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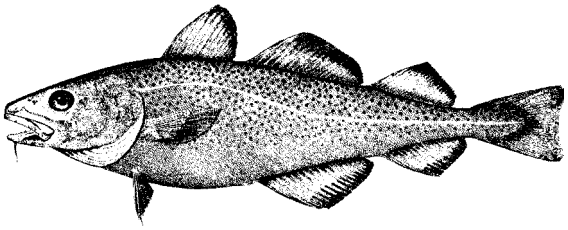
Science | Sciences
Quebec Region | **Stock Status Report 2004/019**



The Northern Gulf of St. Lawrence (3Pn, 4RS) cod in 2003

Background

Cod of the Northern Gulf of St. Lawrence (Divisions 3Pn, 4RS) undertake extensive annual migrations. In winter, they gather off southwestern and southern Newfoundland at depths of more than 400 m (200 fathoms). In April and May, they move towards the Port au Port Peninsula, on the west coast of Newfoundland (Division 4R), where spawning starts. In 2002, a new zone was established in 4R to protect the spawning stock. It is a sector where any groundfish capture is prohibited between April 1st and June 15. During the summer, fish continue their migration and disperse towards the coastal zones, along the West coast of Newfoundland (Division 4R) and towards the Middle and Lower North Shore of Quebec (Division 4S). This migration towards the coasts is associated with warmer water and the presence of capelin, principal prey consumed by cod.

Based on results of many tagging experiments, this stock is generally isolated from adjacent stocks (those of Divisions 4TVn, 2J3KL and 3Ps). The stock can sometimes mix in the Northwest Gulf, (with 4TVn cod), in the Strait of Belle Isle, (with 2J3KL cod), and especially in the area of the Burgeo Bank (with 3Ps cod). A study evaluated that 75% of cod present on the Burgeo Bank (3Psa and 3Psd) in winter may come from the Northern Gulf.

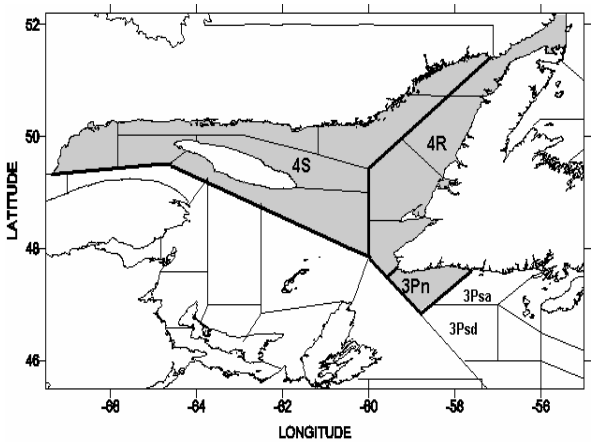


Figure 1. Cod stock management area in the Northern Gulf of St. Lawrence. For reference, fishery areas 3Psa and 3Psd are also indicated.

Landings (in thousands of tons)

Year	*1977-1993*	*1994-1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*[1]
TAC	*70.4*	*0*	*6*	*3*	*7.5*	*7*	*7*	*7*	*0*
Landings	*70.2*	*0.3*	*4.8*	*3.3*	*7.1*	*6.8*	*7.1*[2]	*6.3*[3]	*0.3*

[1] *Preliminary data*
[2] *Include 253 t for recreational fishery*
[3] *Include 34 t for recreational fishery*

Summary

- In 2003, the cod fishery was under moratorium. The sentinel fishery and by-catch amounted to a recorded landing of 275 t.
- The abundance and spawning stock biomass remain low. The spawning stock biomass (SSB) increased between 1994 and 1999, and declined between 2000 and 2002. The estimate of the SSB for 2004 is 38,000 t, which is slightly higher than the current estimate of 35,000 t for 2003.
- The recruitment estimates at age 3 have been declining since 1999 and reached a historic low in 2003. The estimate of recruitment in 2004 (2001 year class) is similar to year classes in the mid 1990's.

- Condition and growth have improved in recent years, and fish now mature at older ages.
- The two trawl surveys indices (CCGS *Alfred Needler* and sentinel) increased from 1995 to 2000. The index from the *Needler* survey decreased in 2001 and 2002, then increased 3-fold in 2003. The index from the July sentinel mobile survey increased in 2001, decreased in 2002 and remained stable in 2003. The sentinel longline index increased from 1995 to 2001, declined in 2002, and remained stable in 2003. The gillnet index declined from 1995 to 2002, but indicated a sharp increase in 2003.
- A portion of the cod found inshore in the Northern Gulf in summer migrate out of this area in winter, but their over wintering locations are uncertain. This is a source of concern regarding the possible impact of fisheries in adjacent areas on recovery of this stock.
- Natural mortality remains high in this stock. Seal predation is a major factor contributing to the mortality of cod smaller than 30 cm.
- With no fishing, the stock may increase marginally in 2004. With a 2200 t fishery in 2004, the stock abundance will not increase.
- Spawning stock biomass is estimated to be below the biological reference points for conservation of this stock. There is a high likelihood that the productivity of a stock below the conservation limit has suffered serious harm.

Biological characteristics of the resource

The biological characteristics of the Northern Gulf cod varied over years, and certain changes occurred during the decline of the abundance of stock when the cold oceanographic conditions were unfavorable for the resource. Growth, condition, size and age at sexual maturity decreased in the middle of the 1980's and the beginning of the 1990's. These changes had a negative impact on egg production because a smaller fish, in bad condition at sexual maturity, is weaker and produces fewer eggs. On the other hand, the natural mortality rate may increase as a fish in bad condition has less chance to survive, particularly after the reproduction, when environmental conditions are unfavorable. However, an improvement of these biological parameters has been noted in recent years so that the assessment is more positive with regards to the biological characteristics of the stock.

The growth of cod increased during second half of the 1990's. Weight and size at age in the commercial fishery increased so that the actual values since 2000 are similar to those observed before the decline of the abundance, in early 1980's. Indeed, the mean weight of a 6-year-old cod in the commercial fishery reached a minimum in 1992 and gradually increased since (Figure 2). The computed value of the mean weight for 2000 is the highest since 1984. Trends are similar for size and weight in the other year-classes. The results from the CCGS *Alfred Needler* is also showing this increasing trend in weight at age in the trawl surveys carried out from 1991 to 1999. Generally, weights at age from the surveys and the fishery have increased from 1990 to 1998 and varied afterwards without showing any trend.

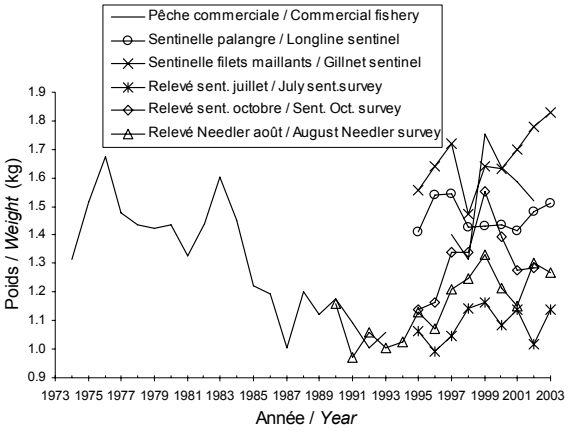


Figure 2. Mean weight of six-year-old cod caught in the commercial fishery, research surveys and fixed gear sentinel fisheries.

Cod stomachs are collected during the *Needler* survey every year. Previous analyses have shown that four size groups of cod can be identified according to their diet: 15-20 cm, 20-50 cm, 50-70 cm and larger than 70 cm. The first group eats mostly invertebrate prey. Large numbers of stomachs are available every year from 1993-2003 only for the middle two categories. In both cases, stomach fullness was very low in 2003 compared with previous years, suggesting that cod from 3Pn,4RS had lower consumption levels in August 2003 than during most of the period from 1993-2002. Stomach fullness is known to decrease with increasing depth for this stock, but stomachs were collected at a similar depth in 2002 and 2003, and depth cannot explain the low feeding levels observed in 2003. Other factors, such as temperature, have yet to be explored.

The feeding of cod in 3Pn, 4RS is influenced by many factors such as season, depth, prey abundance and cod size. The feeding of small cod is mainly composed of invertebrates like amphipods and shrimp. The proportion of fish in stomachs increases with the size of cod. Capelin is the dominant species consumed by cod less than 63 cm. Gadoids (mainly cod) and flatfish become important species consumed for cod above 53 cm.

Deep troughs reaching > 500 m characterize the Northern Gulf of St. Lawrence. In these troughs, water > 150 m flows toward the head of the channels. These waters become progressively more depleted in oxygen as they progress along the Laurentian, Esquiman and Anticosti channels, because of respiration along the way in the absence of replenishing from oxygen-rich surface layers. As a result, values as low as 20% O_2 saturation are typical of the Estuary. Laboratory experiments have shown that 50% mortality occurs in 21% saturation, and that only 5% mortality occurs at 28% saturation. Furthermore, growth rate declines in reduced oxygen conditions. This reduction in growth is the result of a reduced food consumption, which seems to be caused by a slowing of digestion that is proportional to the severity of oxygen depletion.

The condition of cod is a factor studied by a monitoring program whose aim is to determine the general health status of individuals from the Northern Gulf stock. Fish in good condition will have better chances of survival, particularly when environmental conditions are unfavorable. Cod condition shows significant seasonal variations, with a maximum during the fall and a minimum during the spring. The energy reserves accumulated at the end of the fall are critical for cod and must be sufficient to survive winter and pass through the spawning period in the spring. The condition of cod has been monitored through the fixed gear sentinel program since 1995 and more intensively in the last four years. It is considered stable and good for that period.

Description of fisheries

Cod landings in the Northern Gulf of St. Lawrence reached a maximum of more than 100,000 t in 1983 (Figure 3). Then, they regularly decreased until 1993. During the decline, boats using mobile gears captured their allocation, whereas those using fixed gears did not achieve it. Fishery was under moratorium from 1994 to 1996. A reduced

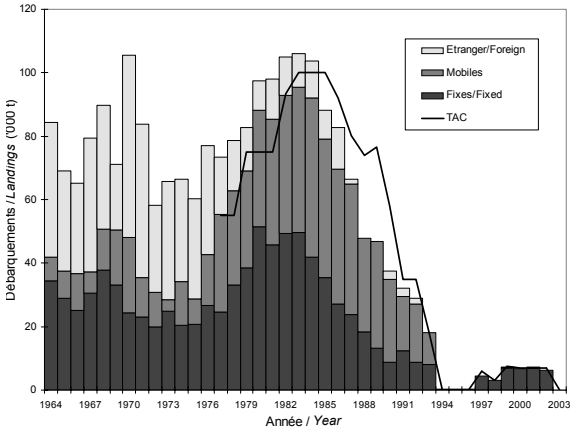


Figure 3. Landings and total allowable catches (TAC).

fishery was authorized in 1997 with a TAC of 6,000 t and landings added up to 4,792 t. The TAC was brought back to 3,000 t for 1998 and 3,296 t were landed. In 1999, the TAC was set to 7,500 t and 7,136 t were landed. In 2000, the TAC was reduced to 7,000 t, and it has been maintained in 2001 and 2002. The landings of the fishing season (May 15 to May 14 of the following year) for 2000, 2001 and 2002 totalized 6,834, 7,150 and 6,338 t respectively. In 2003, the cod fishery faced a second moratorium and there was no commercial fishery.

Sentinel fisheries started in 1994 in order to develop a partnership between industry and the Department of Fisheries and Oceans (DFO). Sentinel fisheries are carried out within a well defined framework and provide abundance indices of the resource. Three types of fisheries are carried out each year: sentinel gillnet fishery on Lower North Shore (division 4S) and on the West coast of Newfoundland (division 4R), sentinel longline fishery and sentinel otter-trawl fishery on the entire territory (3Pn, 4RS). All catches made within the framework of sentinel fisheries are accounted with total landings of the commercial fishery.

To increase our knowledge of the mixture between the Northern Gulf stock and that of the Southern coast of Newfoundland, three surveys financed by the FFAW and directed by DFO were done with commercial trawlers in the area of mixing (3Psa and 3Psd), as well as in 3Pn and 4R in January, March and May 2002 and in January of 2004. The chemical analyses of the trace elements in the otoliths of cod collected during these surveys are completed and are described later. Moreover, these surveys also allowed us to establish a new maturity ogive.

A second moratorium was announced for 2003. Landings were 275 t, most of this is due to sentinel fisheries and some bycatch, mostly from the Atlantic halibut fishery.

Industry perception

The second moratorium has prevented the "Regroupment of the Lower North Shore Fishermen's Associations of Quebec" and the "Fish, Food and Allied Workers Union" of Newfoundland and Labrador to conduct telephone surveys to fixed gear cod license holders in each NAFO zones. However, a series of meetings between DFO staff and fishermen (sentinel and fishermen involved in other groundfish fisheries) were conducted in 2003 to exchange views on the stock status and other biological features.

Generally, industry considers that high catch rates in sentinel fisheries and high bycatch in other fisheries in 2003 were observed over a large geographic area and are indications that cod is abundant and that the moratorium of 2003 was unwarranted.

Resource status

Abundance indices of catch rates from sentinel fixed gear fisheries

Sentinel fixed gear fisheries provide two abundance indices. The first index is derived from longline fisheries, and the second is calculated from gillnet fisheries. The catch and effort data was standardized with the use of a multiplicative model that allows deriving an index which reflects annual trends in cod abundance since 1995.

The abundance index of sentinel gillnet fisheries in 4R and 4S showed very variable catch rates between 1995 to 2002 (Figure 4). However, the gillnet catch rates more than doubled from 2002 to 2003. This increase was observed in all fishing zones. The abundance index of sentinel longline fisheries in 3Pn, 4RS showed an increase in catch rates between 1995 and 2001, followed by a reduction for 2002 and stability for 2003. The overall good catch rates for both sentinel fixed gear fisheries since 1998 are due to the harvest of the 1993 year-class. In 2003, this year-class is 10-year-old and is less abundant, which

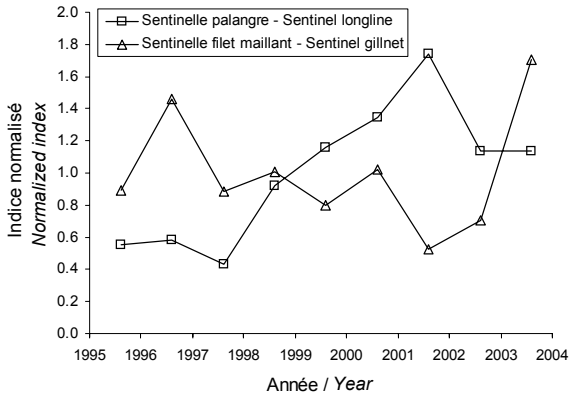


Figure 4. Normalised abundance indices derived from fixed gears

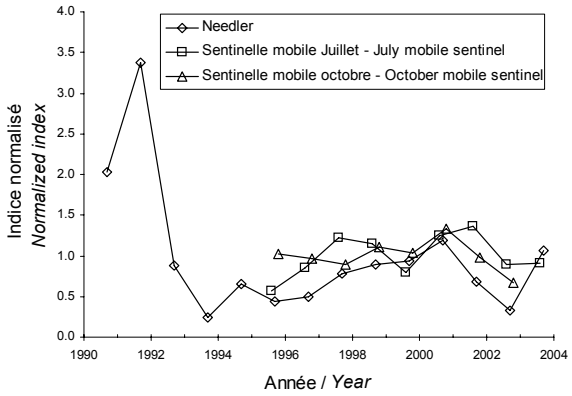


Figure 5. Normalised abundance indices derived from research surveys.

may explain the stability of the abundance index for longline that catches smaller fish than gillnets.

Trawl surveys

The sentinel mobile gear fisheries program began in 1994 in the Northern Gulf of St. Lawrence, but it is only starting in 1995 that surveys have covered Division 4S. The October survey time series (1995 – 2002) was discontinued in 2003 due to the rationalization of the sentinel program. However, the index from the October survey was still used in the calibration of the sequential population analysis (SPA) as the data from 2002 is still recent. Nine trawlers using a stratified random sampling protocol similar to that used by DFO with the *Needler* perform the July surveys. The gears used were adjusted and standardized in 1997 with the addition of restrictor cables, which maintain a constant trawl opening during fishing operations. The data series from July sentinel surveys suggests a gradual increase of the abundance of the stock from 1995 to 2001. This index of abundance decreased afterward in 2002 and remained stable in 2003 (figure 5). All three surveys indicate that the major part of the biomass is found in 4R.

Ten additional tows were carried out in July 2003 in three new shallow strata ranging from 10 to 20 fathoms. Many difficulties were encountered for these tows; unfavorable trawling grounds and an abundance of fixed gear. Many tows did not reach the targeted 30-minute duration. Standardized catches ranged from 0 kg/30 min tow up to 2,107 kg/30 min tow. The inclusion of these tows to the minimum trawlable biomass estimate increases the value from 68,000 t for waters deeper than 20 fathoms up to 99,000 t for waters deeper than 10 fathoms. Given the variability in these 10 tows, the confidence intervals around the estimate of minimal trawlable biomass are very wide.

The results from the *Needler* survey indicate that abundance has increased from 1993 to 2000, but decreased in 2001 and in 2002. The 2002 index is the second weakest of the 13-years series, the only lower value being that of 1993, right before the first moratorium.

An important stratum for cod in the strait of Belle-Isle was not sampled during the 2003 *Needler* survey. Various methods were used to estimate this stratum. One used the proportion in that stratum observed from the *Needler* in three earlier years while another used the proportion in that stratum observed by the mobile gear sentinel survey conducted one month earlier, in July of the same year. The latter resulted in a 3-fold range increase in the index from 2002 to

2003 while the first method indicated a 5-fold increase.

A consistent survey area is required to construct indices of relative abundance using data from stratified-random surveys. When some strata are missed in some years, predicted values for these missing strata need to be obtained. This is normally done based on the distribution of catches in previous years of the survey using a statistical model with terms for year and stratum. This approach requires the assumption that fish distribution does not change from year to year. For the *Needler* survey, an alternative approach would be to fill in missed strata based on cod distribution in the July sentinel survey from the same year. Analyses of the July and August survey data indicated that cod distribution was more similar between July and August surveys in the same year than between August surveys in different years. Substantial differences in cod distribution were evident between August surveys in different years whereas no significant differences in distribution occurred between the July and August surveys in most years. These analyses suggest that it would be better to predict cod densities in missed strata in the August survey based on cod distribution in July in the same year than on cod distribution in August in other years.

Estimate of total population

SPA is an analytical model that allows estimating population by year class by taking into account natural mortality (M) and fishing mortality (F), as experienced by fish available to the fishery. This analysis is also based on catches at the age estimated from commercial fishery and is calibrated with the indices of coastal sentinel fixed gear fisheries, and sentinel mobile gear surveys and those of the scientific survey made by the *Needler*.

To reflect the deterioration of environmental conditions, an increase in wasteful fishing practices and the intensification of predation by seals, it was decided to increase M from 0.2 to 0.4 from 1986 for several cod stocks. Although fish condition improved recently, predation by seals is believed to remain important. Hence M was kept at 0.4 for the entire period 1986-2003 to take account of the combined effect of these factors.

Total mortality rates (Z) of adult Northern Gulf cod (ages 6-10 yr) during the 1990-2003 period were estimated using catch rates from the *Needler* survey and were presented at the 2004 assessment. Z was high in the early 1990's, and declined during the moratorium in the mid 1990s and increased following the re-opening of the fishery in the late 1990's. Total mortality rates during the moratorium were consistent with a natural mortality rate (M) near 0.4. The relationship between Z and fishing mortality yielded an estimate of 0.35 for M during the 1990-2003 period.

Sequential population analysis (SPA) was also used to obtain estimates of natural mortality (M) in blocks of years and for the entire 1990-2003 period. This analysis suggested that M might have been slightly higher in the early 1990's than in later years, though none of the differences were statistically significant. There was no evidence for a substantial decline in M since the early 1990s. The estimate of M for the entire 1990-2003 period was 0.42. Estimates of M from these analyses are consistent with the value currently assumed for M (0.4).

A virtual population analysis (VPA) conducted using the VPA/ADAPT program from the NOAA Fisheries Toolbox resulted in trends in biomass and fishing mortality similar to those of the APL/ADAPT formulation. A non-age structured Catch Survey Analysis (CSA) using recruit and post-recruit data from the catch and the *Needler* survey indicated similar trends in harvest rate and biomass to those observed in the VPA analysis. Similar results were also obtained using an alternative calibration model for SPA (QLSPA).

The proportion of fish sexually mature by size or year-class is used to establish estimates of spawning stock or spawning

biomass. SPA results indicate that the abundance of age 3 fish and older dropped from 559 million in 1980 to 52 million in 1994, before increasing slowly to reach 79 million in 1999. Thereafter, total population decreased to 67 million individuals in early 2004. The spawning stock decreased from 223 million in 1982 to 10 million in 1994. It increased to 23 million individuals at the beginning of 2004. The exploitation rate on 7 to 10 year-old cod from SPA was stable around 20% from 1999 to 2002; the value was very low in 2003 due to the moratorium (Figure 6).

Population numbers were converted to biomass using mean weights at age from the commercial fishery calculated annually. The total biomass, for fish 3 years and older, declined from 604,000 t in 1983 to 32,000 t in 1994 and increased to 69,000 t at the beginning of 2004 (Figure 7). The spawning biomass decreased from

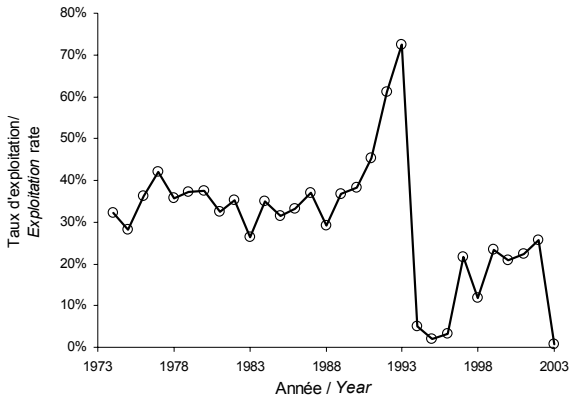


Figure 6. Exploitation rates for cod between age 7 and 10.

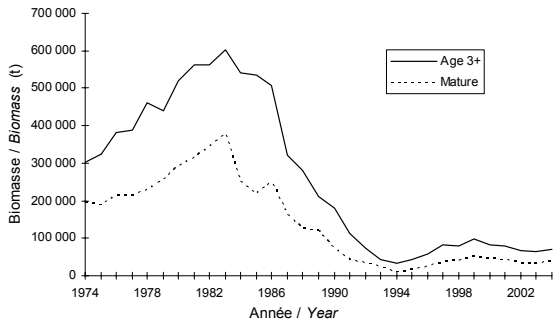


Figure 7. Estimated 3+ biomass and mature biomass.

379,000 t in 1983 to 11,000 t in 1994, to increase thereafter to 38,000 t at the beginning of 2004. Confidence intervals at 95% for the 38,000 t SSB estimate are 23,000 t and 53,000 t.

Estimates for stock abundance and biomass for January 1st, 2004 were based on a mean recruitment (fish age 3 and older) of mean weights at age and maturity ogives from 2001 to 2003. Fishing mortality for the fully recruited individuals is 0.8% (F=0.01) in 2003.

There have been no major signs of recruitment recovery in the past 13 years (Figure 8); commercial catches from 1999 to 2001 were sustained mostly by the 1993 year-class, which was produced prior to the moratorium. Recruitment at age 3 has declined from 28 million individuals in 1998 to a minimum of 13 million individuals in 2003. The estimate of age 2 fish from the *Needler* survey in 2003 is among the strongest to date but is uncertain. This age group was not as strong in the sentinel July survey of 2003. The estimate of recruitment at age 3 in 2004 (2001 year class) is similar to year classes in the mid 1990's. Results from both surveys in 2004 will help assess the strength of this year class at age 3.

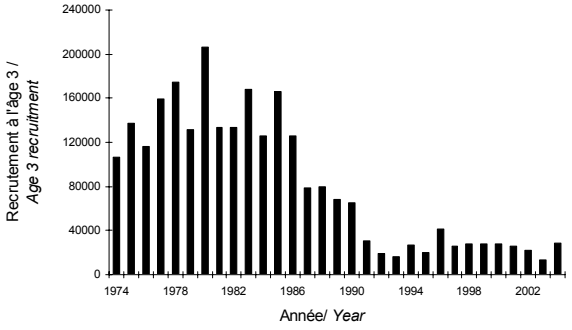


Figure 8. Estimated recruitment at age 3.

Work was presented which examined the productivity of the Northern Gulf cod resource to aid in establishing biomass reference points. These points were based on the concept that biomass could be

partitioned into three zones which were labelled as “healthy”, “cautious” and “critical”. A production analysis was used to estimate the boundary for the critical region in two ways. One method was to estimate the level of spawning stock biomass (SSB) above which the stock was deemed healthy (above 200,000 t) and then use the potential growth in one generation to calculate the “critical-cautious” boundary. This approach estimated that boundary at about 85,000 t. The other method was to use the same analysis to estimate at what SSB there was a probability that the stock would have negative growth, even in the absence of fishing. This yielded an estimate of 110,000 t. Although they incorporate biological aspects that are different than those used in earlier calculations (i.e. stock production as opposed to spawner-recruit considerations), both of these estimates were within the range of earlier techniques.

Sources of uncertainty

The issue of the migration of Northern Gulf cod into 3Ps has been frequently discussed in the past. To avoid catching these fish during the winter fishery in western 3Ps, a portion of Burgeo Bank (3Psd) has been closed to the fishery from November 15 to April 15 since 1999. This area is only part of the area in which cod from the 3Pn, 4RS mix with 3Ps cod. Several research projects were carried out in recent years in order to better describe the extent of mixing (tagging, seasonal evolution of maturities, microchemistry of otoliths). A specific workshop on this issue was held in October 2000 (Chouinard, 2000). The conclusion of this workshop was that a good portion of cod captured during winter in areas 3Psa and 3Psd were from the Northern Gulf stock. In last year’s assessment, we added 75% of the catches made from November to April in 3Psa and 3Psd to the catches of 3Pn, 4RS, which assumes that these catches are from the Northern Gulf. The inclusion of these landings have little impact as the estimated stock size increases by only 5% according to the sequential population estimate, compared to analyses that do not include them.

Estimates of cod stock composition of unknown stock mixture from trace elements of otoliths using reference groups of known identity were presented. The percentage of Northern Gulf cod in aggregations found in 3Psa and 3Psd in January and March 2002 varied from 27 to 64%. Cod sampled in late April 2001 were 40-51% of Northern Gulf origin. Main impact of mixing may be on 3Ps DFO survey results because of variable proportion from one year to the next of 3Pn,4RS fish present at survey time in 3Ps in April, as shown by above trace element analysis and distribution of catches in the western portion of the 3Ps survey.

An additional survey was conducted by FFAW in the 3P mixing area in January 2004. Distributions of cod catches were comparable to those from January 2002, with cod being found mostly southeast of Burgeo Bank.

Results from the *Needler* survey in 2002 and 2003 were reviewed in detail because there were a larger than usual number of unsuccessful tows in 2002 and the model used to fill in missing strata in 2003. Initial estimates indicated a five-fold increase in biomass for cod between 2002 and 2003 (Bourdages *et al*. 2003). The method used to fill in missing strata was reviewed and an alternative was proven better, the resulting increase for 2003 is now in the range of 3 times instead of 5-fold. The impact of such a change in this index has reduced the estimate of the spawning stock biomass by 12%.

Sensitivity analyses were also undertaken to examine the use of various indices and their effect on the estimation of fishing mortality and SSB. These would indicate negligible impacts on fishing mortality. However, the estimates of spawning stock biomass varied from 30,000 t to 44,000 t (Figure 9).

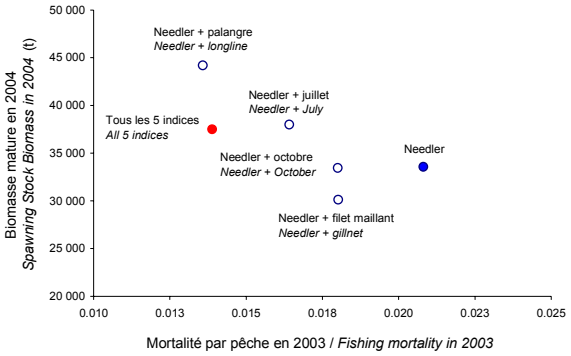


Figure 9. Scenarios regarding mature biomass and fishing mortality according to the indices used in the ADAPT analyses.

Adult mortality from natural causes is very high for this stock. Although causes of this elevated mortality are not fully known, estimates of cod consumed or otherwise killed by seals are high enough that such mortality would contribute to the lack of recovery in this stock. The seal diet data indicate that the consumption is primarily of juvenile cod. However, stomach content data may underestimate the consumption of adult cod, because the heads of large cod may not be consumed.

Tagging and returns of tags

Since 1995, sentinel fishermen tagged more than 60,000 cod in the Northern Gulf of St. Lawrence. So far, 2,700 tags have been returned, which gave a return rate of 5%. Experiments conducted with high value-tag rewards ($100) have provided estimates of exploitation rate that are two to three times higher than those based on the rate of return for traditional tags ($10).

An analysis of exploitation rates based on tag returns was presented at the 2004 assessment. Estimates produced for annual exploitation rate are uncertain, but surprisingly high in some areas (3Pn, 4Rb, 4Rc) - low or variable in others. There are some indications of high initial tagging mortality in some experiments that are not consistent with data from cage retention experiments. This issue needs to be explored further, under various conditions.

Outlook

The current assessment indicates that the mature biomass has decreased by 28% since 1999. At current productivity, the fishing pressure exerted from 2000 to 2002 is unsustainable.

The probability of a decline in spawnins stock biomass increases with the level of catch in 2004 (Figure 10). Overall, year-classes produced after 1993 are less abundant. With the current low stock size combined with the weak recruitment, total catches of more than 2,200 t in 2004 are projected to result in a further reduction of the SSB. A 5% target for growth in the mature biomass could not be achieved without a continued moratorium (Figure 11).

The mid-term outlook suggests that declines in spawning stock biomass are highly likely. A strong recruitment event, which is unlikely under present conditions, and / or a large decrease in natural mortality would be required to change this outlook.

Spawning stock biomass is estimated to be below the conservation limit reference points for this stock. There is a high

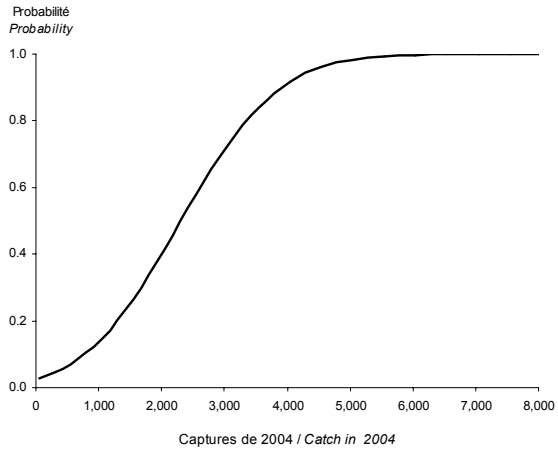


Figure 10. Probability of a decline in mature biomass relative to various catch levels for 2004.

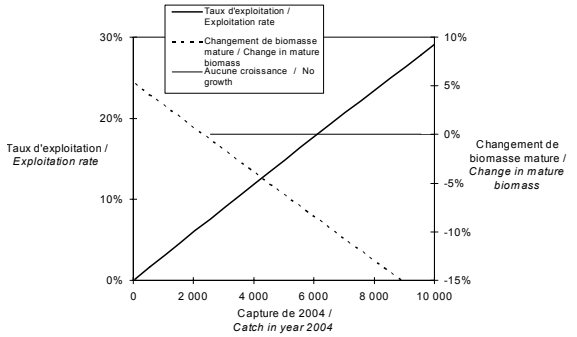


Figure 11. Harvesting rate and projected variation in mature biomass relative to various catch levels for 2004.

likelihood that the productivity of stocks below the conservation limits has suffered serious harm. According to recent analyses presented during the 2004 assessment, the conservation limit for this stock is between 80 to 150 thousand tons. The 2004 SSB is well below this level.

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