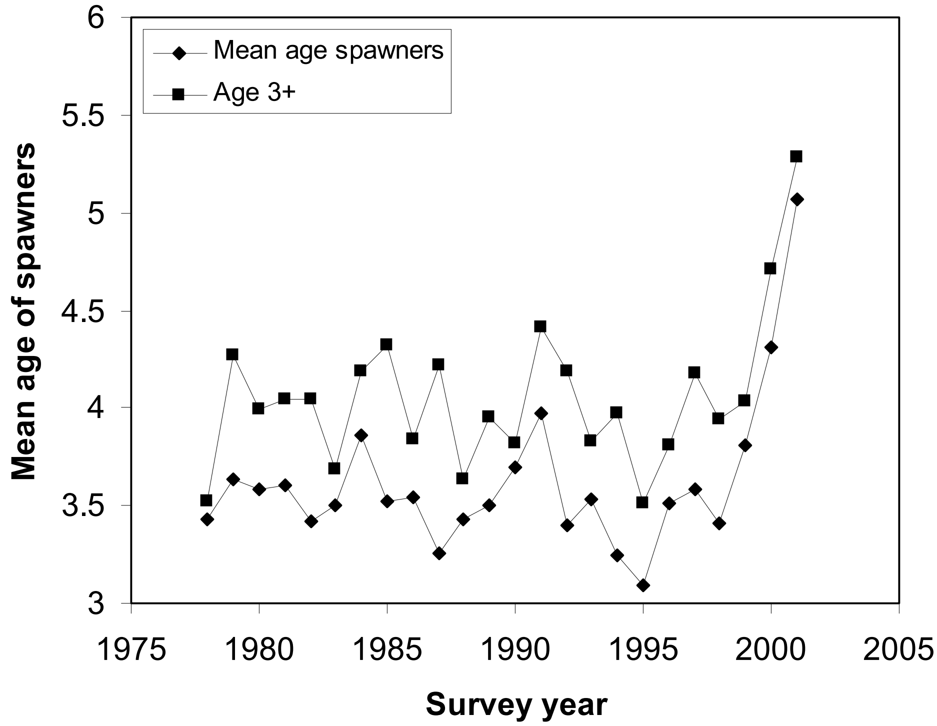


Figure 2.2.10.1. Mean age of spawners in the Georges Bank cod stock (NAFO Div. 5Zej and 5Zem), as estimated from the Canadian spring research vessel survey (mature population), and assuming knife-edge full maturity at age 3 (age 3+).

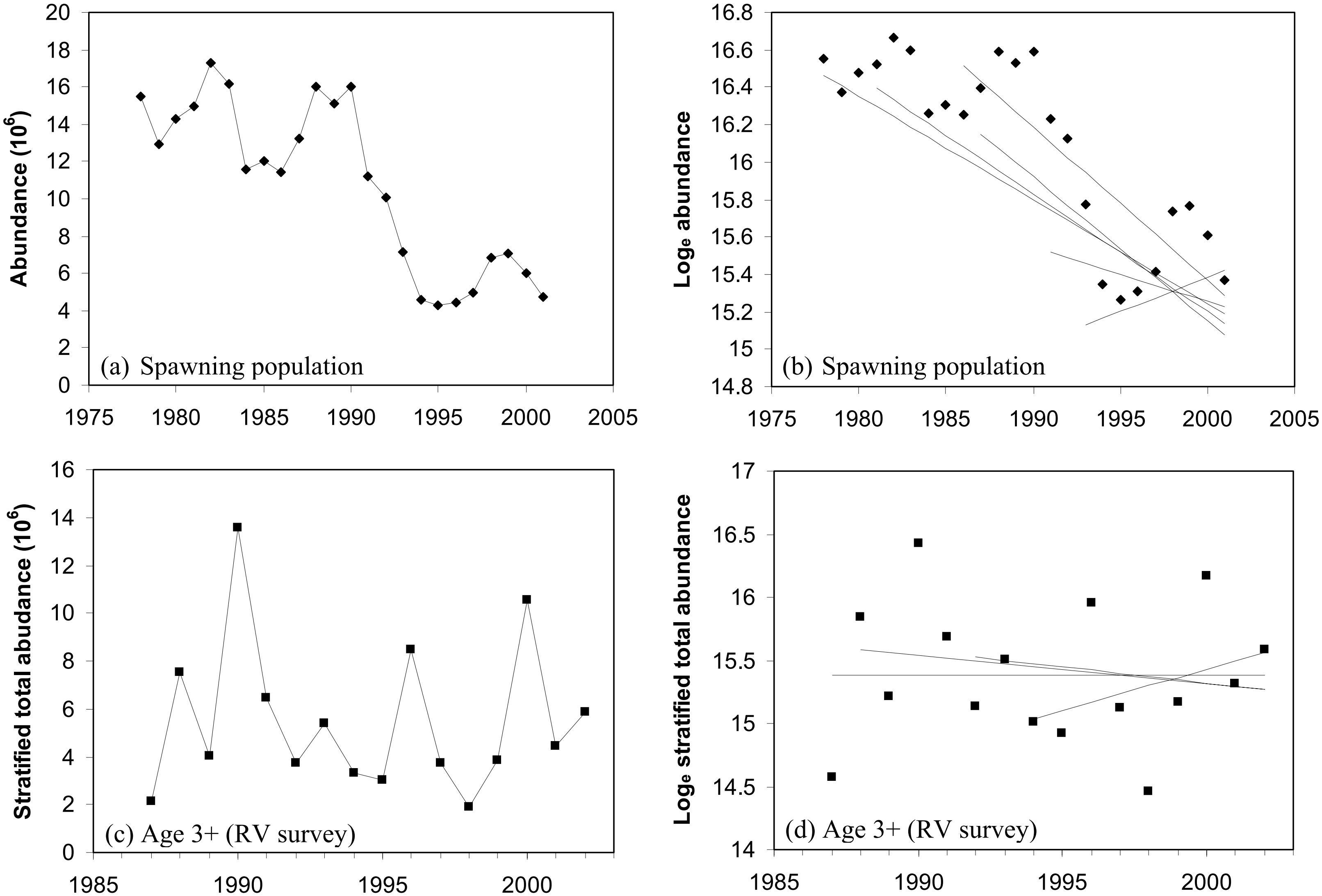


Figure 2.2.10.2. Trends in spawning stock abundance for Georges Bank cod, based on SPA estimates (a, b) and RV survey catches (c, d). Lines in (b) and (d) represent the regression of $\log_e$ abundance versus time over various time periods.

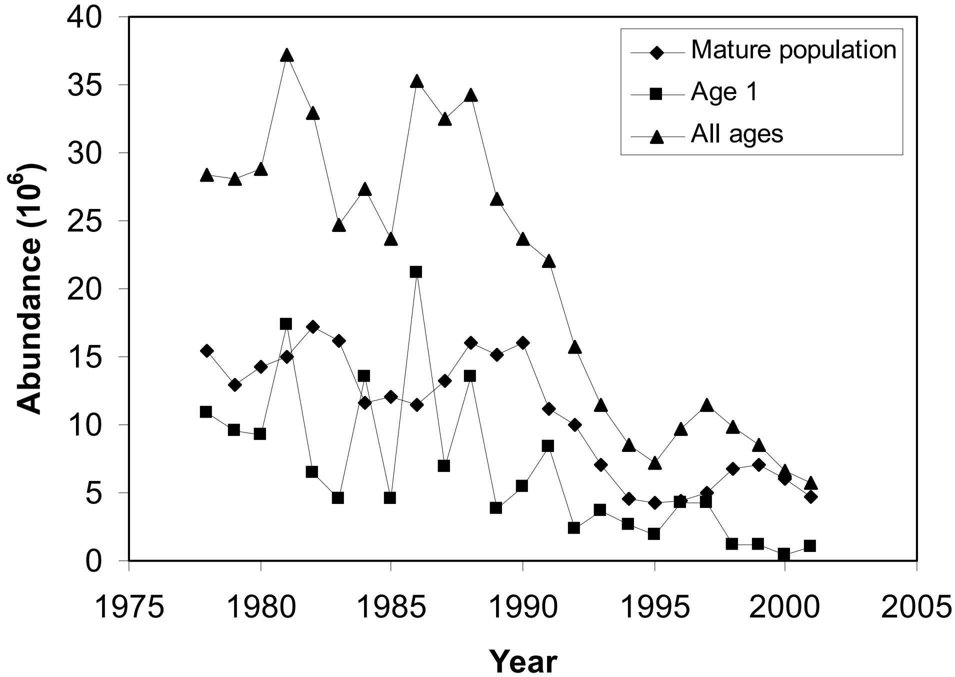
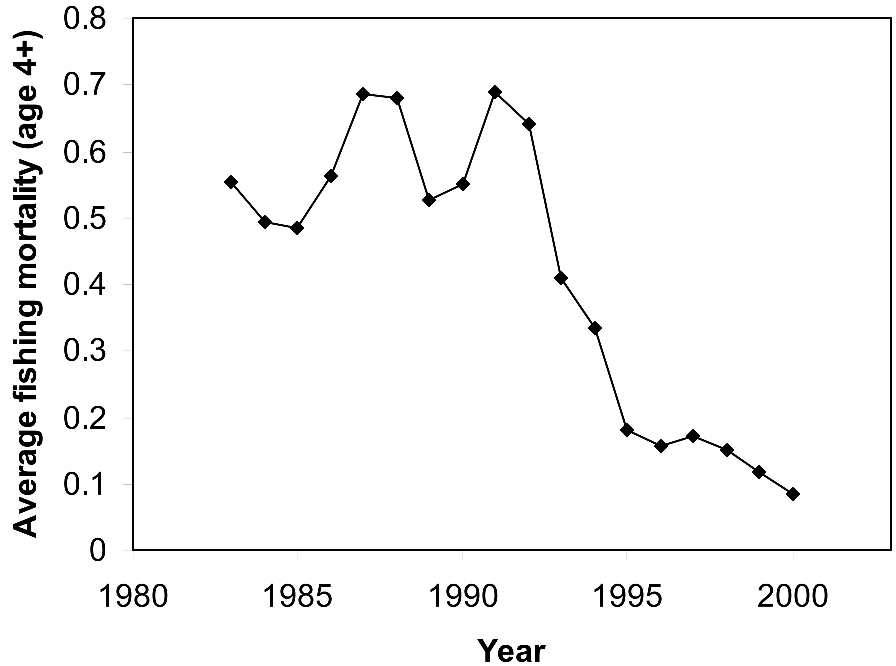


Figure 2.2.10.3. Trends in population abundance and recruitment (age 1) for Georges Bank cod based on SPA estimates.



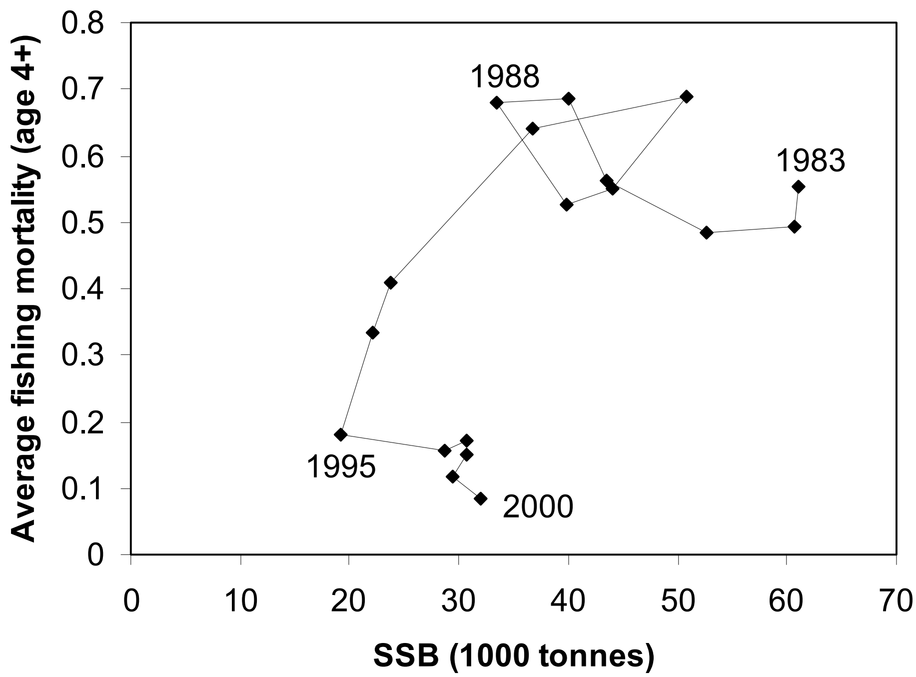


Figure 2.2.10.4. (a) Average fishing mortality (age 4+) over time, and (b) average fishing mortality (age 4+) versus age 4+ stock biomass (after Hunt and Hatt 2001) for Georges Bank cod.

Engel Trawl
30 min. at
3.5 kts./hr.

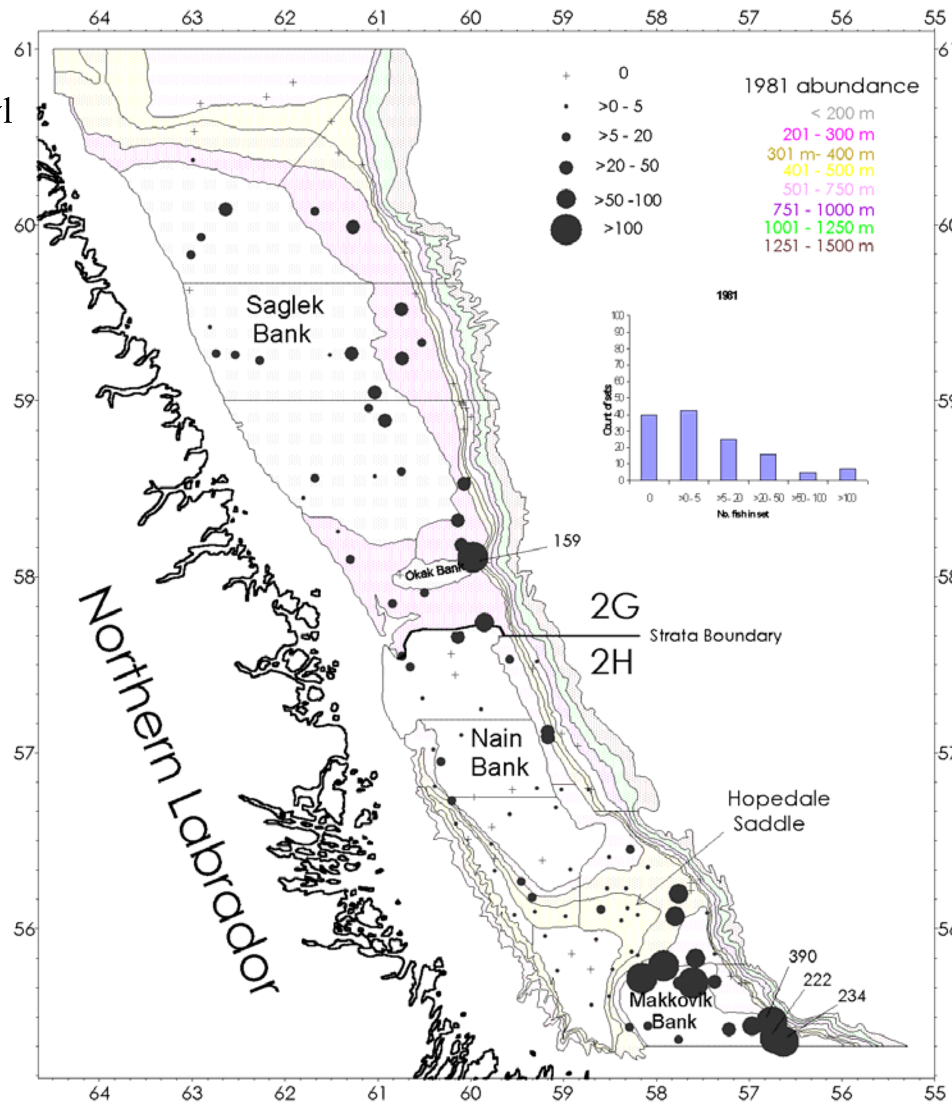


Figure 3.2.1.1. Distribution of cod in the 1981 and 1996 surveys. The 1981 survey used a n Engel trawl and the 1996 survey used a Campelen trawl.

Campelen Tra
15 min. at
3.0 kts./hr.

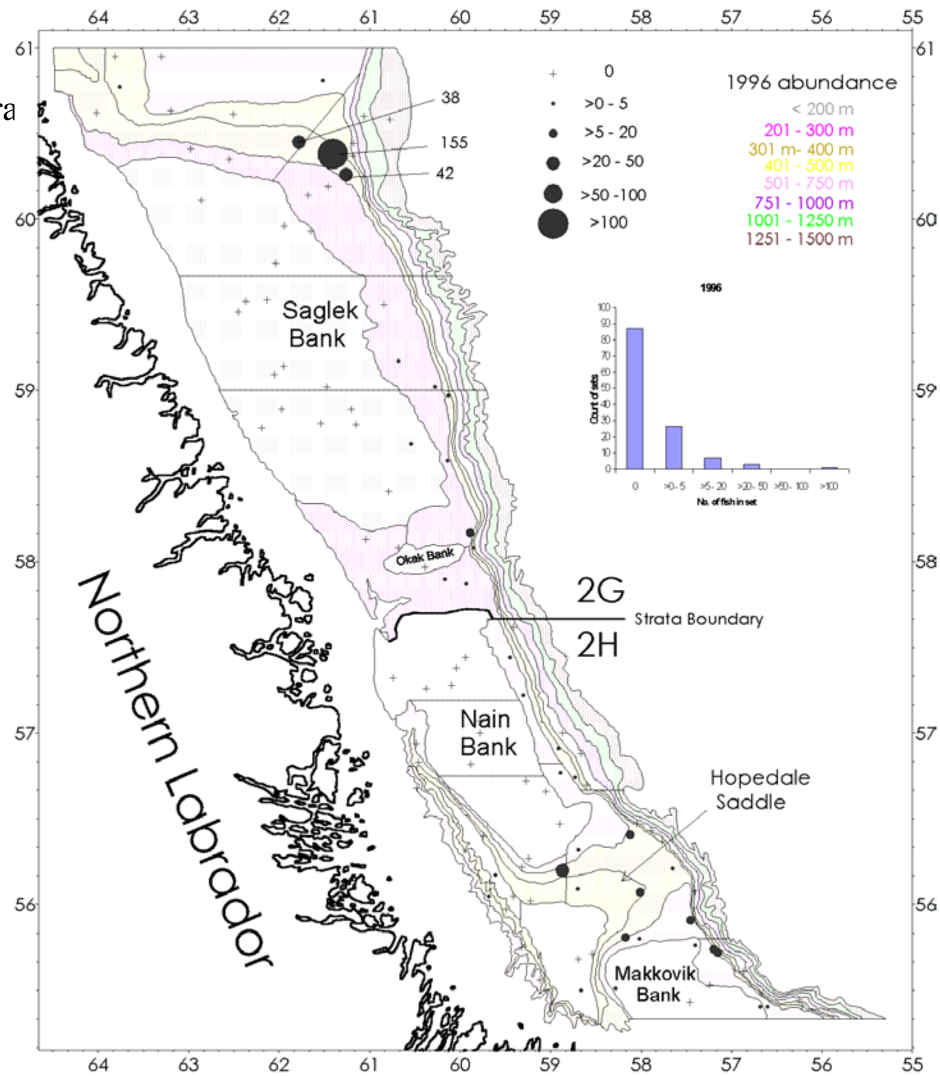


Figure 3.2.1.1. continued

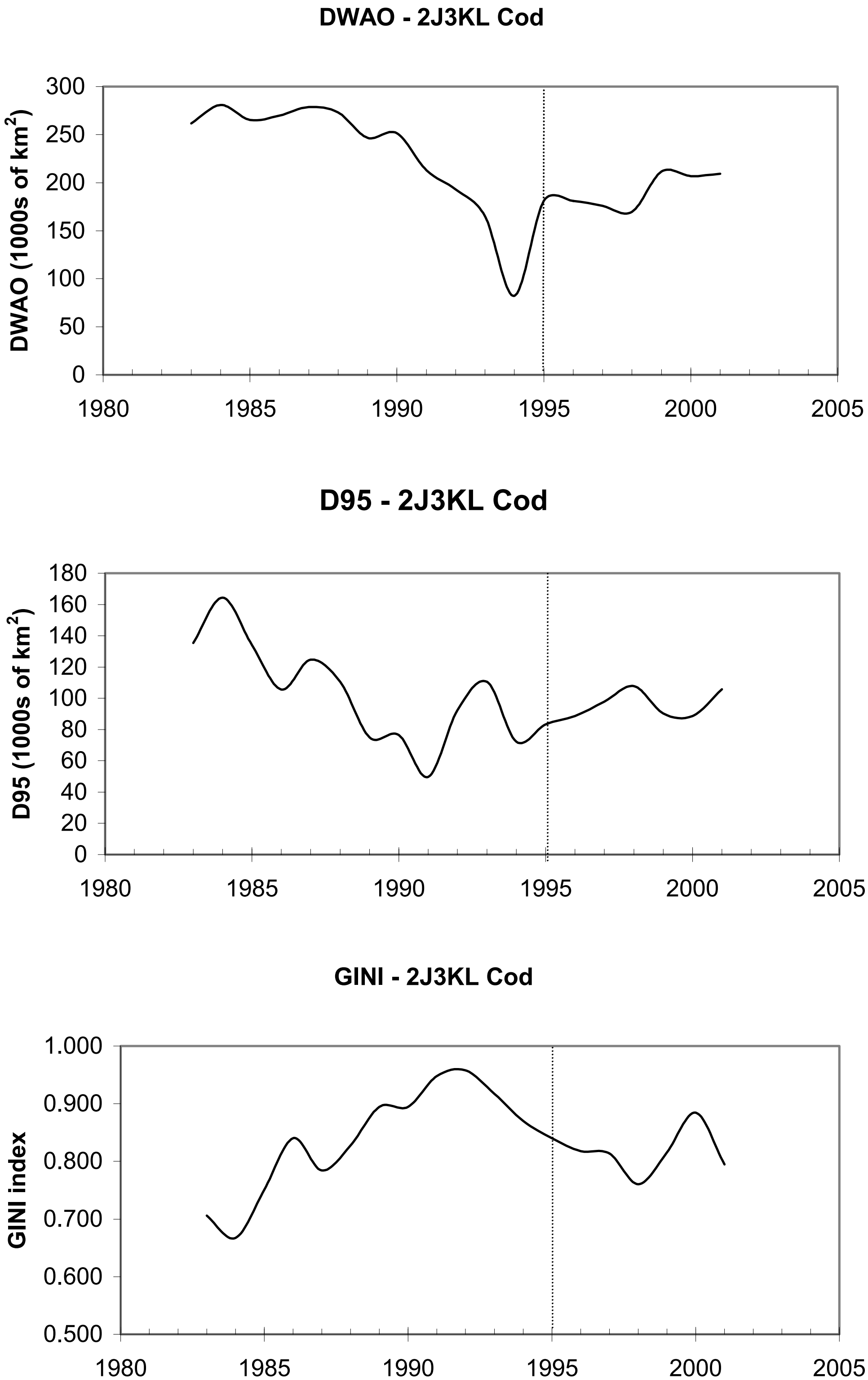


Figure 3.2.2.1. Spatial statistics for 2J3KL cod over the time period 1983-2001. See text for details. The broken vertical line indicates the change from Engel to Campelen trawl.

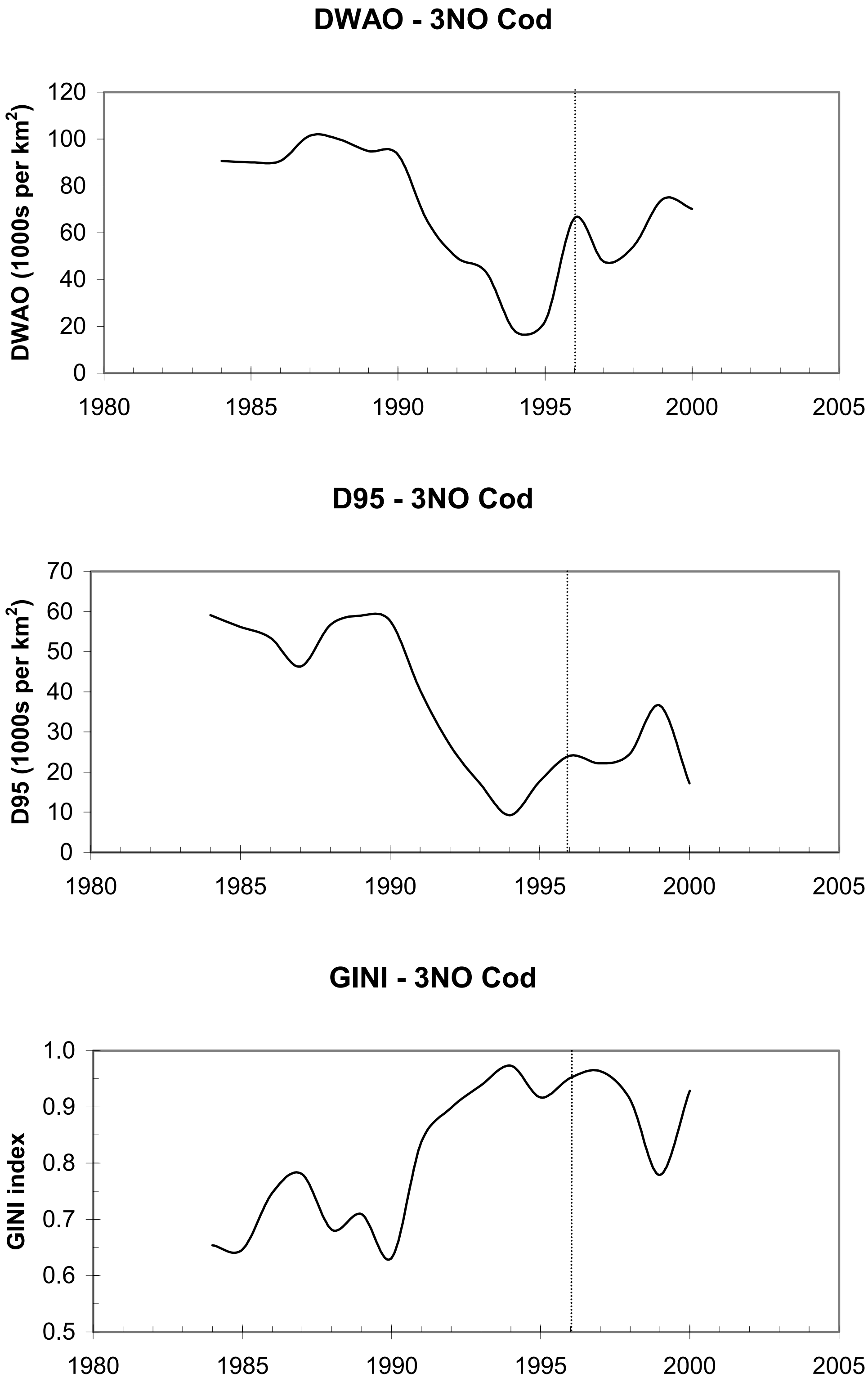


Figure 3.2.3.1. Spatial statistics for 3NO cod over the time period 1984-2000. See text for details. The broken vertical line indicates the change from Engel to Campelen trawl.

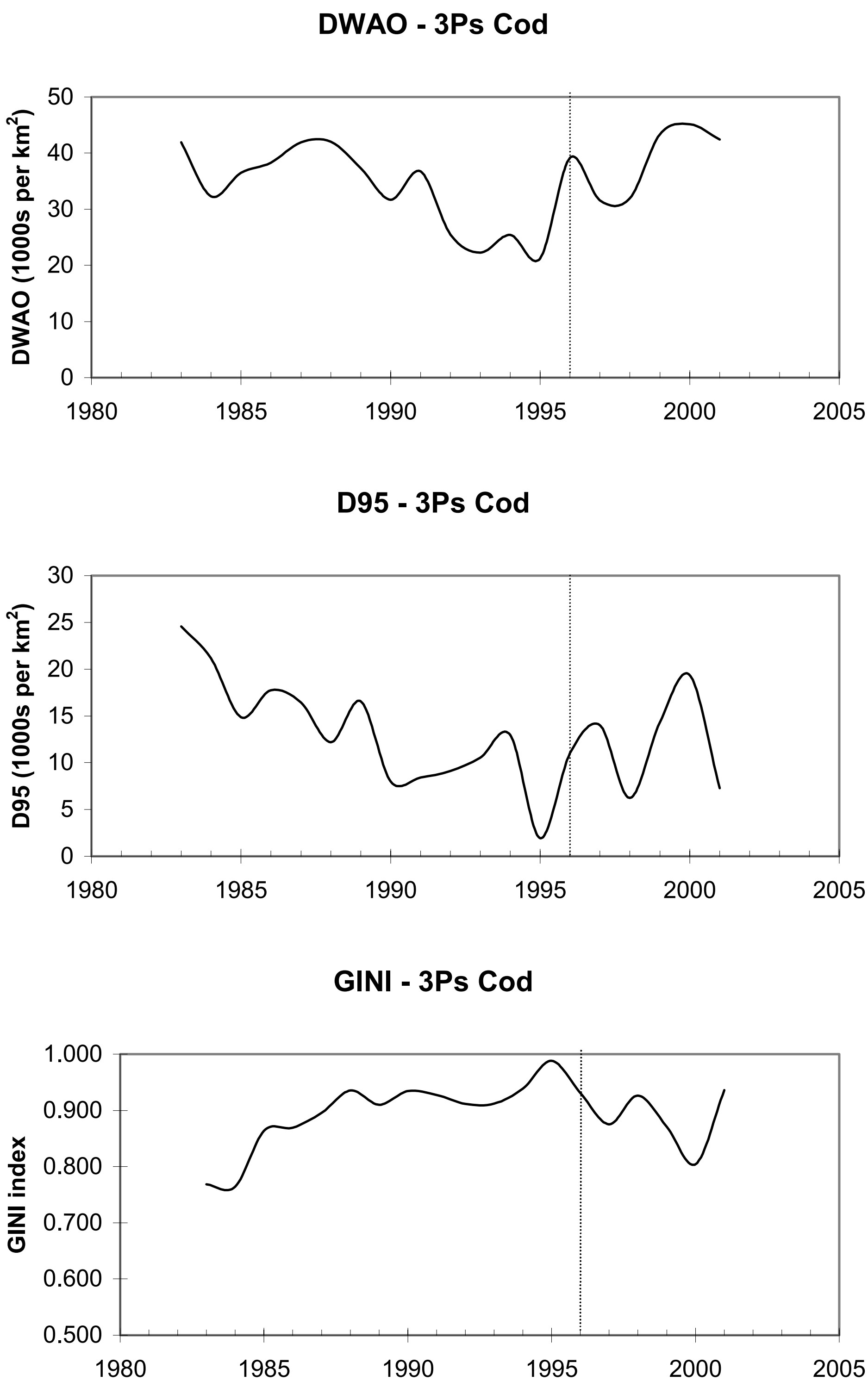
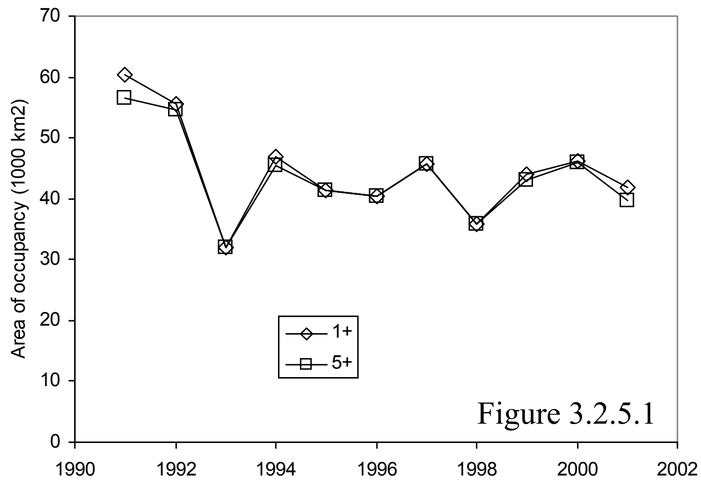
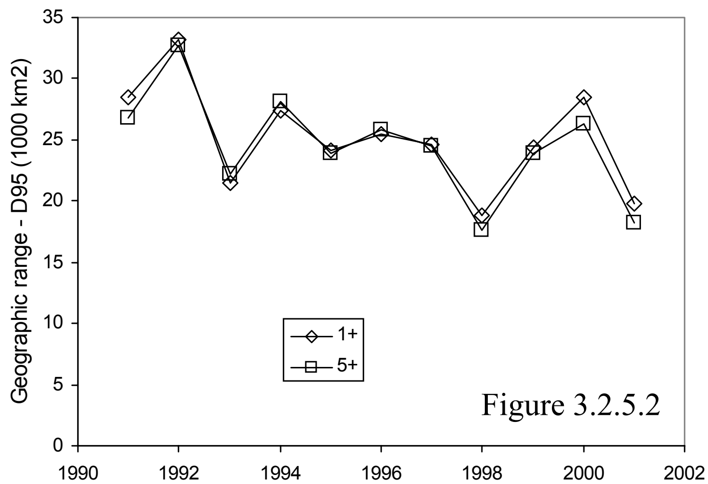
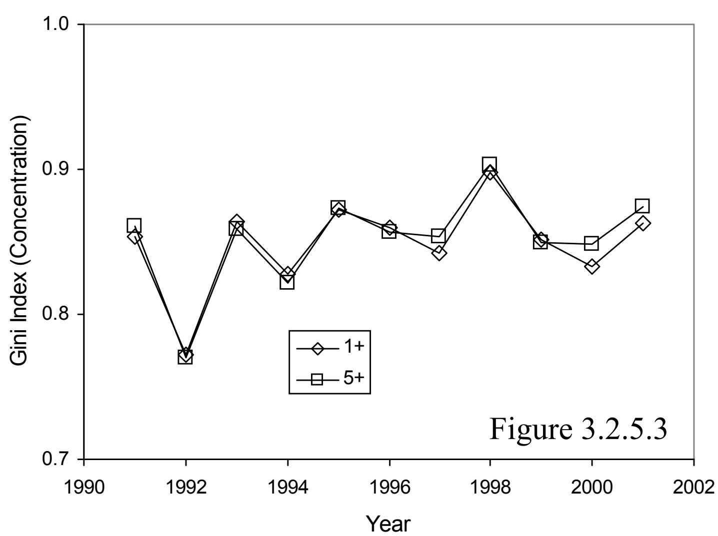


Figure 3.2.4.1. Spatial statistics for 3Ps cod over the time period 1983-2001. See text for details. The broken vertical line indicates the change from Engel to Campelen trawl.







Figures 3.2.5.1-3.2.5.3. Indices of concentration in August for the northern Gulf of St. Lawrence cod aged 1 and 5 years (the latter corresponds roughly to the spawning stock). Figure 3.2.5.1: Area of occupancy (DWAO), Figure 3.2.5.2: Geographic range (D_{95}), Figure 3.2.5.3: Gini index.

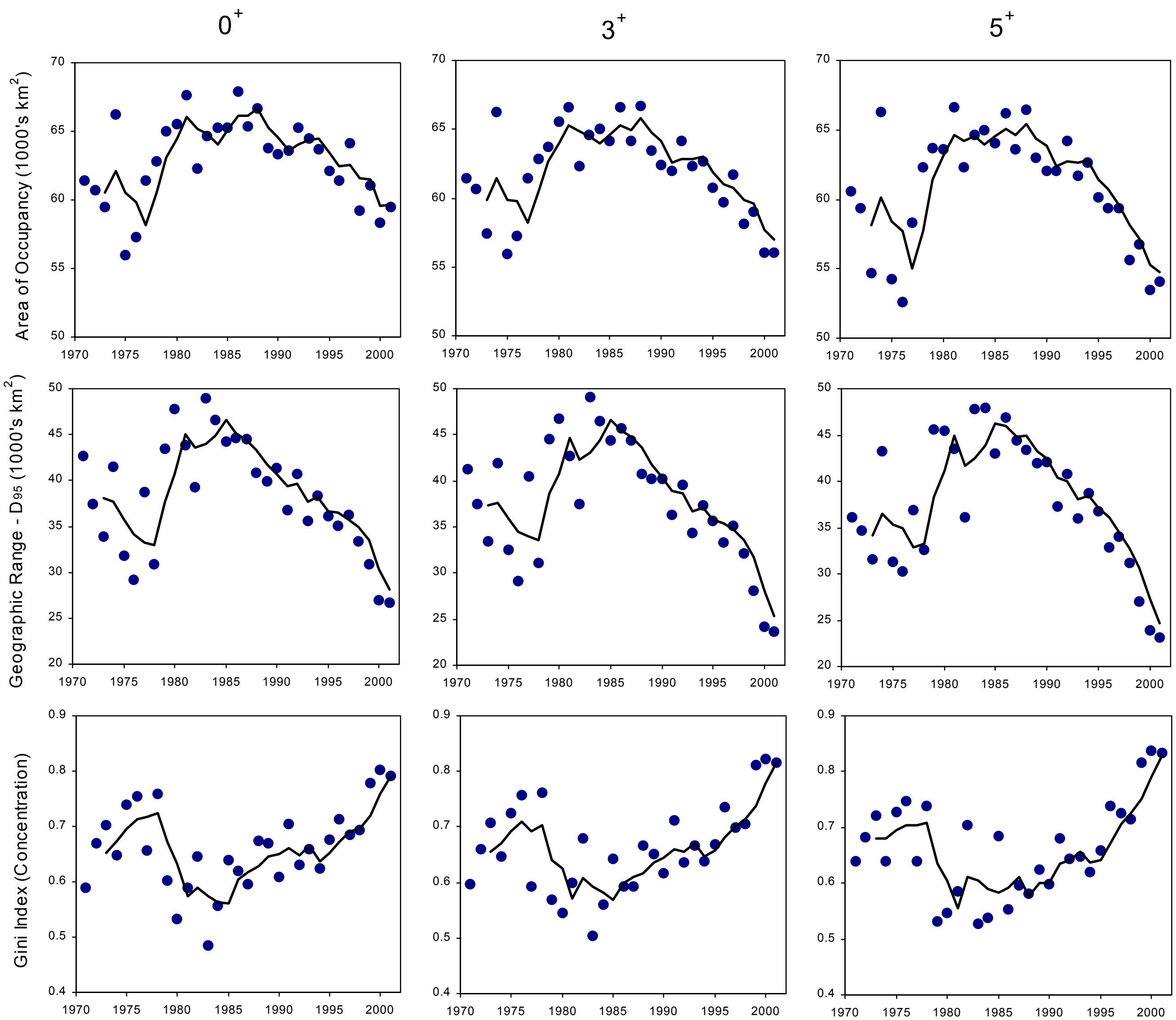


Figure 3.2.6.1. Indices of geographic distribution in September for southern Gulf of St. Lawrence cod aged 0^+, 3^+ and 5^+ years (the latter corresponds roughly to the spawning stock). Line is a 3-yr moving average.

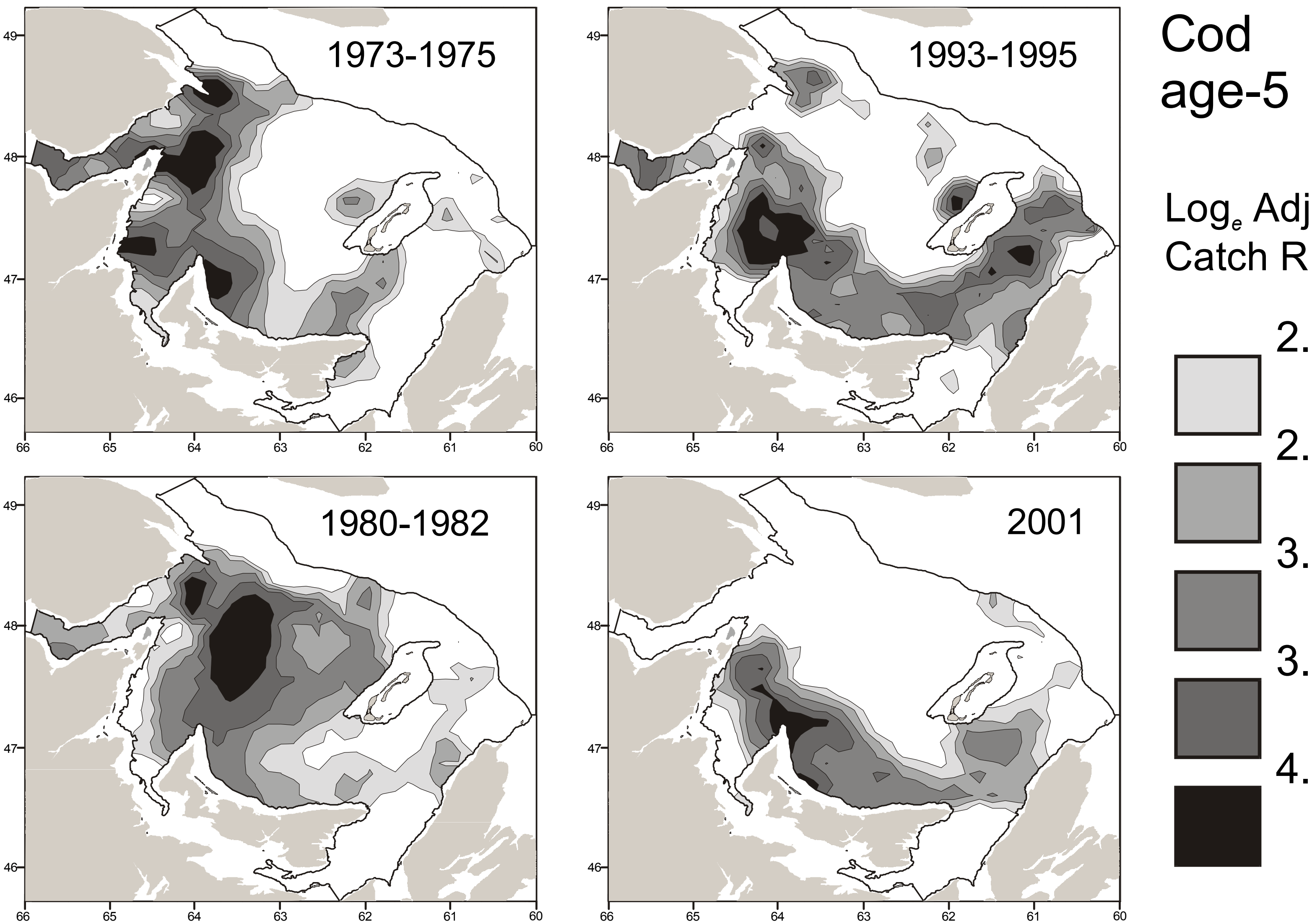


Figure 3.2.6.2. Distribution of 5-yr old cod in September in the southern Gulf of St. Lawrence in 2001 and in three earlier periods. Cod abundance was high in the 1980-1982 period and relatively low in the other periods. Cod density has been adjusted to the same average level (25 fish/tow) in all periods to emphasize changes in distribution rather than changes in overall abundance.

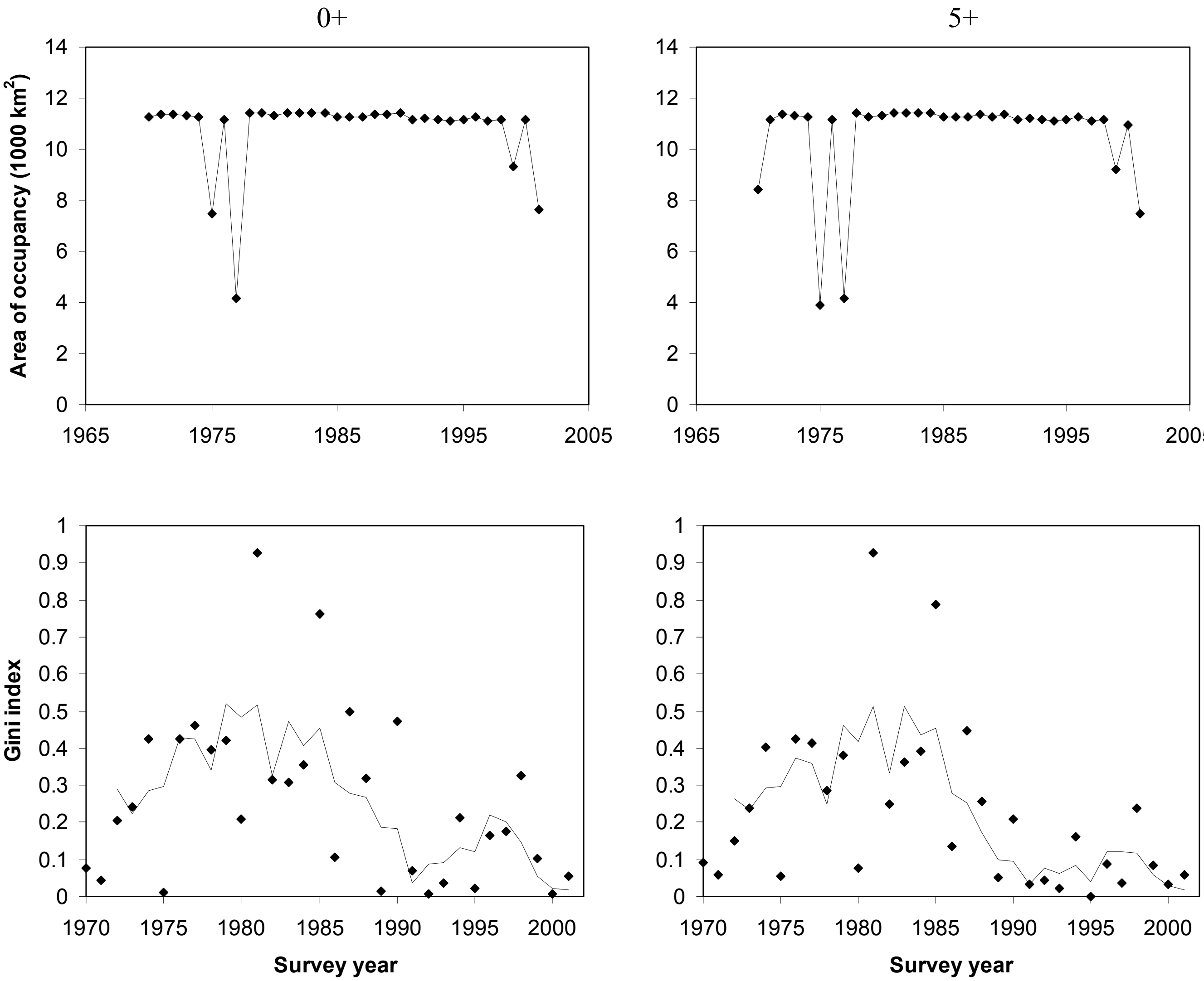


Figure 3.2.7.1. Indices of geographic distribution in July for Sydney Bight cod (NAFO Subdivision 4Vn) aged 0^+ and 5^+ years (the latter corresponds roughly to the spawning stock). Line on the Gini index panels is a 3-yr moving average.

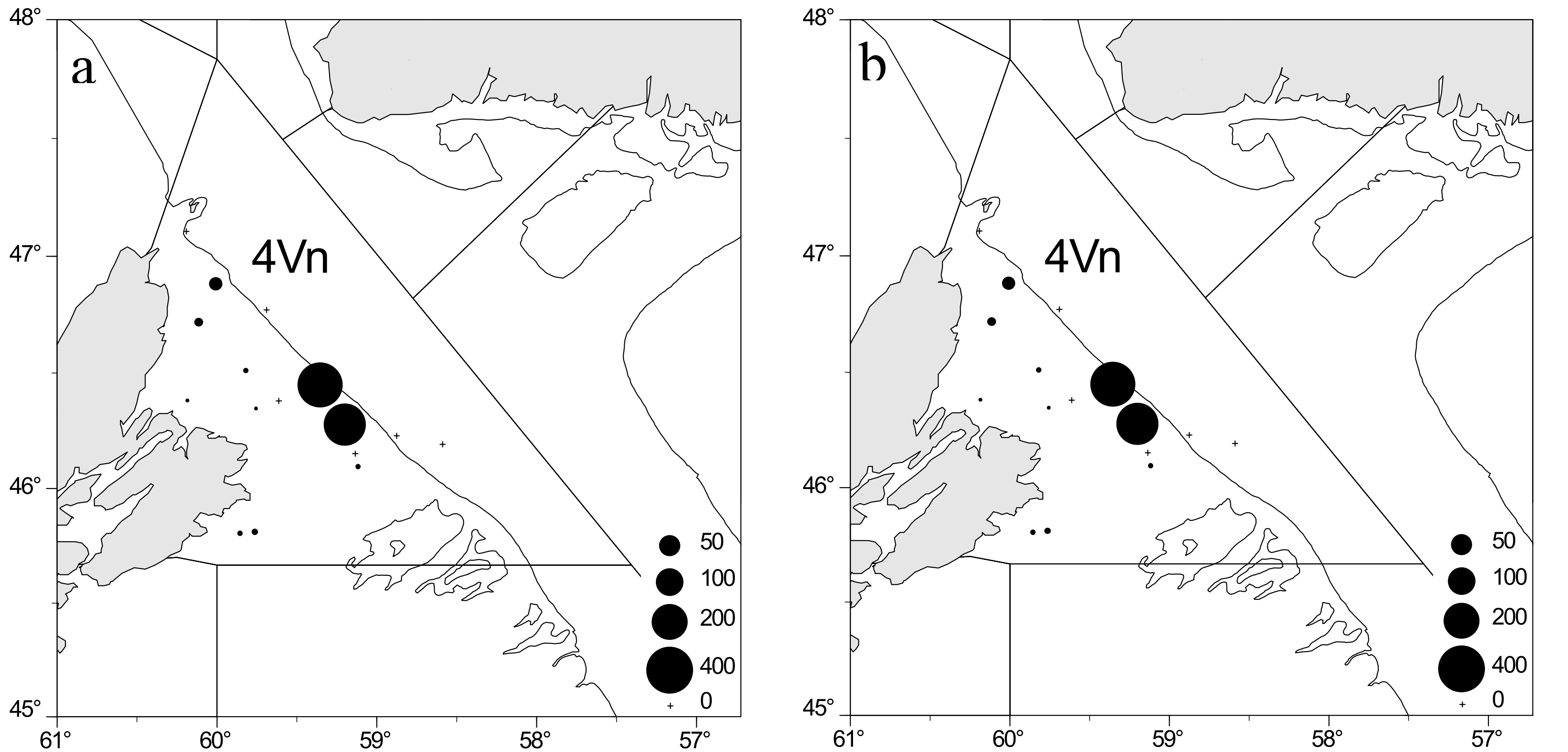


Figure 3.2.7.2. Geographic distribution of research vessel survey catches of cod in Sydney Bight (NAFO Subdivision 4Vn) during July in years (a) 1970, and (b) 2001. Symbols represent number of cod per set.

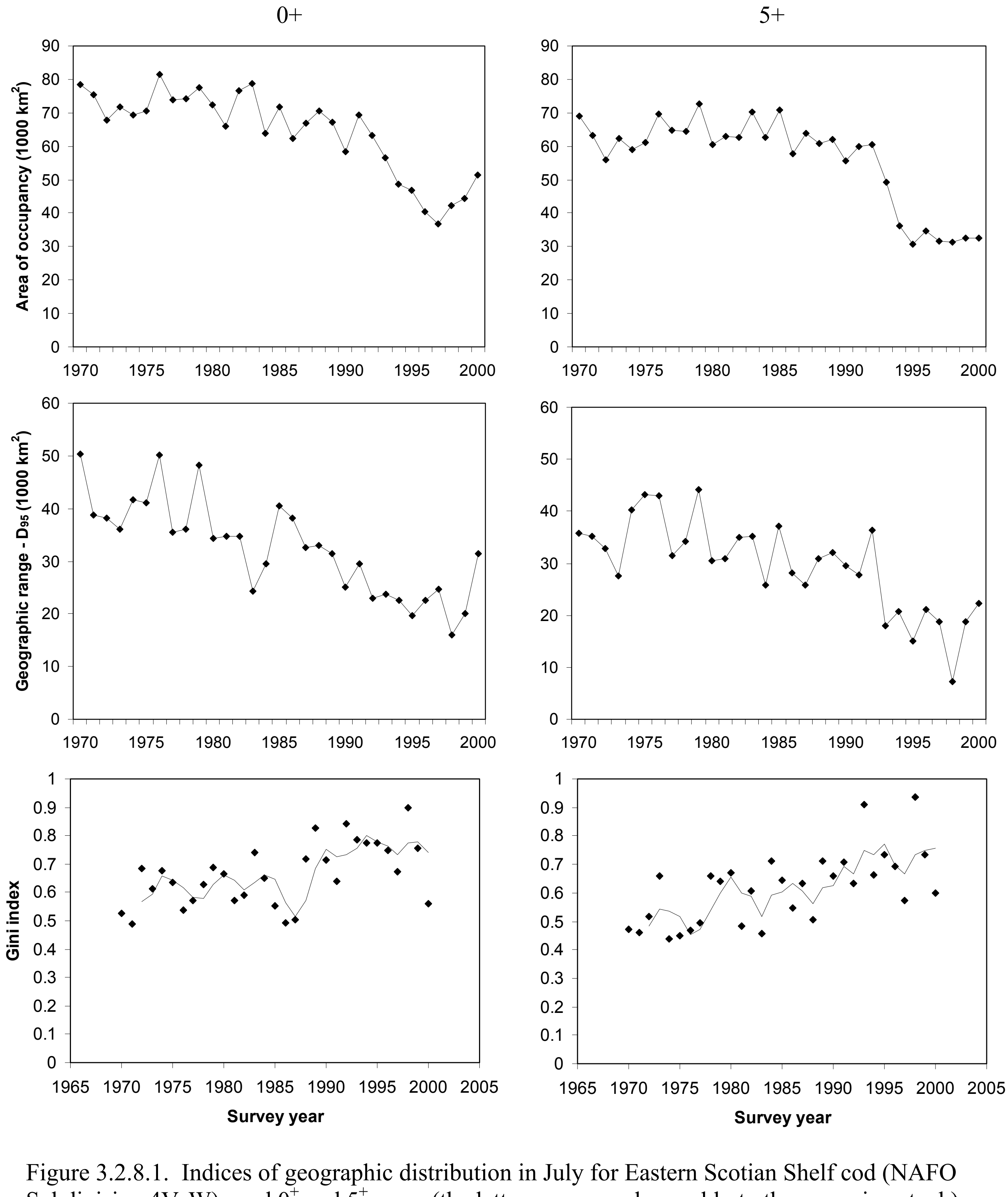


Figure 3.2.8.1. Indices of geographic distribution in July for Eastern Scotian Shelf cod (NAFO Subdivision 4VsW) aged 0^+ and 5^+ years (the latter corresponds roughly to the spawning stock). Line on the Gini index panels is a 3-yr moving average.

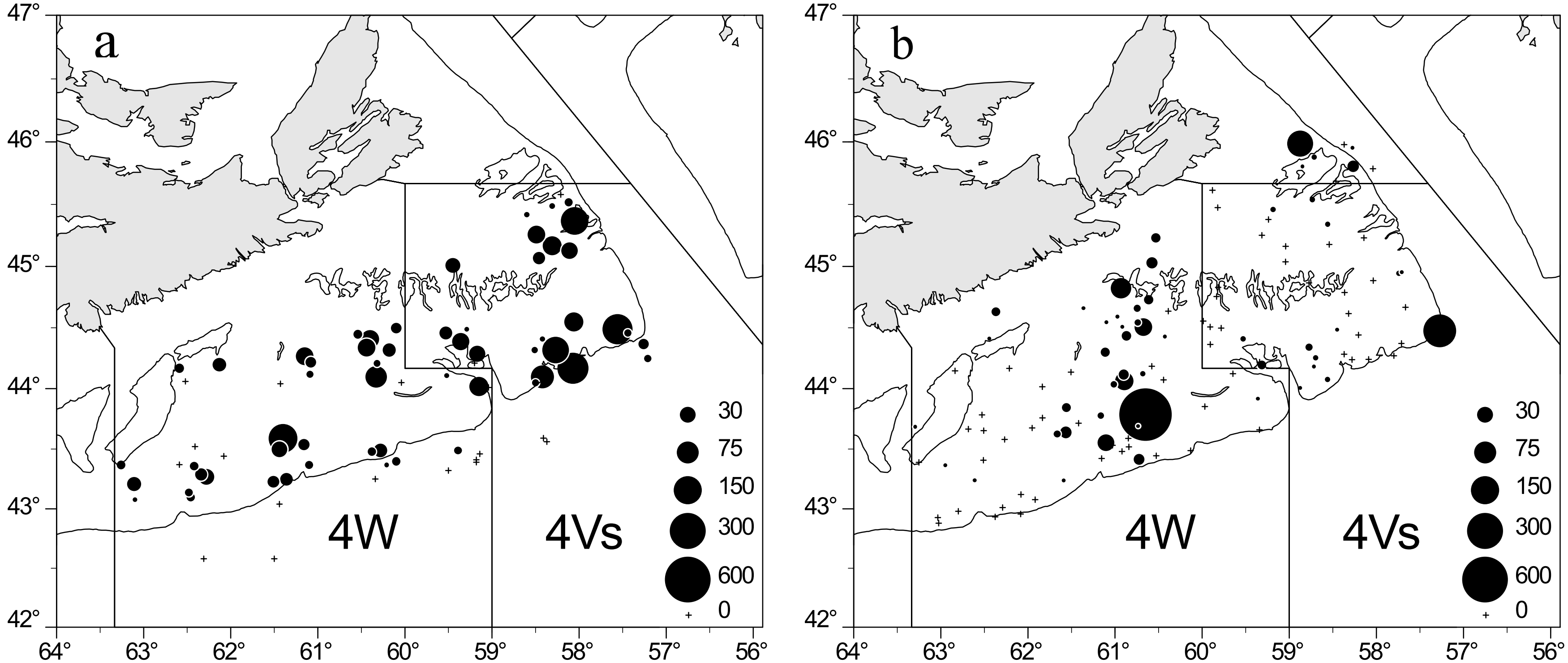


Figure 3.2.8.2. Geographic distribution of research vessel survey catches of cod on the Eastern Scotian Shelf (NAFO Subdivision 4VsW) during July in years (a) 1970, and (b) 2001. Symbols represent number of cod per set.

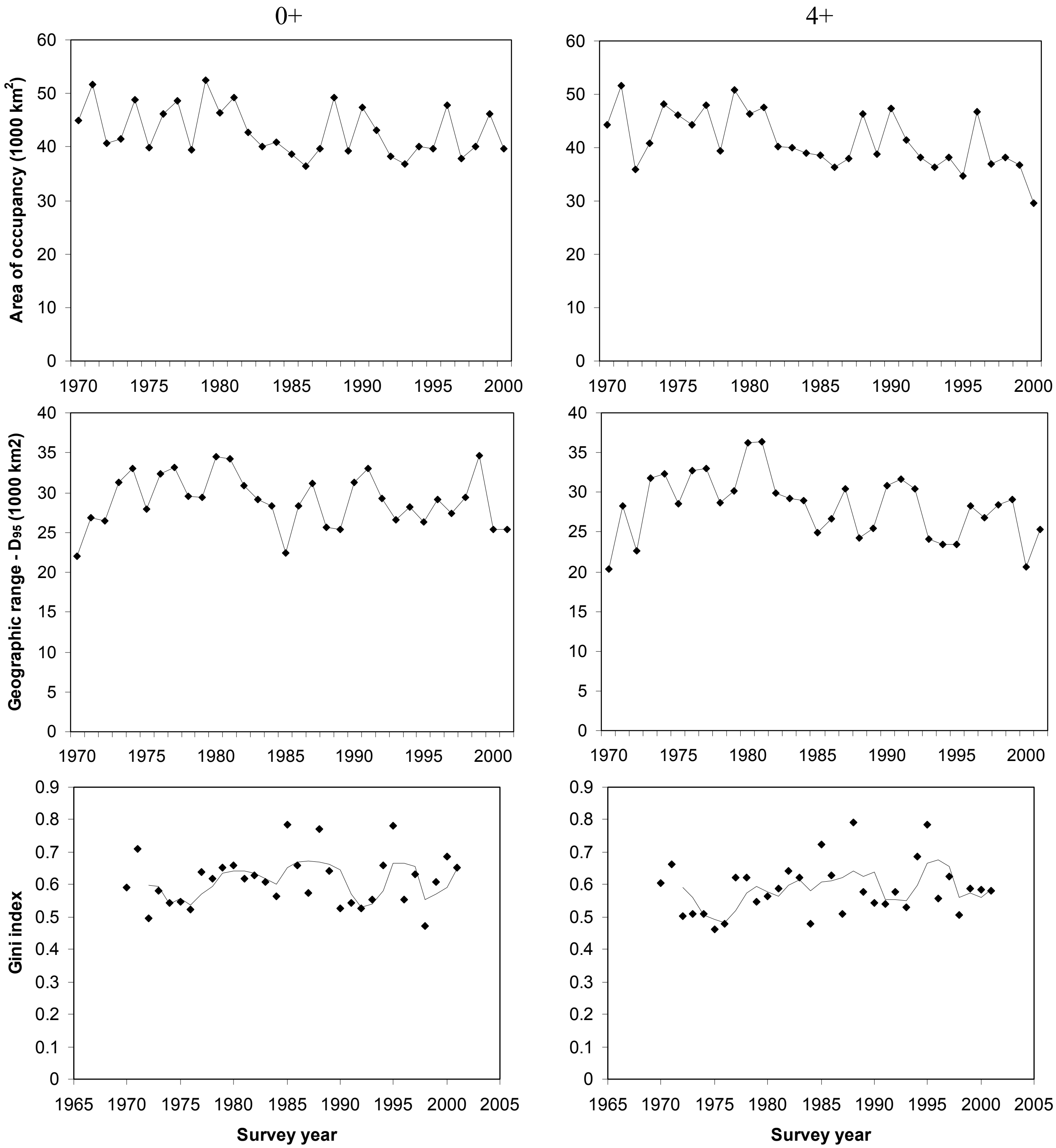


Figure 3.2.9.1. Indices of geographic distribution in September for Western Scotian Shelf/Bay of Fundy cod (NAFO Subdivision 4X/5Y) aged 0^+ and 4^+ years (the latter corresponds roughly to the spawning stock). Line on the Gini index panels is a 3-yr moving average.

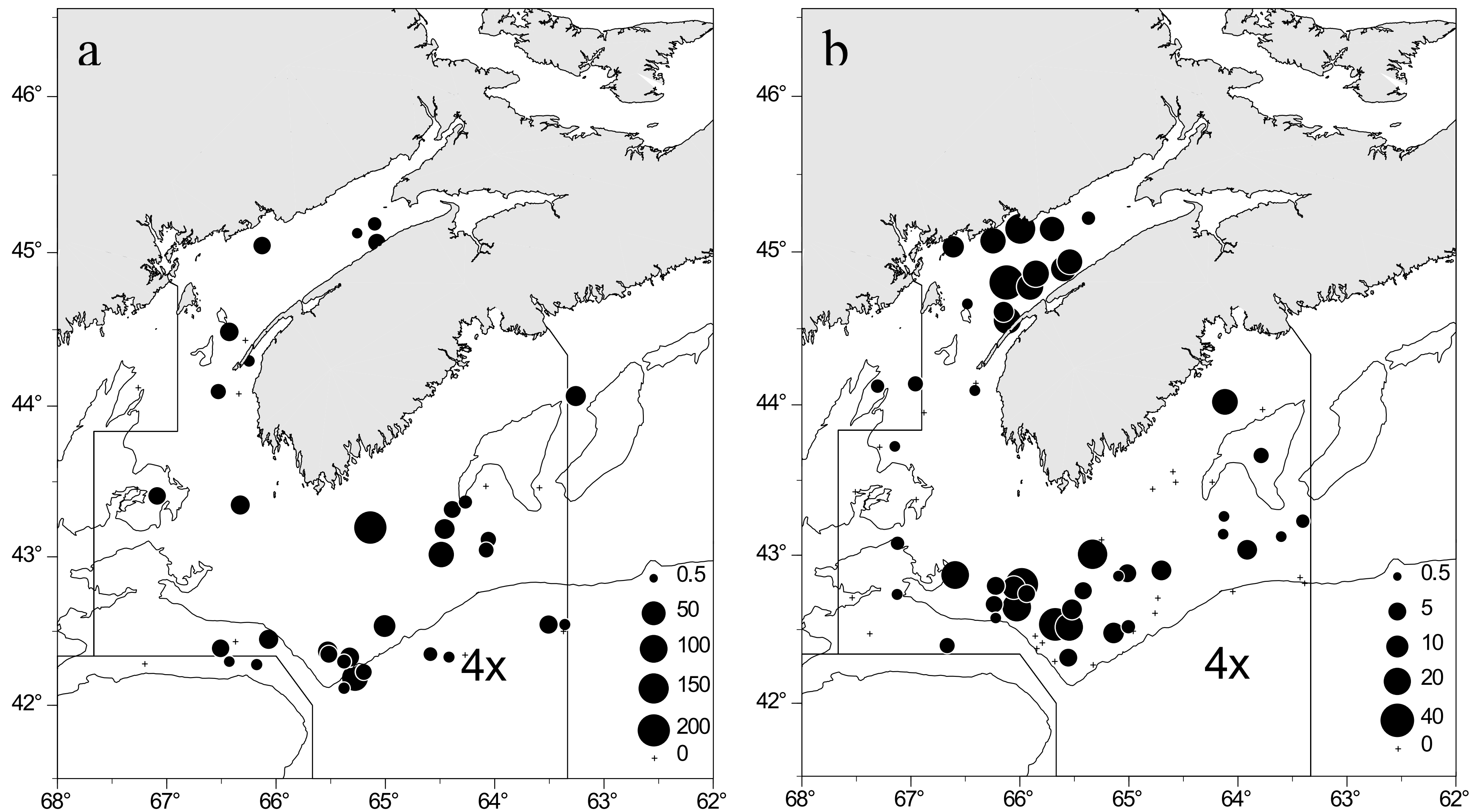


Figure 3.2.9.2. Geographic distribution of research vessel survey catches of cod on the Western Scotian Shelf/Bay of Fundy (NAFO Subdivision 4X/5Y) during July in years (a) 1970, and (b) 2001. Symbols represent number of cod per set. Note change in scale from (a) to (b). Symbols represent number of cod per set.

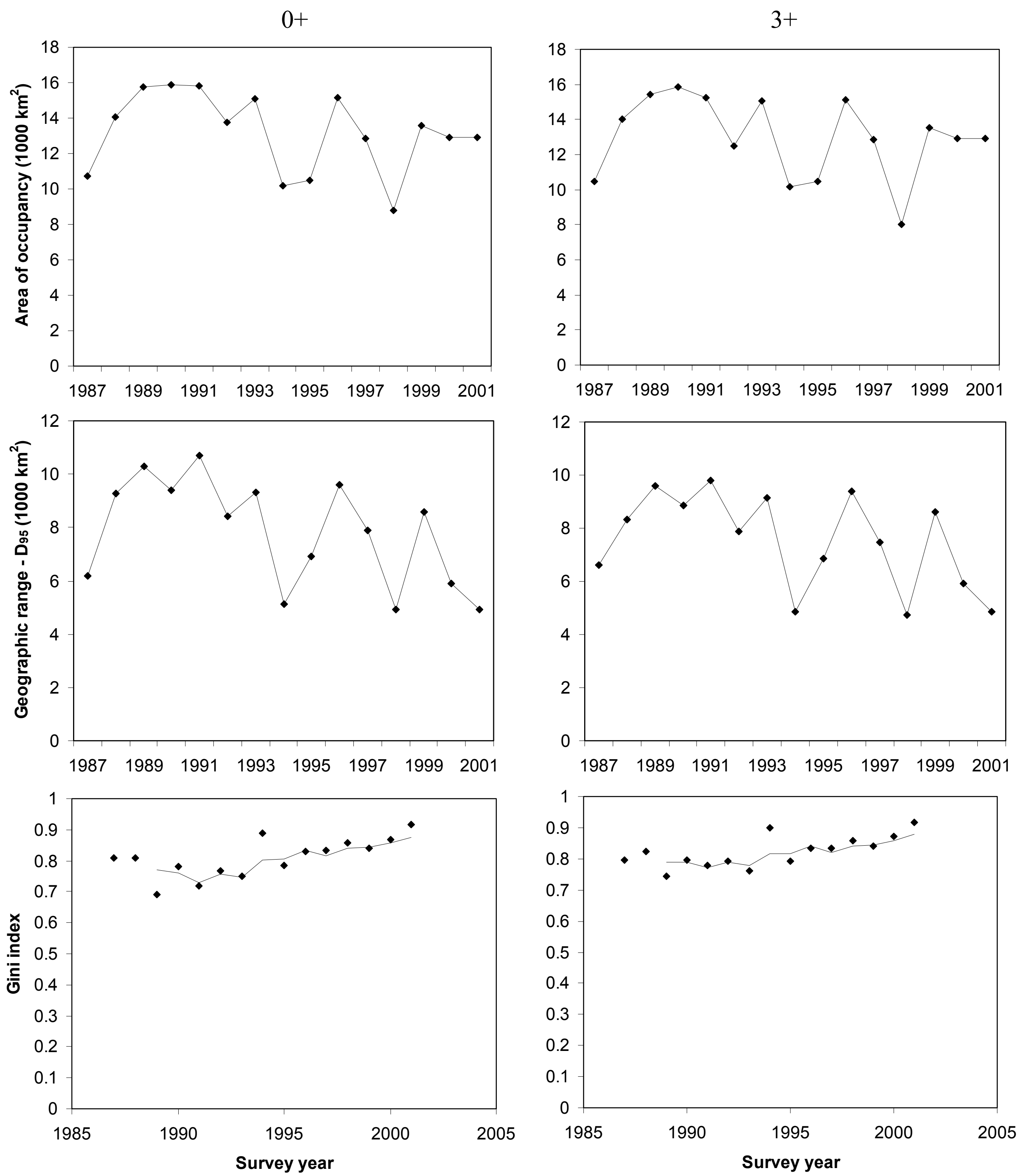


Figure 3.2.10.1. Indices of geographic distribution in September for Georges Bank cod (Unitarea 5Zej and 5Zem) aged 0^+ and 3^+ years (the latter corresponds roughly to the spawning stock). Line on the Gini index panels is a 3-yr moving average.

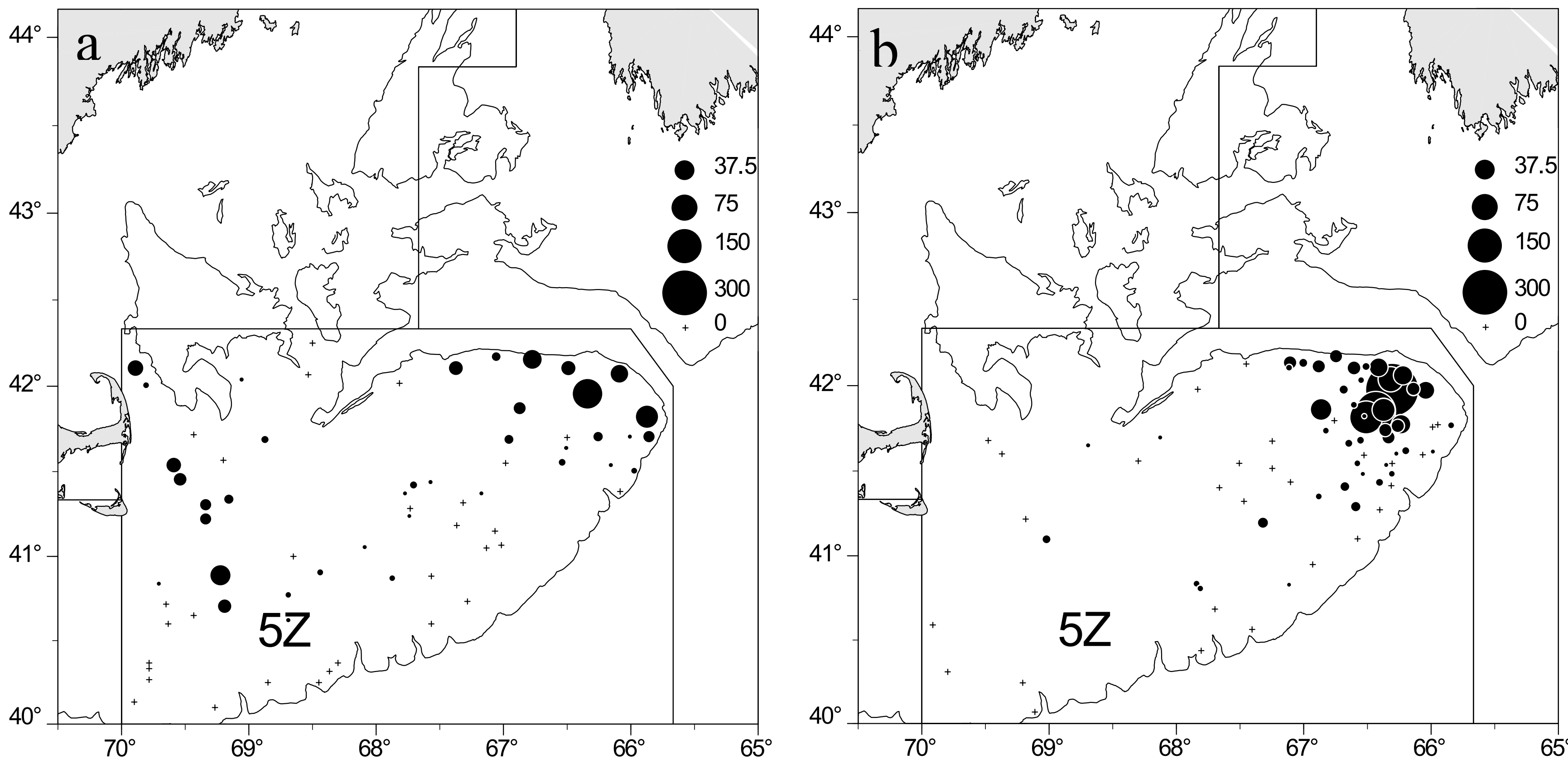


Figure 3.2.9.10. Geographic distribution of research vessel survey catches of cod on Georges Bank (NAFO Unitarea 5Zej and 5Zem), in the spring of years (a) 1987, and (b) 2001. Symbols represent number of cod per set.