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A Summary of the February 2003 Assessment of the Divisions 2J+3KL Stock of Atlantic Cod (*Gadus morhua*)

by

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Abstract

Status of the Divisions 2J+3KL cod stock was assessed based on data from research bottom-trawl surveys, sentinel surveys, pre-recruit surveys, acoustic surveys in specific areas, tagging studies, a questionnaire completed by fish harvesters, catches from the commercial and recreational fisheries, and catch rates from the commercial fishery. The dynamics of those cod that have been in the inshore since approximately the mid-1990s have been different from those of cod occupying the shelf. An index of spawner stock biomass (SSB) in the offshore, based on catches during autumn research bottom-trawl surveys, declined rapidly during the early-1990s, and since the mid-1990s has been less than 2% of average levels during the 1980s. The trend in SSB of those cod that have been inshore was inferred from a sequential population analysis (SPA) that incorporated catches during 1995-2002 and indices from the sentinel surveys and research vessel inshore strata. The SPA estimates indicate that spawner biomass in the inshore increased from 1995 to 41 000 tons in 1998, but has subsequently declined to only 14 000 tons at the beginning of 2003.

Key words: northern cod, stock assessment, stock structure, population analysis, surveys, catch rates, tagging

Introduction

The northern (Div. 2J+3KL, Fig. 1) cod stock off southern Labrador and eastern Newfoundland has supported a commercial fishery since the 16th century. For the century prior to 1960 the catches were generally less than 300 000 tons. With high catches in the late-1960s, mainly by non-Canadian fleets, the stock declined until the mid-1970s. After the extension of jurisdiction in 1977, the stock increased until the mid-1980s but then collapsed in the late-1980s and early-1990s. A moratorium on commercial fishing was declared in July 1992.

Historically many northern cod migrated from overwintering areas offshore to feeding areas inshore. From the 1960s until the moratorium, the fishery was prosecuted with large trawlers in the offshore, mainly in the winter and spring, and a fleet of smaller vessels in the inshore that deployed traps, gillnets and hook and line from late spring to autumn. There have always been some fish that have overwintered inshore. Following the collapse, a substantial portion of the remaining fish in the stock area appears to be inshore throughout the year.

The offshore of Div. 2J+3KL has remained under moratorium, but fish in the inshore became subject to a directed fishery in 1998, when a TAC was established for vessels under 65 feet in length. This fishery opened for a limited period each year until 2002. The whole stock area was once again placed under moratorium in 2003.

The status of the stock was assessed in winter 2001 (DFO, 2001) and scientific documentation was provided to NAFO (Lilly *et al*., 2001). A full assessment was not conducted in 2002, but an update was prepared (DFO, 2002) and reported to NAFO (Shelton *et al*., 2002). A full assessment was again conducted during winter 2003. Technical documentation of this most recent assessment has not been completed, but will eventually appear as Lilly et al. (2003). The following summary is based on the Canadian 2003 Stock Status Report (DFO, 2003), with additional details provided on trends in spawning stock biomass (SSB) as inferred from research bottom-trawl surveys in the offshore and a new sequential population analysis (SPA) for fish in the inshore.

The Fishery

Catches of northern cod increased during the 1960s to a peak of over 800 000 tons in 1968, declined steadily to a low of 140 000 tons in 1978, recovered to about 240 000 tons through much of the 1980s, and then declined rapidly in the early-1990s in advance of a moratorium on directed fishing in 1992 (Fig. 2).

Catches during 1993-1997 came from by-catches, food/recreational fisheries, and DFO-industry sentinel surveys that started in 1995. A small index/commercial fishery limited to fixed gear deployed from small (<65 feet) vessels commenced in 1998. Catches from 1998 to 2002/2003 came from directed cod fisheries, by-catches, sentinel surveys and food/recreational fisheries.

The TAC of 5 600 tons for 2002/2003 was to include all catches, including those from the food/recreational fishery. The index fishery was conducted on the basis of individual quotas. Participants were licensed to fish only in the Division of their home port, with an additional restriction within Div. 3L to either north or south of Grates Point. Therefore, landings within each Division (or area within Div. 3L) should reflect both the availability of fish and the number of licenses in the area.

Participants in the index fishery were permitted to direct for cod with a limited quantity of either gillnets or line trawls. Handlines could be fished in conjunction with either gear. Traps were permitted only to obtain fish for grow-out. Cod taken as by-catch in other fisheries were counted against individual quotas.

The recreational fishery was regulated by license and individuals were limited to 15 fish controlled by possession of tags. License holders were required to complete and return catch logs.

Reported landings were approximately 3 500 tons from the index fishery, 100 tons from the sentinel surveys, and 600 tons from the food/recreational fishery, for a total of 4 200 tons. It is known that in recent years there have been removals in excess of reported landings, but the magnitude of such removals is unknown. When all sources of landings were combined, gillnets contributed 66% by weight, line trawls 1%, handlines 29% and traps 3%. Landings from Div. 2J were <1% by weight, increasing to 16% in Div. 3K and 84% in Div. 3L. The percentage of the total landings taken in Div. 3K has declined steadily from 44% in 1998. The landings have become increasingly concentrated in space. In 2002, 36% was taken in Trinity Bay and an additional 13% was landed at the community of Bonavista just to the north of Trinity Bay.

No sampling of the recreational catch was carried out. Sampling of the commercial catch was insufficient in some cases and was augmented by sentinel survey data. The total catch at age comprised a range of ages, with ages 3-12 being important contributors and age 5 being most prominent. Ages 5-7 were most prominent in gillnets and ages 4-5 were most prominent in handlines.

Industry Perspective

A perspective on several aspects of the 2002 sentinel survey and index fishery is available from the responses to a questionnaire sent by the Fish, Food and Allied Workers Union (FFAW) to all Fish Harvester Committees in Div. 2J+3KL. Responses were received from 74 of 138 committees.

In response to whether commercial catch rates in 2002 were high, average or low compared with historical averages, 12% said high, 28% said average and 61% said low. All but seven responses from southern Labrador (Div. 2J) to northern Bonavista Bay (Div. 3L) were “low”. The appearance of average catch rates for a period at two sites in southern Labrador represents the first indication in many years of the presence of adult cod in Div. 2J. From inner Bonavista Bay to the western side of Trinity Bay the majority of the responses were “high”. From inner Trinity Bay to the southern Avalon Peninsula the responses were “average” or “low”, with responses of “low” coming from almost all sites in Conception Bay and the eastern Avalon Peninsula.

In response to whether commercial catch rates were higher, the same or lower than during the 2001 fishery, 12% said higher, 44% said they were the same, and 44% said lower.

In response to whether "signs" of small (up to 18 inches) fish were better, the same or worse than in 2001, 64% said better, 26% said the same and 10% said worse. Improving signs of small fish have been noted for several years. In response to whether the overall condition of cod caught during 2002 was good, average or poor, 60% said good and 40% said average. Good or average condition has been noted every year in these surveys.

In response to whether the trends seen in standardized sentinel and commercial catch rates are reflective of their perception of the overall trend in stock status, 72% said yes and 28% said no. Most of the "no" responses came from Bonavista Bay and Trinity Bay. It is understood that fish harvesters who said "no" meant that the actual status is better than reflected by those indices.

Resource Status

Stock structure

Since the mid-1990s, there has been a dichotomy between the inshore and the offshore. Cod in the offshore have been small and at very low density, whereas cod in the inshore have included larger sizes and have been found in relatively high densities in some times and places. Various observations, both historic and recent, and much of the genetic information, are consistent with the hypothesis that there are in the inshore populations that are distinct from those in the offshore. It is thought that these inshore populations have historically been small relative to the populations that migrated into the inshore from the offshore during spring/summer.

Tagging studies, conducted during the post-moratorium period while the overall stock size remains extremely low, indicate that the inshore of Div. 3KL is currently inhabited by at least two groups of cod: (1) a northern resident coastal group that inhabits an area from western Trinity Bay northward to western Notre Dame Bay and (2) a migrant group that overwinters in inshore and offshore areas of Subdiv. 3Ps, moves into 3L during late spring and summer and returns to Subdiv. 3Ps during the autumn. The tagging also indicates considerable movement of cod among Trinity, Bonavista and Notre Dame Bays. It is not known if there is currently movement between the inshore and the offshore in Div. 2J+3KL. There has been only one reported offshore recapture of a cod tagged inshore after the mid-1990s, but of course there has been no directed offshore cod fishery during this period, so recaptures could come only from fisheries directed at other species.

Population Indices

The offshore biomass index values from the autumn research bottom-trawl surveys in Div. 2J+3KL have been very low for the last 10 years. The average trawlable biomass of 28 000 tons during 1999-2002 is about 2% of the average in the 1980s (Fig. 3).

Slightly elevated presence of fish has been noted since about 1999 on the outer shelf near the 3K/3L boundary. Extension of the survey into the inshore since 1996 (with the exception of 1999) has resulted in some moderate catches in some years, particularly in the Trinity Bay to Bonavista Bay area.

The spawning stock biomass index computed from the autumn surveys has remained steady during the most recent four years at less than 2% of the average level of the 1980s (see Appendix 1).

The biomass index from the spring research bottom-trawl survey in Div. 3L continues to be very low, at less than 1% of the average in the 1980s (Fig. 4).

Hydroacoustic studies have been conducted in Smith Sound in western Trinity Bay (Div. 3L) at various times since spring 1995.   Surveys in January provided average indices of biomass that increased from 1999 to a peak of about 26 000 tons in 2001 and then declined to 23 000 tons in 2002 and 20 000 tons in 2003.

Hydroacoustic studies were also conducted in two specific areas in the offshore. Biomass estimates from these studies are considered to be more uncertain than those from Smith Sound. Biomass estimates for Hawke Channel in Div. 2J declined from 1994 to 1996 and varied between 2 000 and 7 000 tons during 1998-2002. Biomass estimates from the saddle along the Div. 3K/3L boundary declined from about 450 000 tons in 1990 to less than 5 000 tons in 1994. Biomass in the area was extremely low through the mid-1990s, but has increased somewhat in recent years (about 1 000 tons in 2000-2001 and about 9 000 tons in 2002). Most of the fish in both areas in recent years have been younger than age 6.

The sentinel surveys in Div. 2J+3KL were initiated in 1995 to provide catch rates and biological samples of cod in inshore waters. Catch rates have been relatively low since the start of the survey in Div. 2J and in 3K north of White Bay. However, fish have existed in sufficient density to enable moderate to high catch rates in some times and places from White Bay to the southern boundary of the stock. Catch rates have declined since 1998 in Div. 3K and southern Div. 3L.

The sentinel survey data were standardized to remove site and seasonal effects and produce annual indices of total catch rate and catch rate at age for Div. 3K and 3L combined. Gillnets and line trawls were treated separately (Fig. 5). Gillnet catch rates increased from 1995 to 1998 but then declined to 2002. Line trawl catch rates showed relatively little change from 1995 to 1996, increased in 1997, and then declined to 2002, with a small increase in 2001.

The sentinel survey catch rates at age indicated that the 1990 and 1992 year-classes were relatively strong and that subsequent year-classes are weaker. The catch rate at age 3 in the small mesh (3 ¼ inch) gillnets in 2002 (the 1999 year-class) were the highest in the time series, providing evidence of improved recruitment.

Commercial catch rates were calculated from catch and effort data recorded in logbooks maintained by commercial fishermen in the <35 foot sector. The overall spatial pattern for gillnets, the predominant gear, has been similar among years (Fig. 6). Catch rates have been consistently low in Div. 2J (not illustrated) and northern Div. 3K. Since the fishery opened in 1998, catch rates have declined in both southern Div. 3K and southern Div. 3L, and have remained high only in northern Div. 3L, most notably in southern Bonavista Bay and northern Trinity Bay. The area in which high catch rates can be obtained has declined considerably since 1998.

The catch rates from logbooks were standardized to remove site and seasonal effects and to produce an annual estimate of total catch rate for Div. 3K and 3L combined. Gillnet catch rates declined from 1998 to 2002 (Fig. 7). Data were insufficient to fit the same model to catch rates from line trawl.

Inshore surveys of young cod (ages 0 and 1) have been conducted with beach seines in shallow coastal waters, which are thought to be the main nursery areas for northern cod. Surveys were conducted over a broad spatial scale in 1992-1997 and 2000 and on a finer spatial scale in 1995-96 and 1998-2002. Catch rates of young cod were low in the mid-1990s but higher in the late-1990s.

Population Biology

The proportion mature at age increased among young female cod sampled during the autumn bottom-trawl surveys during the early-1990s and has fluctuated since (Fig. 8). For example, the proportion of age 6 cod that are mature increased from about 0.4-0.6 in the 1980s to greater than 0.6 since the early-1990s. Males generally mature about one year younger than females and show a similar trend over time.

Size-at-age of cod sampled during the autumn surveys declined during 1983-1985 and again in the early-1990s, especially in 2J (Fig. 9). Size-at-age has increased in recent years but is below peak values observed in the late-1970s. Much of the variability in growth is related to variability in water temperature.

Condition of cod, as measured by both gutted body weight and liver weight relative to fish length, declined in the offshore during the early-1990s, especially in 2J. Since the mid-1990s, condition levels have been similar to those measured in the mid-1980s.

Population Analysis

Age specific mortality rates (proportion of population dying in a year) were calculated from catch rates during the autumn Div. 2J+3KL bottom-trawl survey. The rates for all ages rose to very high levels by the early-1990s, and remained extremely high for a few years after the start of the moratorium in 1992. The paucity of older fish (7+) in the survey since the early-1990s prevents estimating total mortality on these older ages. For younger ages (Fig. 10), mortality has remained very high (40-60% per year at age 4 and 60-80% per year at age 6).

A recruitment index was derived from catch rates of juvenile (ages 0-3) cod during various studies that have been conducted since the early-1990s. Studies that are still contributing data are the stratified-random bottom-trawl surveys, both inshore and offshore, sentinel surveys (line trawl, 5.5 inch gillnet and 3.25 inch gillnet) and beach seine surveys. The recruitment data from inshore and offshore were treated together because the inshore appears to be an important nursery area for cod spawning in both the inshore and the offshore.

These data were combined to produce a single index of relative year-class strength (Fig. 11). This index was low through much of the 1990s, but shows a pulse of better recruitment starting toward the end of the decade, with the 2000 year-class higher than any other in this short series. The 2001 and 2002 year-classes appear weak. The 2002 year-class is estimated with low precision.

It should be noted that strength of all of these year-classes is much lower than the strength of those that occurred during the 1980s. Moreover, the ability of the index to predict recruitment to the fishable population remains uncertain, particularly because it does not pick up the 1992 year-class that was relatively strong in sentinel and commercial catches.

A large-scale tagging study of adult (>45 cm) cod was initiated in spring 1997 in the Div. 2J+3KL and Subdiv. 3Ps cod stock areas. During 1997-2002 a total of about 78 000 cod were tagged and released and approximately 13 000 of these tagged cod have been reported as recaptured to date. A model has been developed which provides estimates of exploitation rate and exploitable biomass based on tag returns and reported catch. This model also provides estimates of cod body growth rates and the movement rates between stocks and Subareas within stock boundaries.

Results of the tagging experiments (Fig. 12) indicate an exploitation rate close to 20% in the inshore in 2002 associated with a reported catch of 4 200 tons. This harvest rate is in percent of exploitable biomass (approximately ages 4+), which was estimated to be 22 000 tons in the inshore regions of Div. 3KL. The exploitable biomass estimates increased during 1999-2001, but declined sharply in 2002. The tagging studies provided evidence of natural mortality of 55% in Div. 3K and 33% in Div. 3L. These estimates are considered to be independent of unreported catch.

Prior to the collapse of the Div. 2J+3KL cod stock, sequential population analysis (SPA) for the stock as a whole was the main tool used to estimate stock size and trends over time. This method was reintroduced in the current assessment and applied to those cod in the inshore since the mid-1990s. The analysis using ADAPT incorporated catch at age for ages 2 to 10 for years 1995-2002 (Table 2), mean numbers per two from the fall stratified random bottom trawl survey in inshore strata for ages 2 to 9 and years 1996 to 2002 (with the exception of 1999 when no survey was carried out; Table 3), sentinel survey 5 ½ inch gillnet catch rate index for ages 3 to 9 for years 1995 to 2002 (Table 4), sentinel survey 3 ¼ inch gillnet catch rate index for ages 2 to 9 for years 1996 to 2002 (Table 5), and sentinel line trawl catch rate index for ages 3 to 9 for years 1995 to 2002 (Table 6). The structure imposed on the ADAPT estimation included a 10+ age group in the population, a domed-shaped PR with respect to fishing mortality, M = 0.5, and catches assumed to be exact. The parameter estimates are given in Table 7. Estimates of bias corrected numbers at age and fishing mortality at age are given in Tables 8 and 9. The residuals are plotted in Fig. 13-16. Spawning stock biomass computed from the ADAPT bias-corrected numbers at age at the beginning of the year, cohort model estimates of proportion mature at age form survey data, and beginning of year weights at age derived from commercial sample data, indicate that spawner biomass in the inshore increased from 1995 to 41 000 tons in 1998, but has subsequently declined to only 14 000 tons at the beginning of 2003 (Fig. 17). The ADAPT estimate of 4+ biomass at the beginning of 2003 is about 30 000 tons. Fishing pressure on older age classes has been increasing and the exploitation rate is currently at approximately 35%, a level comparable to levels estimated during the stock collapse in the late-1980s and early-1990s.

Both the SPA and a recruitment model indicate that the 1999 and 2000 year-classes are stronger than other year-classes since the mid-1990s, but are very weak compared to historic levels.

The SPA indicates that the inshore spawner biomass has been decreasing since 1998 when the fishery reopened. Deterministic projections indicate that the stock will grow slightly in the short term as a consequence of the incoming recruits, but will decline thereafter if exploitation rates remain at current levels. Projections also indicate that even without fishing the spawner biomass will not grow during the next decade to the level reached in 1998, under the assumption that stock productivity does not increase above present levels.

Under a precautionary approach, conservation limit reference points need to be defined to demarcate when the stock is considered to have impaired productivity and is thus in a situation in which serious harm has occurred. Northern cod productivity is impaired and serious harm has occurred. When the spawner biomass of the Div. 2J+3KL cod stock as a whole approaches 150 000 tons, the available data will be reviewed with the objective of determining appropriate spawner biomass limit reference points in keeping with a precautionary approach. Based on historic data, it is anticipated that appropriate conservation limit reference levels will be set at levels greater than 300 000 tons for the stock as a whole. Recovery of spawner biomass to this level is expected to take many years. While the stock remains below this level, there is a high likelihood that the productivity of the stock will remain impaired.

Multispecies Considerations

The quantity of cod consumed by harp seals during the period 1965-2000 was calculated using estimates of harp seal population numbers, energy requirements of individual seals, the average duration of seal occurrence within Div. 2J+3KL, the relative distribution of seals between inshore and offshore, and stomach contents of seals sampled in the inshore and offshore in winter and summer. An average diet was calculated for each of the four combinations of area (inshore and offshore) and season (winter and summer) using all stomach content data collected in Div. 2J+3KL during the years 1982 and 1986-1998. Uncertainty in the estimates of numbers at age, diets, residency time in Div. 2J+3KL and the proportion of seals in nearshore areas, were used to evaluate the possible range in consumption estimates. The only factor effecting annual changes in the estimates of prey consumption is the estimate of seal population numbers. Recent estimates of harp seal population size show that the population reached about 5 million in 1996 and has been fairly stable since.

Based on the average diets, it is calculated that harp seals consumed 37 000 tons of cod in 2000 (with a 95% confidence interval of 14 000-62 000 tons) (Fig. 18).

Diet data from the inshore show that the per capita consumption of cod by harp seals has not declined with the collapse of the cod stock.

Numbers of cod at age consumed by harp seals from 1986 to 1998 were estimated from otoliths found in seal stomachs and total consumption estimates calculated from the seal consumption model. From 1986 to 1996 cod age 0 and 1 were the predominant age groups found in harp seal stomachs. In 1997 and 1998 older fish (ages 3-5) were the dominant age groups and fish as old as age 7 were found more frequently than in previous years. With this shift to older, larger cod the total number of fish consumed has decreased in recent years while the estimates of total biomass consumed have been relatively constant.

The estimates of cod consumption may be biased upwards because stomach content analysis relies on the presence and identification of hard parts (such as cod otoliths). Diet contributions from soft bodied animals or species with small otoliths may be missed or underrepresented.

The estimates of consumption of large cod by seals may also be biased downwards because incidences of belly-feeding will go undetected in diet studies. Belly-feeding is a mode of predation on fish which are usually too large to be consumed whole. The seal takes a bite from the belly of the fish, removing the liver and gut, but not consuming the muscle or hard parts. The weight of fish killed during an incident of belly feeding is much greater than the weight of fish consumed. Observations of belly-feeding were more frequent during 1998-2000 than in recent years, and occurred mainly in Notre Dame Bay and southern Bonavista Bay. Reports are still received, most notably from Smith Sound (Trinity Bay) where seal sightings have increased.

The trend in biomass of capelin, historically the major prey of cod in Div. 2J+3KL, has been uncertain since the late-1980s. Biomass estimates from hydroacoustic surveys in the offshore have been much lower since the early-1990s compared with the 1980s, but indices of capelin biomass from the inshore have not shown such extensive declines. Some studies of cod condition and feeding indicate that cod may not be faring well in certain seasons and areas, and that this is due to low availability of capelin. Other studies and observations do not suggest any concerns at present about cod growth or condition. Whatever the present circumstances, there remains concern that there may not be sufficient capelin to support a recovery of the cod stock, especially in the offshore and in the north.

Sources of uncertainty

The Div. 2J+3KL cod stock is not recovering and the exact causes remain uncertain. While a number of factors are contributing to lack of recovery, it is uncertain whether or not one or more factors are dominant. Based on available data, it appears that seal predation could be the major factor but very little is known about harp seal diet in the offshore where cod mortality rates are particularly high. Unreported by-catch in the offshore by both domestic and foreign fisheries could also be a contributing factor. Cod mortality rates in the inshore are also high and there are many reports of predation by seals on adult cod. Harp seal diet data also show that cod are continuing to be eaten despite the small size of the stock. The evidence is thus stronger for the inshore that harp seals are playing a role in the high mortality of the cod and delaying recovery. However, unreported by-catches and illegal fishing could also be important.

The ecosystem in which the Div. 2J+3KL cod stock is but one component has experienced dramatic changes since the 1980s. The relative importance of fishing, physical environment and biological interactions in causing and sustaining those changes is difficult to discern. There is considerable uncertainty regarding the extent to which climate variability and climate change may be influencing various aspects of cod well-being, particularly at the early life history stages. There is also much uncertainty about the biomass and availability of prey for cod at various stages of its growth, notably macrozooplankton during its larval and juvenile stages and capelin during its mid-life.

The potential for cod currently in the inshore to repopulate the offshore remains uncertain. Genetic studies using micro-satellites have demonstrated a population substructure between most inshore and offshore areas. It has been suggested that this substruture indicates a low likelihood that inshore-spawning cod will contribute to offshore recovery. However, evidence of substructure may not preclude inshore-spawning cod playing a role in future offshore recovery. If fish currently in the inshore could recolonize the shelf, then allowing the inshore biomass to increase makes it more likely that inshore fish may move offshore.

It is unknown whether cod currently offshore undergo spring/summer feeding migrations to the inshore, and whether a rejuvenating population in the offshore would make use of the rich feeding opportunities that the inshore historically provided. However, there is a strong possibility that offshore cod will continue to migrate inshore and that an inshore fishery could crop off a sizeable portion of any growth in the offshore. Many of the fish historically caught in the inshore were immature, so inshore removals may capture some offshore fish before they have a chance to spawn.

Outlook

The SPA indicates that the inshore spawner biomass has been decreasing since 1998 when the fishery reopened. Deterministic projections indicate that the stock will grow slightly in the short term as a consequence of the incoming recruits, but will decline thereafter if exploitation rates remain at current levels. Projections also indicate that even without fishing the spawner biomass will not grow during the next decade to the level reached in 1998, under the assumption that stock productivity does not increase above present levels.

The information on feeding by seals and trends in the harp seal population indicate that predation by seals is a factor contributing to the high total mortality of cod in the offshore and the high natural mortality of adult cod in the inshore.

Under a precautionary approach, conservation limit reference points need to be defined to demarcate when the stock is considered to have impaired productivity and is thus in a situation in which serious harm has occurred. Northern cod productivity is impaired and serious harm has occurred. When the spawner biomass of the Div. 2J+3KL cod stock as a whole approaches 150 000 tons, the available data will be reviewed with the objective of determining appropriate spawner biomass limit reference points in keeping with a precautionary approach. Based on historic data, it is anticipated that appropriate conservation limit reference levels will be set at levels greater than 300 000 tons for the stock as a whole. Recovery of spawner biomass to this level is expected to take many years. While the stock remains below this level, there is a high likelihood that the productivity of the stock will remain impaired.

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Table 1. Landings (thousand metric tons)

Year	62-76 Avg.	77-91 Avg.	1997	1998	1999	00/01	01/02	02/03
TAC	N/A	N/A	0	4	9	7	6	6
Can. Fixed	88	90	1	5	8	5	7	4
Can. Mobile	9	84	+	+	0	+	+	+
Others	405	38	0	0	+	+	+	+
Totals	502	212	1	5	8	5	7	4

+ Catch less than 500 t.

Table 2. Catch nuumbers at age (thousands) used in the inshore ADAPT.

	2	3	4	5	6	7	8	9	10
1995	0	7	30	71	55	20	11	3	0
1996	1	40	237	297	341	129	23	5	3
1997	0	8	23	54	56	84	21	3	2
1998	3	96	229	395	689	384	237	74	18
1999	7	70	238	638	795	1157	370	253	68
2000	5	141	258	419	437	328	294	151	178
2001	10	249	778	710	611	365	190	272	234
2002	6	166	296	399	335	235	124	77	227

Table 3. Research vessel inshore bottom trawl survey mean numbers per tow at age index.

	2	3	4	5	6	7	8	9
1996.92	3.64	1.61	1.21	0.78	1.02	0.54	0.26	0.24
1997.92	1.80	1.11	0.78	0.46	0.06	0.11	0.05	0.05
1998.92	1.42	0.42	0.20	0.06	0.06	0.02	0.01	0.01
2000.92	4.28	2.01	0.63	0.22	0.06	0.04	0.03	0.01
2001.92	5.15	1.93	0.90	0.31	0.04	0.01	0.00	0.02
2002.92	3.94	0.78	0.34	0.17	0.04	0.00	0.01	0.01

Table 4. Sentinel survey catch rate at age index for 3 ¼ inch mesh gillnets.

	2	3	4	5	6	7	8	9	10
1996.5	0.014	6.955	13.612	5.257	5.461	0.245	0.027	0	0
1997.5	0.011	6.264	9.195	4.341	3.016	2.218	0.354	0.044	0
1998.5	0.038	5.056	5.979	3.466	4.892	2.148	0.828	0.211	0.005
1999.5	0.243	5.487	4.377	2.897	1.286	1.113	0.261	0.094	0.021
2000.5	0.171	6.486	5.994	1.955	1.045	0.333	0.265	0.116	0.058
2001.5	0.245	6.423	6.201	1.845	0.719	0.167	0.052	0.059	0.014
2002.5	0.402	10.235	6.427	1.404	0.553	0.167	0.022	0.013	0.016

Table 5. Sentinel survey catch rate at age index for 5 ½ inch mesh gillnets.

	3	4	5	6	7	8	9	10
1995.5	0.001	0.038	0.852	1.112	0.455	0.259	0.064	0.014
1996.5	0.027	0.107	0.711	3.908	1.637	0.477	0.106	0.028
1997.5	0.015	0.069	1.144	1.708	3.048	0.756	0.099	0.042
1998.5	0.027	0.069	0.899	4.312	2.733	1.459	0.408	0.055
1999.5	0.011	0.076	0.818	1.358	1.921	0.586	0.314	0.078
2000.5	0.015	0.059	0.561	0.895	0.596	0.722	0.314	0.154
2001.5	0.008	0.048	0.255	0.607	0.363	0.175	0.242	0.073
2002.5	0.017	0.047	0.339	0.475	0.392	0.163	0.087	0.110

Table 6. Sentinel survey catch rate at age index for line trawls.

	3	4	5	6	7	8	9
1995.5	0.08	0.38	0.35	0.14	0.05	0.00	0.01
1996.5	0.18	0.28	0.33	0.16	0.04	0.01	0.00
1997.5	0.09	0.26	0.30	0.19	0.13	0.03	0.01
1998.5	0.19	0.31	0.20	0.18	0.04	0.06	0.02
1999.5	0.16	0.30	0.38	0.11	0.02	0.02	0.02
2000.5	0.18	0.39	0.20	0.18	0.02	0.02	0.00
2001.5	0.30	0.37	0.21	0.07	0.04	0.01	0.00
2002.5	0.25	0.37	0.24	0.10	0.02	0.00	0.02

Table 7. Parameter estimates and associated standard error for the ADAPT model fit for inshore catch and survey indices.

		MSE = 0.56					
				Standard		Relative	Relative
		Parameter	Estimate	Error	Bias	Bias	error
Population est	3	N[2003 3]	51437	31718	13578	0.26	0.62
	4	N[2003 4]	16060	6278	2398	0.15	0.39
	5	N[2003 5]	7058	2375	925	0.13	0.34
	6	N[2003 6]	3460	1188	478	0.14	0.34
	7	N[2003 7]	1176	471	199	0.17	0.40
	8	N[2003 8]	455	246	109	0.24	0.54
	9	N[2003 9]	233	149	70	0.30	0.64
	10	N[2003 10]	654	547	262	0.40	0.84
		Fratio[1995 10]	0.50	0.06	0.01	0.02	0.12
RV inshore	2	q ID#[1]	0.00014286	5.54152E-05	1.95E-07	0.00	0.39
	3	q ID#[2]	0.000102206	3.77417E-05	-3.48E-07	0.00	0.37
	4	q ID#[3]	8.1003E-05	3.00051E-05	-4.52E-07	-0.01	0.37
	5	q ID#[4]	6.04244E-05	2.32671E-05	-3.94E-07	-0.01	0.39
	6	q ID#[5]	3.21497E-05	1.37582E-05	-6.58E-08	0.00	0.43
	7	q ID#[6]	3.38994E-05	1.68083E-05	7.00E-07	0.02	0.50
	8	q ID#[7]	3.57785E-05	2.02759E-05	2.0932E-06	0.06	0.57
	9	q ID#[8]	6.95462E-05	4.44033E-05	7.78222E-06	0.11	0.64
Gillnet 5 1/2 inch	3	q ID#[9]	7.52E-07	2.51E-07	-1.31E-08	-0.02	0.33
	4	q ID#[10]	6.81282E-06	2.30E-06	-1.31E-07	-0.02	0.34
	5	q ID#[11]	0.000106852	3.79546E-05	-2.02E-06	-0.02	0.36
	6	q ID#[12]	0.00038974	0.000151787	-5.52E-06	-0.01	0.39
	7	q ID#[13]	0.000553074	0.000244484	-1.16E-07	0.00	0.44
	8	q ID#[14]	0.0004537	0.000228008	1.09975E-05	0.02	0.50
	9	q ID#[15]	0.000271587	0.000156083	1.86219E-05	0.07	0.57
Linetrawl	3	q ID#[16]	0.000926737	0.000309655	-1.60803E-05	-0.02	0.33
	4	q ID#[17]	0.003114053	0.00104992	-5.97176E-05	-0.02	0.34
	5	q ID#[18]	0.003850531	0.001367708	-7.28249E-05	-0.02	0.36
	6	q ID#[19]	0.003280798	0.001277718	-4.64772E-05	-0.01	0.39
	7	q ID#[20]	0.001732238	0.000765725	-3.63E-07	0.00	0.44
	8	q ID#[21]	0.001415611	0.000721711	3.67582E-05	0.03	0.51
	9	q ID#[22]	0.001800128	0.001118495	0.000181425	0.10	0.62
Gillnet 3 1/4 inch	2	q ID#[23]	3.1353E-06	1.15E-06	-2.20E-08	-0.01	0.37
	3	q ID#[24]	0.00049017	0.000171282	-5.38097E-06	-0.01	0.35
	4	q ID#[25]	0.000825151	0.00028788	-1.08442E-05	-0.01	0.35
	5	q ID#[26]	0.000539489	0.00019382	-7.87268E-06	-0.01	0.36
	6	q ID#[27]	0.000530269	0.000207128	-6.5246E-06	-0.01	0.39
	7	q ID#[28]	0.000276322	0.000122593	6.76E-08	0.00	0.44
	8	q ID#[29]	0.000124912	6.31072E-05	2.98942E-06	0.02	0.51
	9	q ID#[30]	0.000105474	6.20854E-05	7.70308E-06	0.07	0.59

Table 8. Bias corrected ADAPT estimates of numbers at age (thousands).

	2	3	4	5	6	7	8	9	10+
1995	25111	35935	15741	18033	6267	1288	761	907	0
1996	22506	15231	21790	9524	10883	3759	766	453	548
1997	19545	13650	9207	13034	5548	6338	2181	447	601
1998	20060	11854	8273	5567	7864	3322	3780	1306	631
1999	27280	12165	7116	4841	3073	4241	1721	2111	1105
2000	29037	16541	7324	4133	2448	1261	1696	762	1704
2001	37496	17608	9924	4244	2186	1152	516	804	1244
2002	62427	22735	10488	5422	2032	863	423	170	857
2003		37859	13661	6133	2982	977	345	163	392

Table 9. Bias corrected ADAPT estimates of fishing mortality at age.

	2	3	4	5	6	7	8	9	10+
1995	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.00	0.00
1996	0.00	0.00	0.01	0.03	0.03	0.04	0.03	0.01	0.01
1997	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00
1998	0.00	0.01	0.03	0.09	0.10	0.13	0.07	0.06	0.03
1999	0.00	0.01	0.04	0.16	0.35	0.35	0.26	0.13	0.07
2000	0.00	0.01	0.04	0.12	0.22	0.34	0.20	0.22	0.11
2001	0.00	0.02	0.09	0.21	0.37	0.41	0.48	0.40	0.20
2002	0.00	0.01	0.03	0.08	0.20	0.33	0.34	0.53	0.26

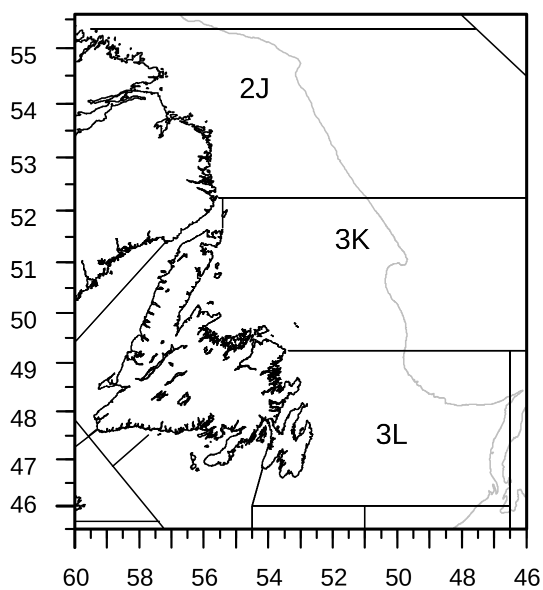

Fig. 1. Divisions 2J, 3K and 3L within the NAFO Convention Area.

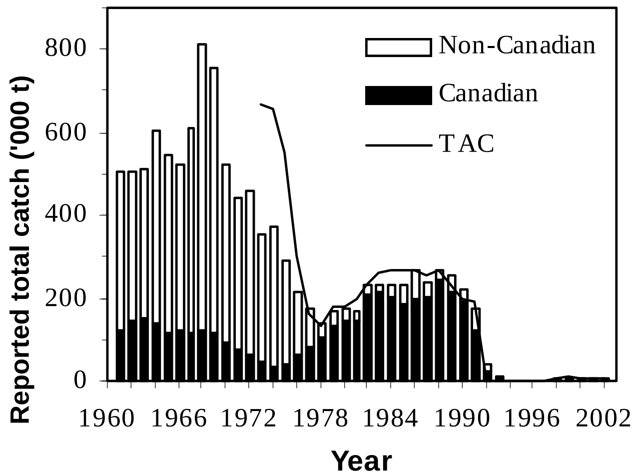

Fig. 2. Reported catch and total allowable catch (TAC, thousands of tons).

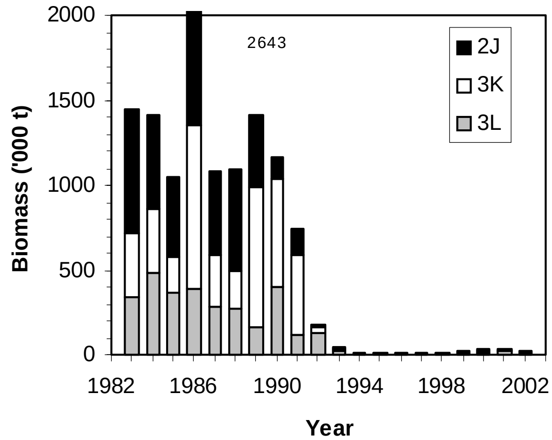

Fig. 3. Biomass index from autumn bottom-trawl surveys in 1983-2002.

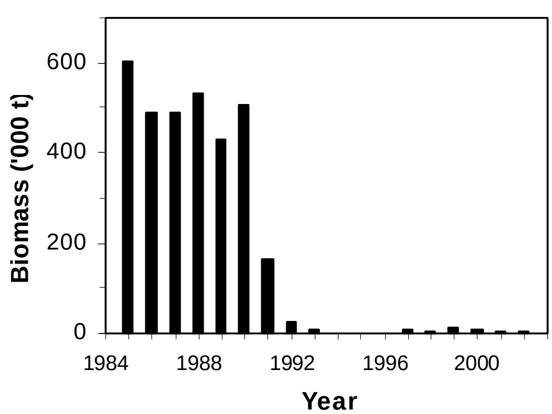

Fig. 4. Biomass index from spring bottom-trawl surveys in Div. 3L during 1985-2002.

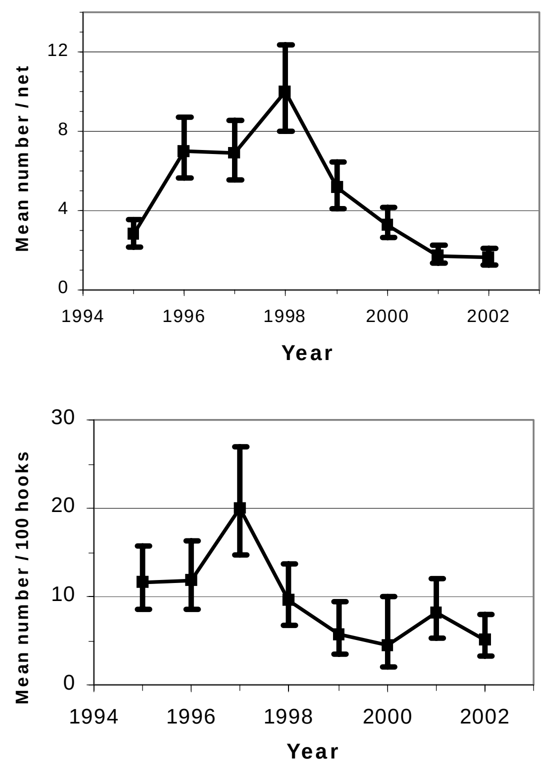

Fig. 5. Standardized catch rates from sentinel surveys in Div. 3KL; gillnets above and line trawls below.

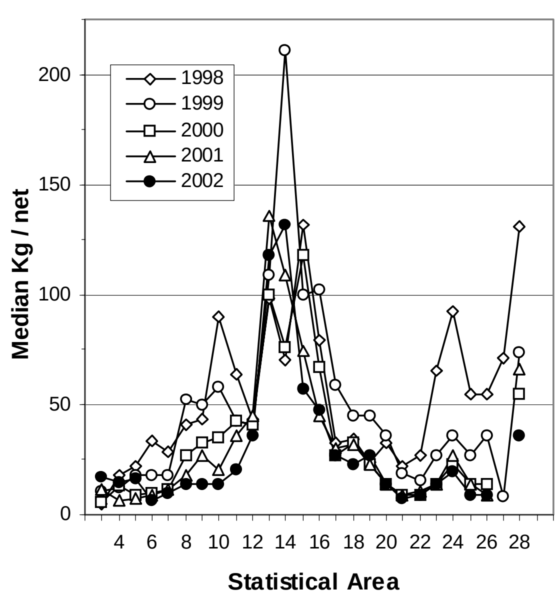

Fig. 6. Median gillnet catch rates from the commercial fishery by statistical area from north to south, for the years 1998-2002. From north to south, area 2 starts at Cape Bauld, 6 at Cape St. John, 10 at Cape Freels, 14 at Cape Bonavista, 20 at Grates Point, 24 at Cape St. Francis and 27 at Cape Race.

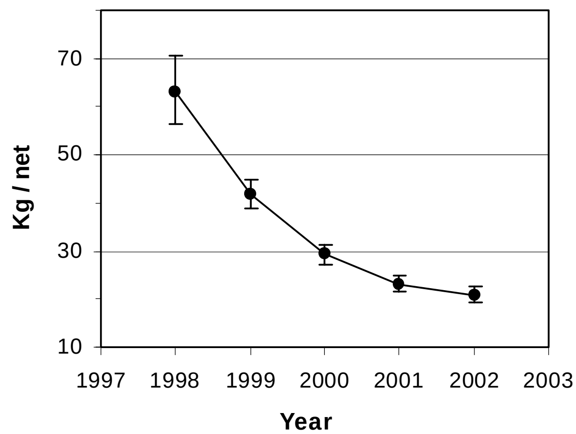

Fig. 7. Standardized catch rates from the gillnet fisheries for cod by vessels <35 feet in Div. 3KL.

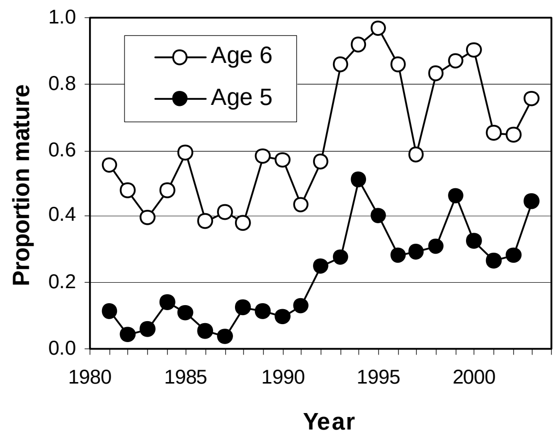

Fig. 8. Percentage of females mature at ages 5 and 6 as predicted from modelling the maturity data.

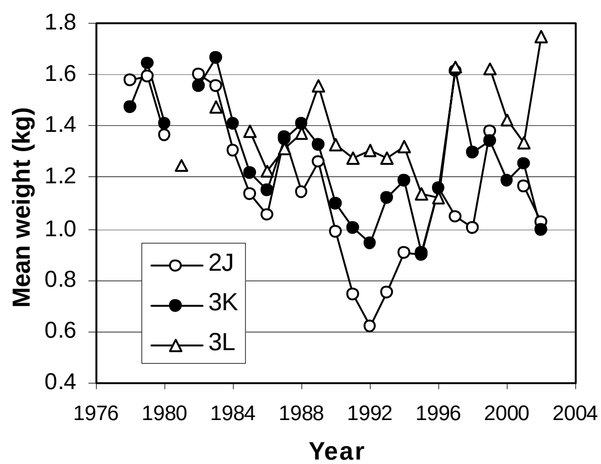

Fig. 9. Mean weight (kg) at age 5 of cod sampled during autumn research surveys.

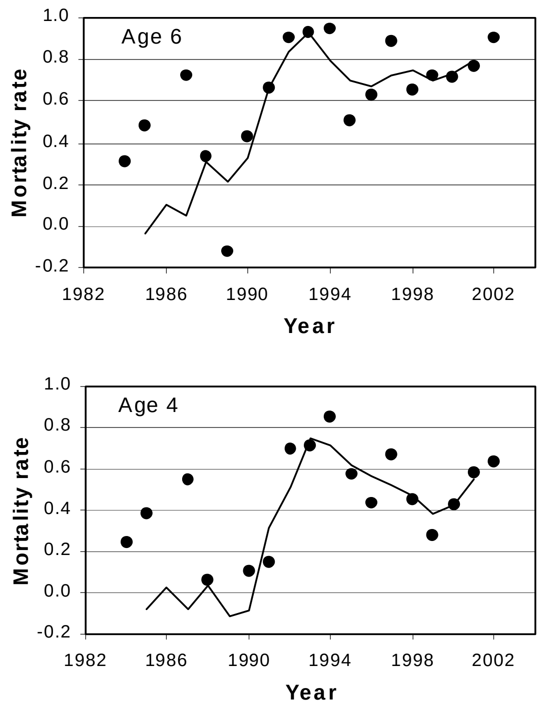

Fig. 10. Age specific mortality calculated from catch per tow at age during the autumn bottom-trawl surveys in Div. 2J+3KL. As an example, in the age 4 panel, the value of 0.85 in 1994 is the mortality experienced by the 1990 year-class from age 3 in 1993 to age 4 in 1994. The line is a 3-year moving average. Data points less than –0.2, which occurred only before 1990, are not shown.

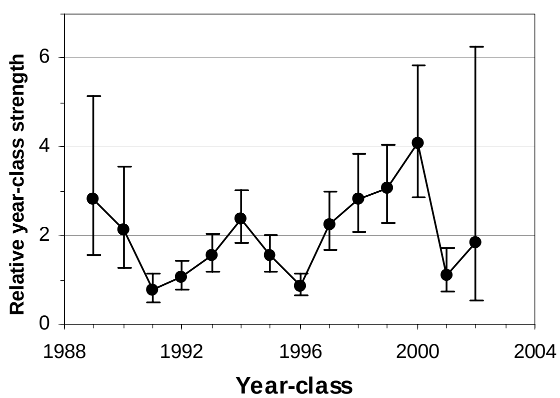

Fig. 11. Standardized year-class strength.

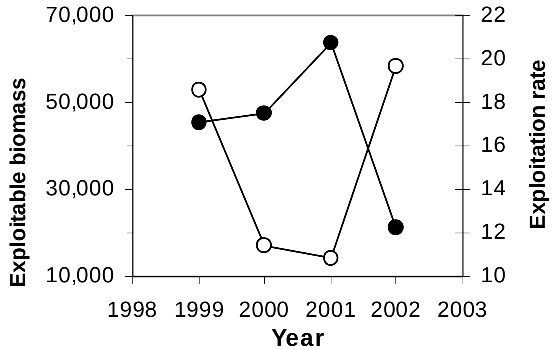

Fig. 12. Tagging model estimates of exploitable biomass (closed symbols) and percentage exploitation rates (open symbols) for inshore Div. 3KL.

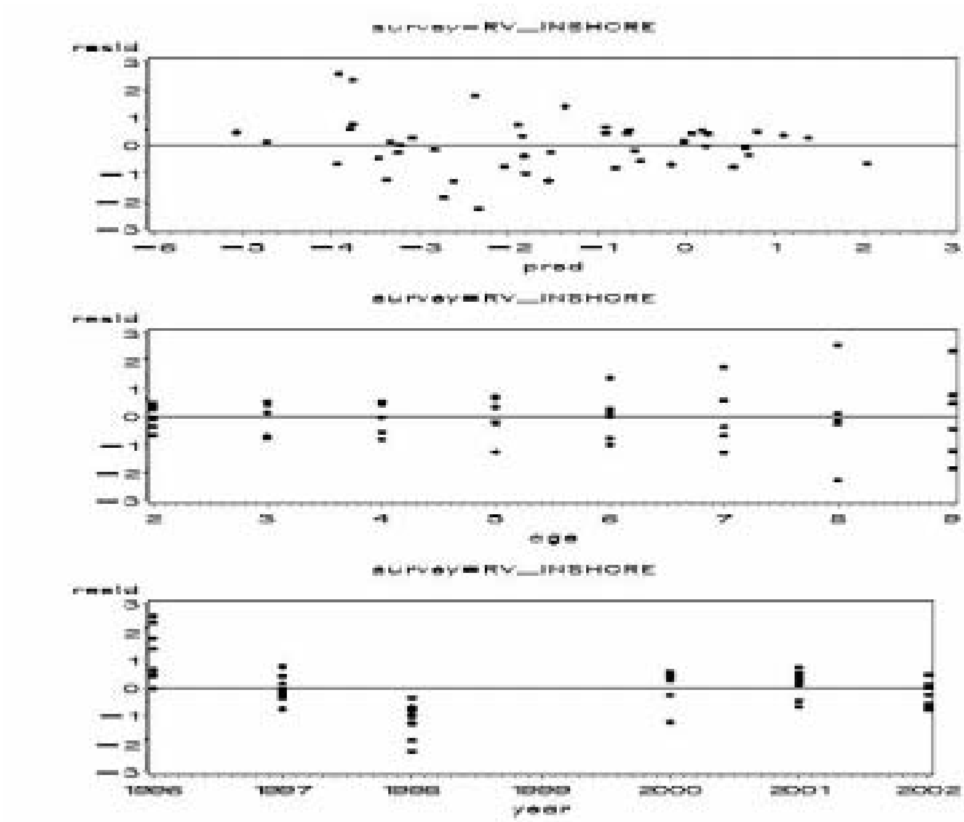

Fig. 13. Standardized residuals for the RV inshore bottom trawl survey by predicted value, age and year.

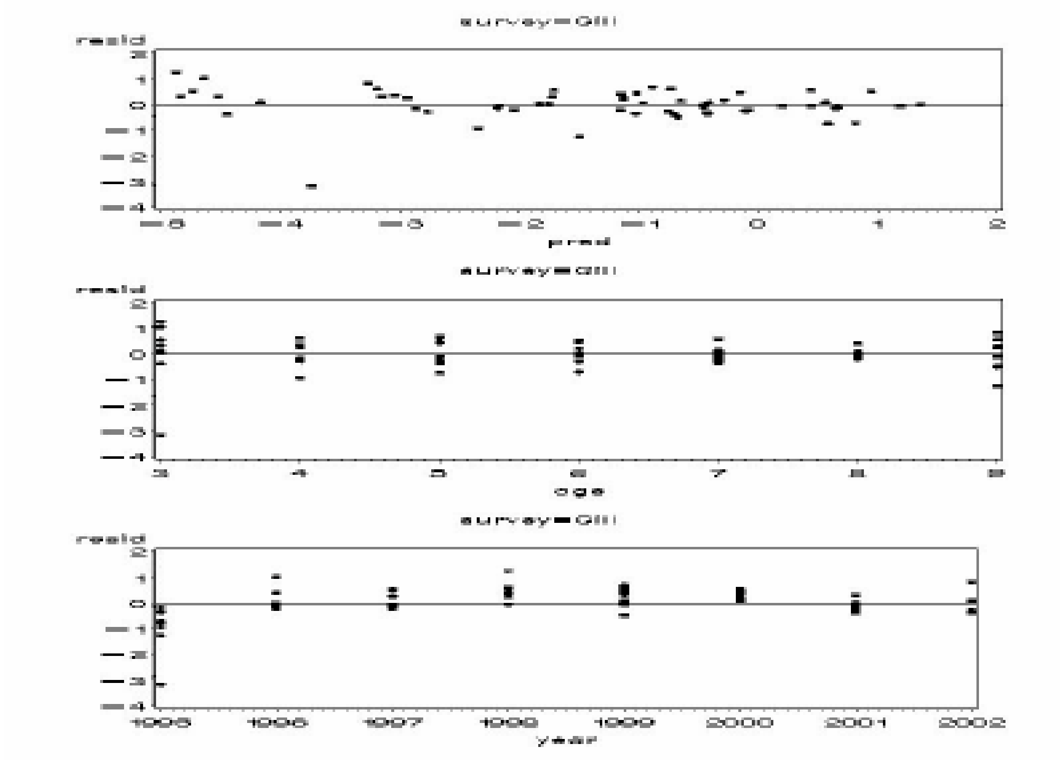

Fig. 14. Standardized residuals for the sentinel 5 ½ inch mesh gillnet survey index by predicted value, age and year.

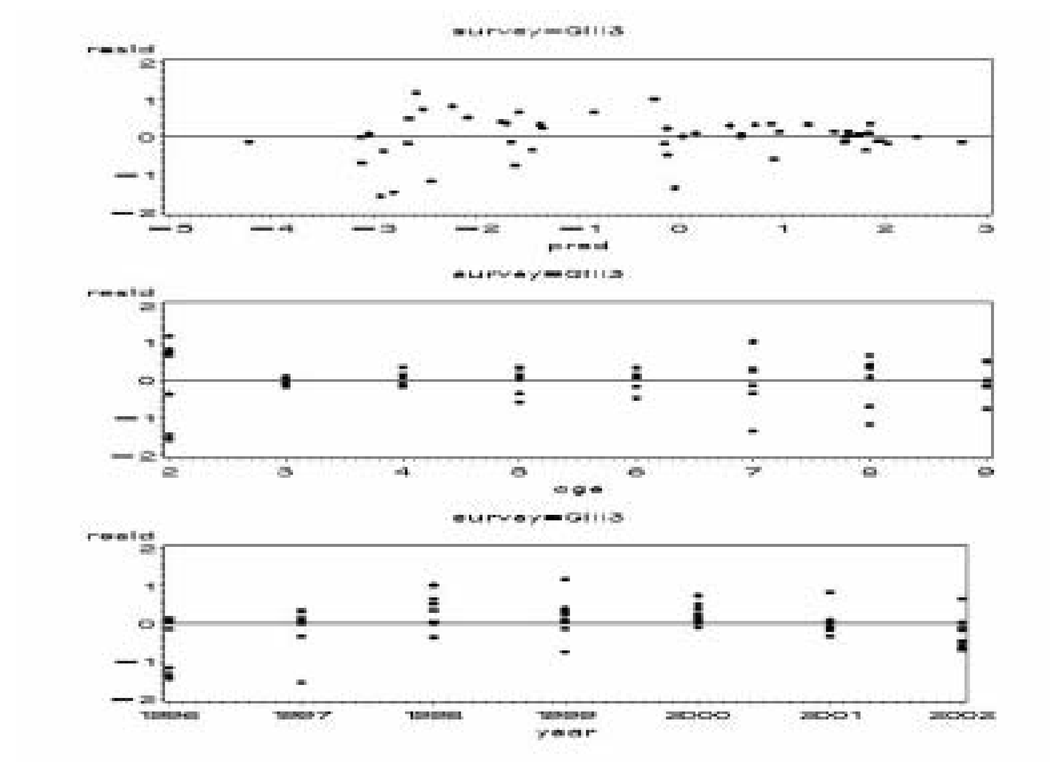

Fig. 15. Standardized residuals for the sentinel 3 ½ inch mesh gillnet survey index by predicted value, age and year.

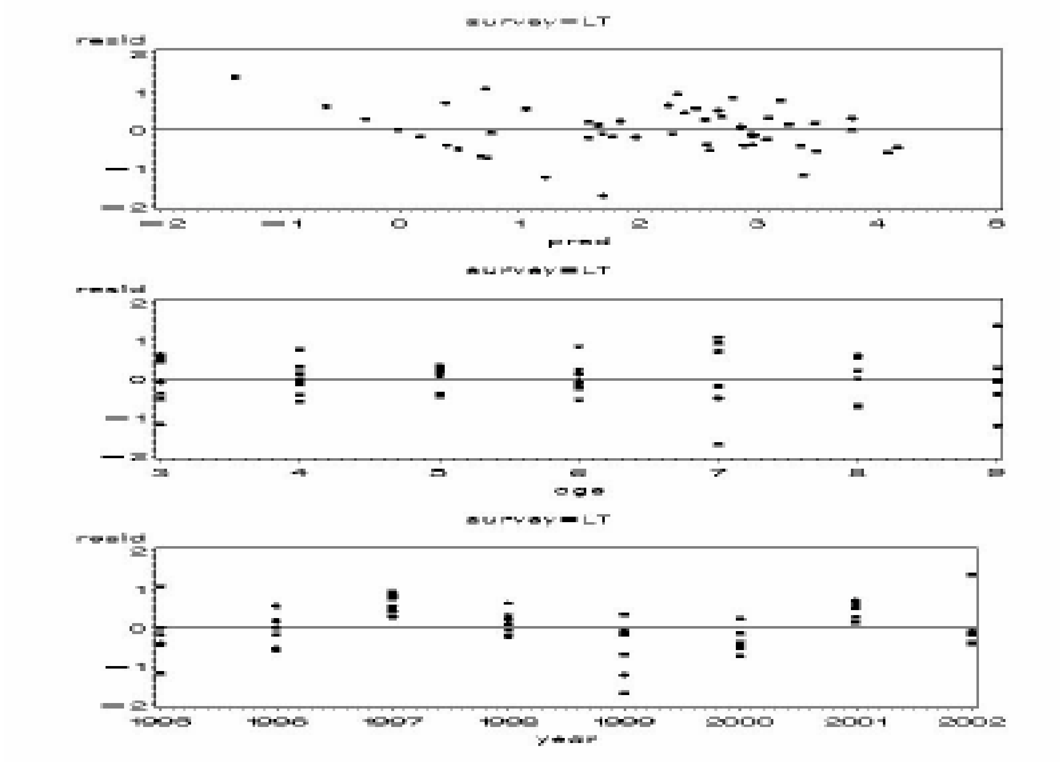

Fig. 16. Standardized residuals for the sentinel line trawl survey index by predicted value, age and year.

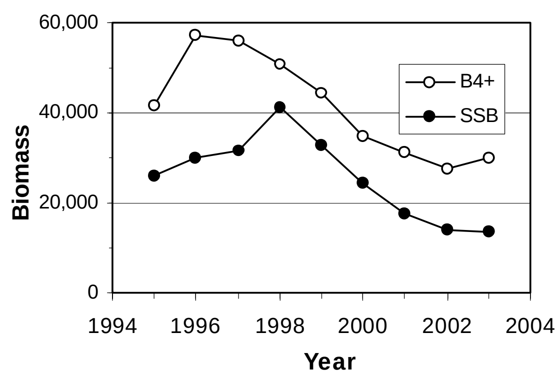

Fig. 17. SPA estimates of spawner biomass and exploitable (4+) biomass for the inshore.

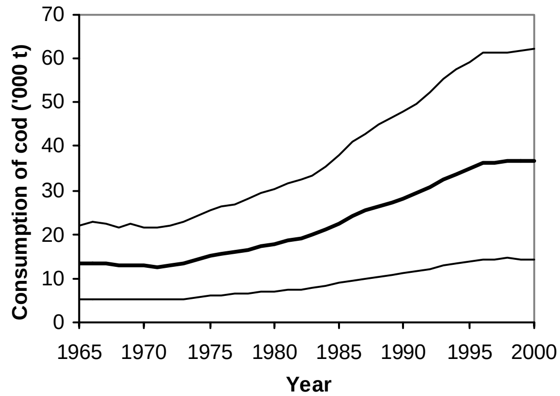

Fig. 18. Consumption (with 95% confidence intervals) of cod by harp seals in 1965-2000, based on diets averaged over 1982 and 1986-1998 (from Stenson and Perry, 2001).

Appendix 1. Spawner stock biomass in the offshore:

An index of spawner stock biomass in the offshore was derived from catches and sampling during autumn bottom-trawl surveys and commercial weights at age. Because the surveys were conducted during the autumn, it was thought that the population biomass estimated in a given year would provide an appropriate index for spawner biomass in the following spring. The spawner biomass on January 1 in year y was computed as

$$\sum_{a=1}^{20}(N_{a-1,y-1} \times Pm_{a-1,y-1} \times W_{a,y})$$

where N is population number, Pm is proportion mature, W is individual weight, a is index of age (a = 1-20) and year is index of year (y =1984-2003). N was computed by areal expansion of the stratified arithmetic mean catch per tow in index strata in Div. 2J, 3K and 3L combined (see Lilly *et al*., 2001, Table 26). Pm is the estimated proportion of female cod that were mature, as estimated from a probit model fitted by cohort to observed proportions mature at age (see Lilly *et al.*, 2001, Table 38 for the observed proportions). W is the weight on January 1 as estimated from mid-year commercial weights (see Lilly *et al*., 2001, Table 11). Weights derived from sampling of the commercial catch are used so as to be consistent with the weights used in the inshore SPA. [Note that the spawner biomass calculated as described here differs from the total biomass as illustrated in Fig. 2 of the paper in the use of commercial weights, rather than the actual weights of the catch, and extrapolation from a mean catch per tow rather than a summation of biomass estimates calculated for individual strata. (In some years, some strata were not surveyed.)]

Since 1999, the spawner biomass has been at about 1.5% of the biomass in the period 1984-1989 (excluding the very high value in 1987).

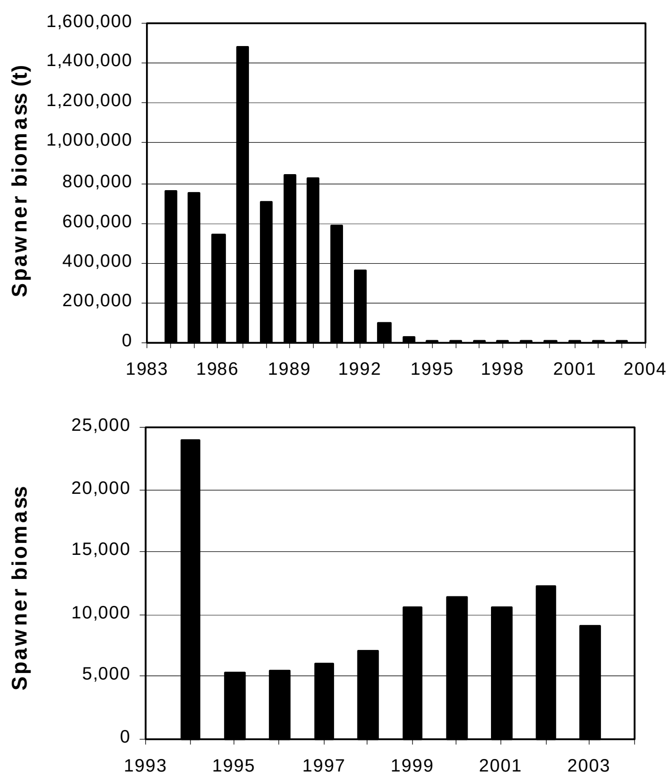

Fig. A1. Index of spawner stock biomass in the offshore.