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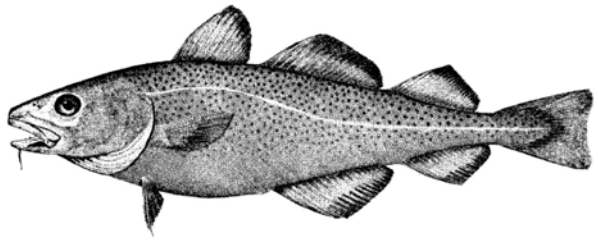
Canadian Science Advisory Secretariat
Science Advisory Report 2011/028

RECOVERY POTENTIAL ASSESSMENT FOR THE LAURENTIAN SOUTH DESIGNATABLE UNIT OF ATLANTIC COD (*GADUS MORHUA*)



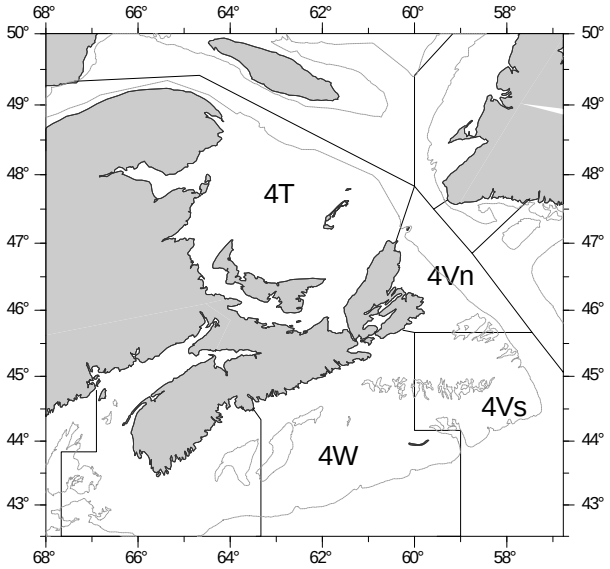


Figure 1: Laurentian South Designatable Unit (NAFO Divisions 4TVW) of Atlantic cod. Grey dashed line is the 200 m contour.

Context :

In its 2003 assessment of Atlantic Cod, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated the Maritimes Designatable Unit (DU) Special Concern. In April 2010, COSEWIC re-assessed Atlantic Cod and split the previous Maritimes DU into two populations, the Laurentian South DU and the Southern DU. The Laurentian South DU was designated Endangered, a higher risk category than Special Concern, due to a 90% decline in abundance over 3 generations.

A recovery potential assessment (RPA) was introduced by DFO Science to provide the information and scientific advice required to meet various requirements of the Species at Risk Act (SARA), including decisions regarding the listing of Laurentian South cod under the Act and developing a recovery strategy. The RPA or the Laurentian South DU was conducted on February 21 – 25, 2011, jointly with the RPAs for the other DUs of Atlantic cod from eastern Canada.

This science advisory report describes the status of cod populations in the Northwest Atlantic Fishery Organization Divisions 4T-4Vn(Nov-Apr) (southern Gulf of St. Lawrence cod), 4Vn(May-Oct) (4Vn resident cod), and 4VsW (eastern Scotian Shelf cod). These populations constitute the Laurentian South DU. Historic population trajectories are described and the populations are projected into the future to assess the probability of achieving recovery targets assuming that current productivity conditions were to persist in the future. This scientific advice also addresses the major threats to the survival and recovery of Laurentian South cod and the limiting factors. The measures that can help its recovery are listed.

SUMMARY

- The Laurentian South DU of Atlantic Cod consists of three stocks or management units: southern Gulf of St. Lawrence cod (management unit 4T-4Vn(Nov-Apr)), 4Vn resident cod (4Vn(May-Oct)), and eastern Scotian Shelf cod (4VsW). Until recently, the southern Gulf stock was the largest of the components.

- Long term projections were undertaken for the southern Gulf and eastern Scotian Shelf stocks and at the DU level. Future productivity conditions are very uncertain. Thus, these projections should not be interpreted as forecasts of future stock status because they depend on assumptions about future productivity and fishing mortality. The probability of current conditions continuing for a long period of time is unknown. These projections are explorations of the consequences of particular productivity assumptions.

- Projections are illustrated using the median and the 2.5^{th} and 97.5^{th} percentiles. The full range of uncertainty should be considered when interpreting these projections.

Southern Gulf of St. Lawrence Cod

- The southern Gulf population is at the lowest level observed in the 61-year record and is declining. Abundance of mature cod in 2008-2010 is estimated to average 37% of the average level in the mid to late 1990s and 10% of the average level in the mid 1980s.

- Natural mortality of southern Gulf cod aged 5 years and older (5+) is estimated to be unusually high (averaging 0.66 in 1994-2010). Predation by grey seals is considered to be a major component of this high natural mortality.

- Most other components of productivity are also currently low for southern Gulf cod. Weight-at-age declined to a low level in the late 1970s and early 1980s and has remained low since then. Recruitment rate (recruits per unit of spawning stock biomass (SSB)) was exceptionally high in the mid to late 1970s but declined to a low level in the 1990s and 2000s, comparable to the rates observed in the 1950s and 1960s. There has been no evidence of a compensatory increase in recruitment rate at the recent low levels of SSB.

- During the small directed fishery for southern Gulf cod in 2007 and 2008, fishing mortality is estimated to have been 0.11 for fully-recruited ages (9-10), a small fraction of natural mortality, but still unsustainable given current stock productivity. With the closure of the directed fishery in 2009, fully-recruited fishing mortality dropped to 0.014, a negligible level.

- A conservation limit reference point (LRP) has been established for southern Gulf cod, based on the SSB below which the probability of poor recruitment is high. The LRP is estimated to be 80,000 t. Estimated SSB has been below the LRP since 2003. Estimated SSB at the beginning of 2010 is 39,500 t.

- Productivity of the southern Gulf cod stock has been very low throughout the past 20 years. If these conditions persist in the future, this stock is expected to continue to decline, even with no fishing. Under these conditions, the probability of reaching the LRP would be zero.

- In 2009, following closure of the cod-directed fishery, fishing mortality of southern Gulf cod due to scientific monitoring activities and bycatch in fisheries directing for other species was

at a very low level. The effect of this level of fishing mortality on the projected population trajectory and thus on the probability of population survival is negligible. In contrast, fishing mortality at the level estimated in 2007 and 2008, when there were small cod-directed fisheries, accelerates the projected population decline and thus decreases the probability of population survival.

- The only additional action that can be taken to improve the chances for recovery of southern Gulf cod would appear to be action to reduce the rate of natural mortality on adult (5+) cod. Given that predation by seals is considered to account for a high proportion of this mortality, grey seal removal would be expected to reduce natural mortality, though large declines in natural mortality would likely require substantial seal removals.

Eastern Scotian Shelf (4VsW) Cod

- The SSB of 4VsW cod reached the lowest level observed in the 53-year record in 2003 at about 7,500 t. Recently, it has rapidly grown to 64,000 t and is approaching the long term mean (75,000 t).

- Natural mortality of 4VsW cod aged 5 years and older (5+) was estimated to be unusually high in the 1990s and early 2000s (peaking at approximately 1.1) but has recently declined to 0.36.

- For 4VsW cod, most other components of productivity were at their lowest values in the period 1990-2000 and then have shown some recovery since then. Weight-at-age, condition, and area occupied all show such a pattern. There have also been improvements in recruitment rate in some recent years.

- Since the closure of the directed fishery in 1993 fishing mortality (ages 5-15) is estimated to have been 0.035, a small fraction of natural mortality. More recently it has dropped further to about 0.01, a negligible level.

- A LRP has been established for 4VsW cod, based on 40% of the spawning stock biomass at Maximum Sustainable Yield (MSY) during the productive period before 1990. The LRP is estimated to be 50,000 t. Estimated SSB has been below the LRP since 1992 with the exception of the 2009 estimate of 64,000 t, 25% above the LRP.

- If 1994-2009 productivity conditions persist in the future, projections indicate that SSB of the 4VsW population would be expected to decline below the LRP and then stabilize in the long term at a low level, even with no fishing. Productivity conditions have improved in the past few years compared to the average of those used in the projections.

- Removals of 4VsW cod at the level of the bycatch fishery since closure of the cod-directed fishery in 1993 have no detectable effect on the probability of survival or recovery.

- The only additional action that can be taken to improve the chances for recovery of 4VsW cod would appear to be action to reduce the rate of natural mortality on adult (5+) cod. Predation by grey seals is considered to be a significant component of natural mortality but its relative contribution is of unknown magnitude. Even without establishing the degree of causality, it is noted that the Sable Island grey seal population was under 50,000 animals when 4VsW cod was productive; the current Sable herd size is around 300,000, six times larger.

4Vn Resident Cod

- Catches of the 4Vn resident component (referred to as 4Vn) of the DU declined from 1985 until closure of the fishery in September 1993. Currently, landings have been restricted to bycatch only, which is very small relative to natural mortality.

- Both DFO and industry led sentinel surveys indicate that the abundance of cod in the 4Vn stock has declined to low levels and is currently at or near the lowest levels seen.

- Natural mortality has been high during the recent period. The possible causes of this increased natural mortality are not understood.

- A LRP, based on the minimum SSB from which the stock has readily recovered, was determined based on area-expanded mature survey biomass of July. The LRP corresponds to the 1973-1978 period, with a mean value of about 8,400 t. Currently (2004-2009) the biomass is about 2,250 t, or about 25% of the limit.

- Recruitment was highest for the 4Vn stock from 1975 to 1988. Recruitment rate was low for the early part of the time series, but higher since 1998.

Laurentian South Designatable Unit (DU)

- The demersal juvenile stage (4 - 35 cm long) is the most habitat-dependant period in the life-cycle of Atlantic Cod. Physical disturbance of structural components of habitat can reduce its value and increase mortality of juvenile cod. Existing data lack the spatial resolution required to evaluate the amount of suitable habitat available to demersal juveniles and whether it has changed in the past three generations, especially in the offshore. However, there is no indication that the amount of suitable habitat is currently limiting recovery of cod in this DU.

- In the mid 2000s, the combined survey indices of abundance and biomass of mature cod from the three stocks in the Laurentian South DU were near or below the lowest levels previously observed. Since then, these indices have increased slightly due to increases in the 4VsW stock.

- DU-level projections could be done combining the southern Gulf and 4VsW stocks only. Based on the survey indices, these two stocks comprise greater than 90% of the abundance of mature cod in the DU. According to projections, the combined mature abundance of the southern Gulf and 4VsW stock components would be expected to decline if current productivity conditions were to persist. The probability of exceeding their mature abundance 36 years earlier (i.e., the probability of no decline over 36 years) falls to zero early in this projection.

BACKGROUND

Rationale for Assessment

Considering the sharp decline in abundance of mature individuals (by about 90%) over the last three generations, the Laurentian South DU of Atlantic Cod (*Gadus morhua*) was designated as Endangered in April 2010 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

As part of the assessment process, scientific information is needed to support the development of social and economic cost assessment scenarios for recovery, to better inform public consultations, and to support other entities involved in the decision of whether to add the species to Schedule 1 of the *Species at Risk Act*. The recovery team also requires this information to develop a recovery strategy, and if necessary, one or more action plans.

Laurentian South DU

The Laurentian South DU consists of three populations or stocks: southern Gulf of St. Lawrence cod (management unit 4T and 4Vn(Nov-Apr)), 4Vn resident cod (4Vn(May-Oct)), and eastern Scotian Shelf cod (4VsW).

Southern Gulf cod overwinter along the southern slope of the Laurentian Channel in 4Vn. In April and early May, they migrate into the southern Gulf of St. Lawrence to spawn, and then disperse throughout the southern Gulf to feed. They migrate back out of the Gulf to their overwintering grounds in 4Vn in November. The timing of this fall migration has shifted over time, from late November-early December in the early 1980s to early November in the late 1990s. Until recently, this was the largest component of the DU.

4VsW cod is composed of several spawning components, including summer and fall components. This stock does not undertake the long migration seen for southern Gulf cod. There is, however, a movement to deeper and warmer water in the winter months.

Substantial evidence supports the presence of a distinct spawning component of cod in 4Vn (known as the 4Vn resident stock), separate from the Southern Gulf component. However, there is substantial mixing with other components of the Laurentian South DU, particularly with the Southern Gulf stock in winter, but also with the eastern Scotian Shelf stock following spawning in summer. The 4Vn stock is present in the Sydney Bight area from May to October, but migrates offshore in winter, mixing with the southern Gulf stock during this period. The 4Vn stock is by far the smallest component of the DU, comprising only 2-4% of the total biomass.

Species Biology

Atlantic Cod is a demersal species that occurs widely in cool temperate waters overlying continental shelves on both sides of the North Atlantic. Following a pelagic period as eggs, larvae and early juveniles, cod settle out of the water column and become demersal. This transition to a demersal life style occurs at lengths of 30-60 mm. Recently-settled juvenile cod tend to be most concentrated in shallow waters, with distribution spreading into deeper waters at older ages. Cod are relatively long-lived and may reach ages of 20 years or more when mortality is low.

Cod in the southern Gulf of St. Lawrence are slow-growing compared to neighbouring populations such as those on the Scotian Shelf. In recent decades, 6-year-old southern Gulf cod reach an average length of 46 cm in September compared to an average length of 52.5 cm for 6-year-old 4VsW cod in July. Cod in these populations now begin to mature at an age of 4 years, though maturation began at later ages historically. Most fish in these populations are now sexually mature by 7 years of age.

Cod in the southern Gulf population are highly migratory while those in the 4VsW and resident 4Vn populations undertake more minor seasonal movements. Cod in all three populations move into warmer deeper waters in winter. Cod in these populations are most widely distributed during the summer feeding season. They feed on krill, shrimp, and small fish, primarily herring, American Plaice, and Capelin for southern Gulf cod, with sandlance an important prey of cod on the Eastern Scotian Shelf. Large cod were historically the most important predator of juvenile cod while grey seals appear to be the most important predator of larger cod in this area. An annual natural mortality rate of about 15-20% is considered normal for adult cod, but natural mortality in these populations increased to unusually high levels in the 1980s and has been near 45-50% annually for adult cod over most of the last 20 years.

ASSESSMENT

Historic and Current Abundance and Trends

Southern Gulf cod

The status of this stock is currently monitored by a research vessel bottom-trawl survey (1971-2010), a sentinel bottom-trawl survey (2003-2010), and a sentinel longline program (1995-2010). In 2010, the abundance and biomass indices from all three monitoring programs were the lowest on record. All three programs indicate that the stock has been declining since the early to mid 2000s.

A population model is available for this stock. This model estimates abundance at age since 1950 and separate trends in natural mortality for ages 2-4 and 5+ since 1977. This model differs from the model used in the most recent assessment of this stock (February 2009), primarily in its treatment of natural mortality. The new model also takes into account changes in age at maturity over time. Differences between the results reported here and in the previous assessment (e.g., the level of SSB) reflect the changes in model structure rather than changes in stock status. The new model estimates that stock status was similar in 2009 (the most recent year covered by the last assessment) and in 2010. Although population levels differ somewhat between the two models, the estimated trends in 5+ abundance and biomass are very similar.

The abundance and biomass of cod aged 5 years and older (5+) declined by about 70% from the mid 1950s to the mid 1970s (Fig. 2). Despite this large decline, spawning stock biomass (SSB) and mature abundance changed little over this period because of a dramatic decrease in age at maturation (i.e., the loss of old fish was compensated for by an increase in the proportion of young fish that were mature). Both 5+ and mature biomass and abundance increased sharply in the late 1970s and early 1980s, reflecting the recruitment of unusually strong year-classes (Fig. 2). The stock then collapsed rapidly in the late 1980s and early 1990s. The rate of decline slowed following the closure of directed fishing in late 1993, though mature abundance continued to decline at a slower rate from then to the present. Mature biomass stabilized briefly with the reduction in fishing effort in the early 1990s but began to decline again in the early

2000s. Estimated SSB at the beginning of 2010 (39,500 t) is 34% of the average level in the mid to late 1990s and 11% of the average level in the 1980s. Average mature abundance in 2008-2010 is estimated to be 37% of the average level in the mid to late 1990s and 10% of the average level in the mid 1980s.

Year-classes produced in the mid to late 1970s were unusually strong given the low SSB that produced them (Fig. 3). The 2003-2005 and 2007 year-classes are estimated to be the weakest in the 61 year record. Recent estimates of 2+ abundance are the lowest on record.

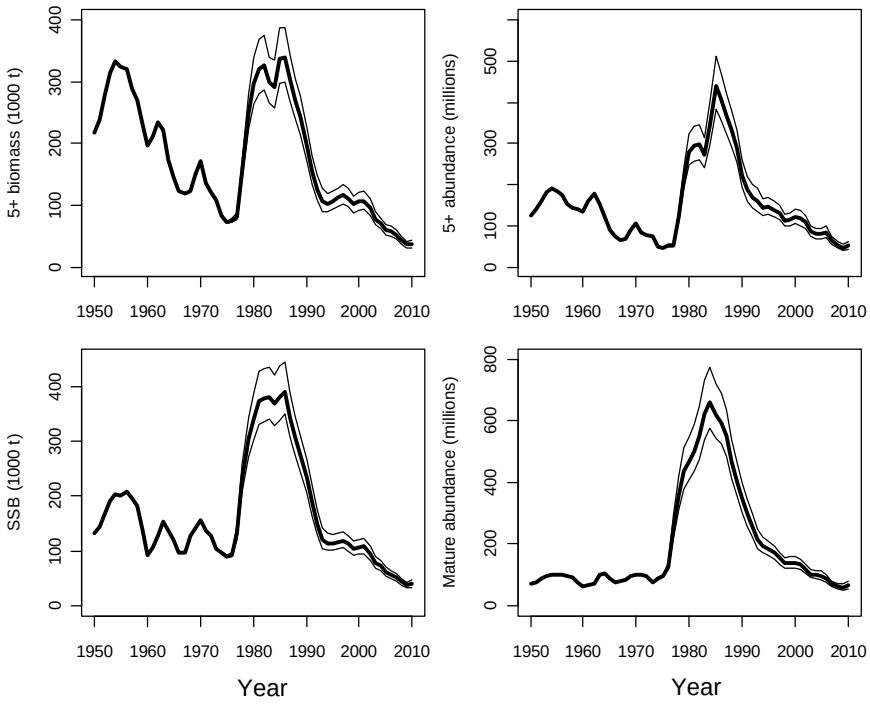


Figure 2: Biomass and abundance of the southern Gulf cod population. Heavy lines show the median estimate and light lines show the uncertainty (95% probability) around these estimates.

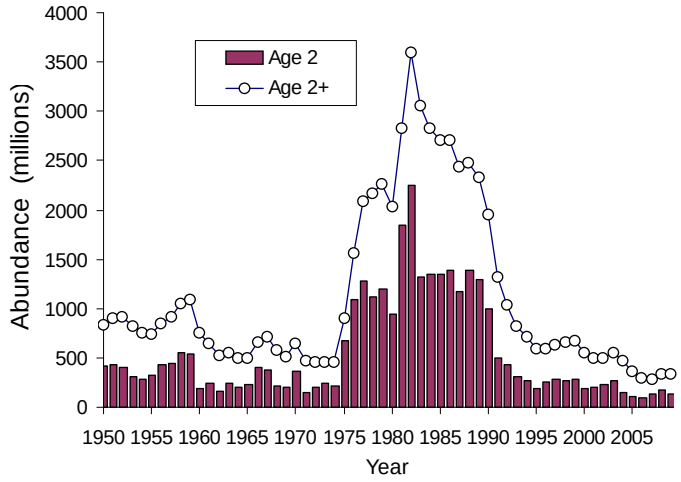


Figure 3: Recruitment (age 2) and total (2+) abundance of southern Gulf cod.

4VsW cod

The status of this stock is currently monitored by a research vessel bottom-trawl survey in July (1970-2010), a sentinel fixed gear survey (1995 - 2010), and a March bottom trawl survey (1986-2010). The March survey does not track cohorts well and the sentinel survey covers only a small portion of the stock area so neither is used in the estimation of stock status. In the last few years. the July survey series has shown some improvement (Fig. 4).

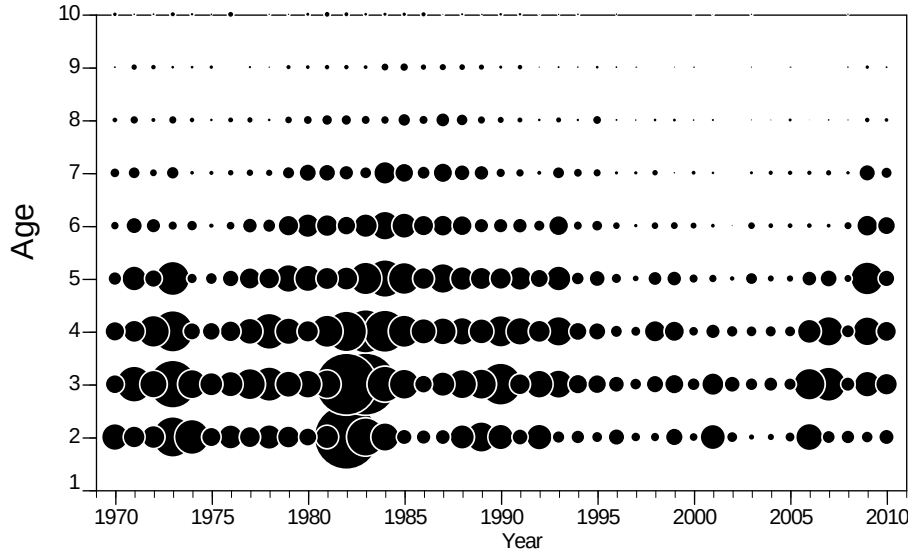


Figure 4: Numbers at age for 4VsW cod from the July survey. The area of the symbol represents the relative abundance at age.

A population model is available for this stock. The stock has not been assessed since 2003, but a new population model was developed for the RPA. This model estimates abundance at age since 1958 and separate trends in natural mortality for ages 1-4 and 5+ since 1970. The SSB started at a high level and then fell in the early 1970s (Fig. 5). It rebounded quickly after a period of strong recruitment, but then collapsed a second time in the late 1980s and early 1990s (Fig. 5). SSB remained at the lowest levels observed from the mid 1990s to the mid 2000s. Although a couple of recruitment events happened after the closure of cod-directed fishing in 1993, it was not until the last few years that the SSB responded. Both mature biomass and mature abundance have shown a recent improvement to the vicinity of the long term mean (Figs. 5 and 6). Recruitment has not returned to the levels seen in the 1970s (Fig. 7). Since 1990, there have been three peaks in recruitment, 1992, 1998 and 2004 year-classes.

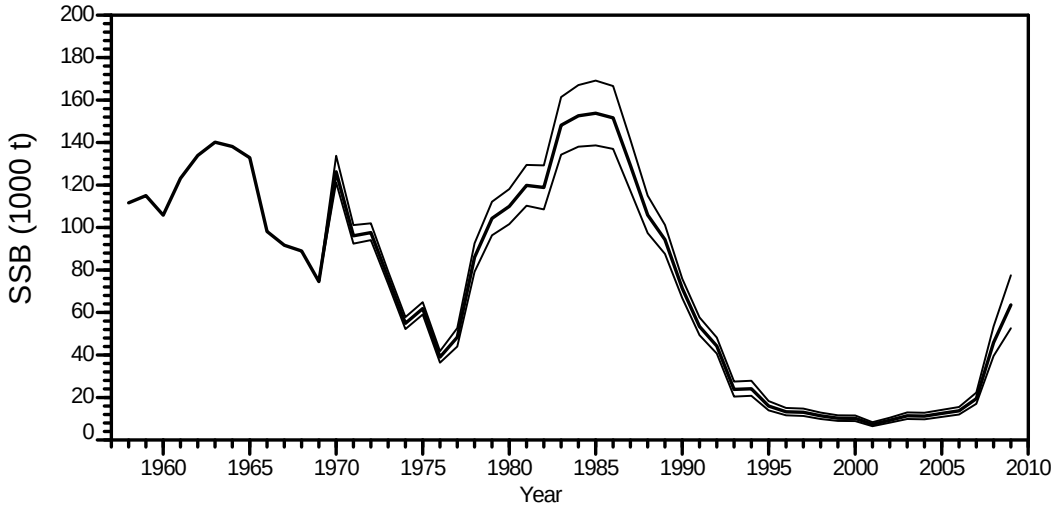


Figure 5: SSB for 4VsW cod. Heavy lines show the median estimate and light lines show the uncertainty (95% probability) around these estimates

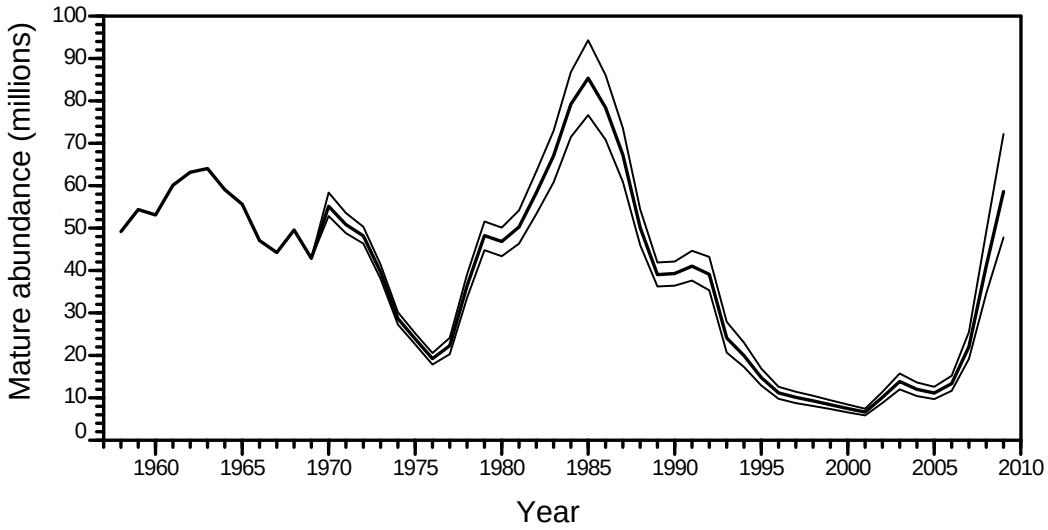


Figure 6: Mature abundance (number of fish, millions) for 4VsW cod. Heavy lines show the median estimate and light lines show the uncertainty (95% probability) around these estimates.

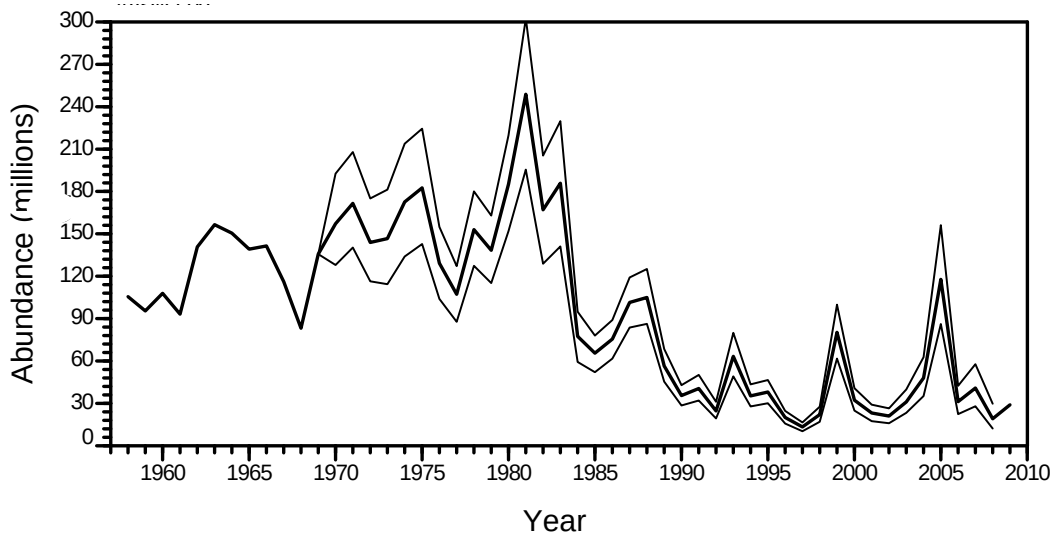


Figure 7: Recruitment at age 1 for 4VsW cod. Heavy lines show the median estimate and light lines show the uncertainty (95% probability) around these estimates.

4Vn cod

Two surveys are available to monitor the 4Vn stock – the July DFO groundfish survey (1970 to 2010) and a sentinel fixed gear survey (1994 to present). Abundance and biomass indices from the July survey were highest from 1980 to 1990, but declined to low levels since then (Fig. 8).

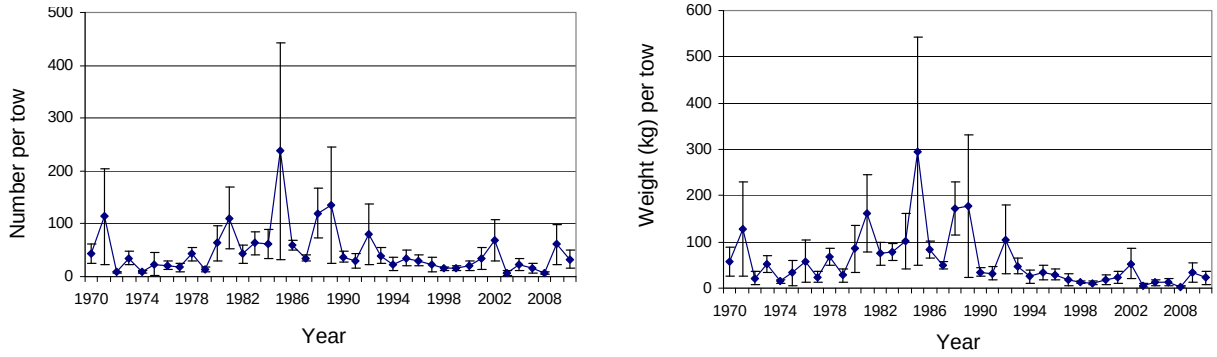


Figure 8: Number and weight per tow (mean and two standard errors) for 4Vn cod from the July research vessel survey.

While a shorter time series, the biomass index from the sentinel fixed gear survey has shown a similar decline, and now is at the lowest levels observed (Fig. 9).

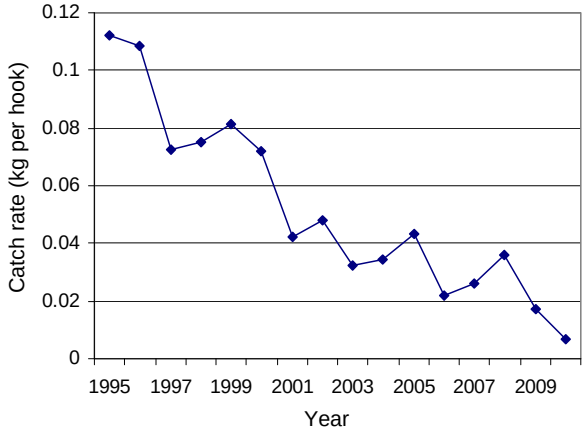


Figure 9: Catch rate index for 4Vn cod abundance from September sentinel fixed gear survey.

A recruitment index (sum of age 2-4 fish along cohorts) is available from the July research vessel survey (Fig. 10). While considerable variation is seen, recruitment was highest in the early part of the time series, but has generally been low from 1988 onwards. The estimate for 1999 was high, but this strong signal did not translate into a subsequent increase in biomass.

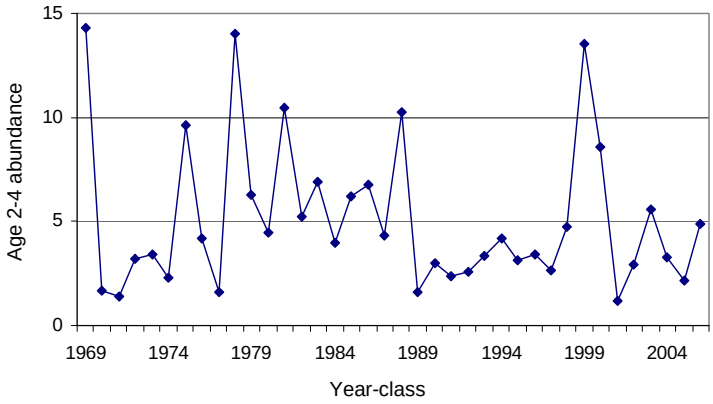


Figure 10: Recruitment index (age 2-4 cohort numbers) for 4Vn cod from July research vessel survey.

Laurentian South DU

No population model is available for 4Vn but its contribution to the abundance and biomass of this DU is small (less than 10%). Based on the population models for southern Gulf and 4VsW cod, the combined 5+ biomass and abundance of these two components of the DU declined to the lowest observed levels in the late 2000s and then recovered slightly due to increases in the 4VsW component (Fig. 11).

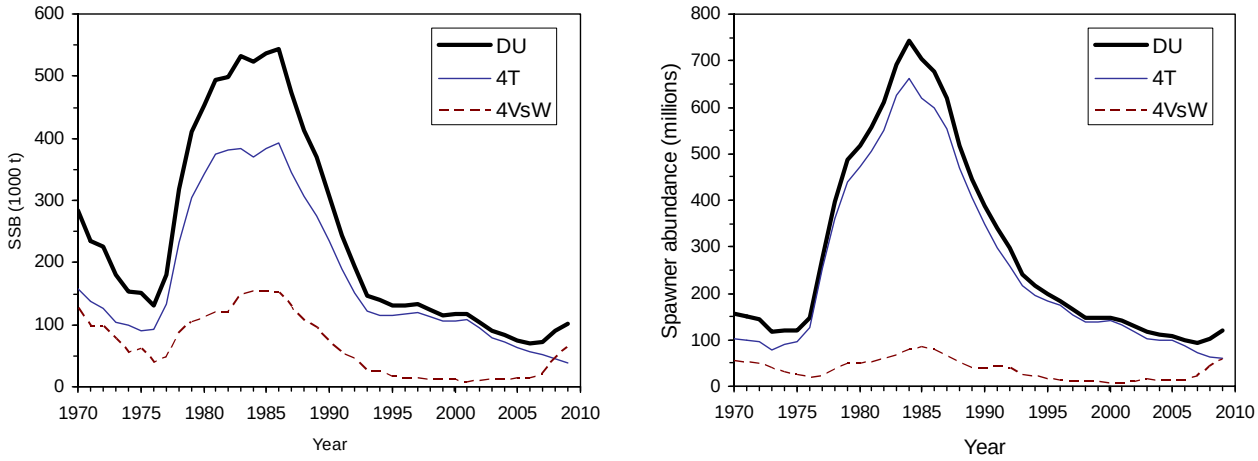


Figure 11: Spawning stock biomass (left panel) and spawner abundance (right panel) for the Laurentian South DU (upper line) and its two main components (southern Gulf cod, light line; 4VsW cod, dashed line).

Historic and Current Distribution and Trends

Southern Gulf cod

An index of geographic range was calculated based on catches in the September survey. The area occupied by southern Gulf cod was highest in the 1980s and lowest in the 2000s (Fig. 12). For juvenile cod (≤ 38 cm), area occupied declined from an average of about 60,000 km^2 in the 1980s to an average of about 46,000 km^2 in the 2000s. For adult cod (≥ 39 cm), area occupied declined from an average of about 64,500 km^2 in the 1980s to an average of about 47,000 km^2 in the 2000s.

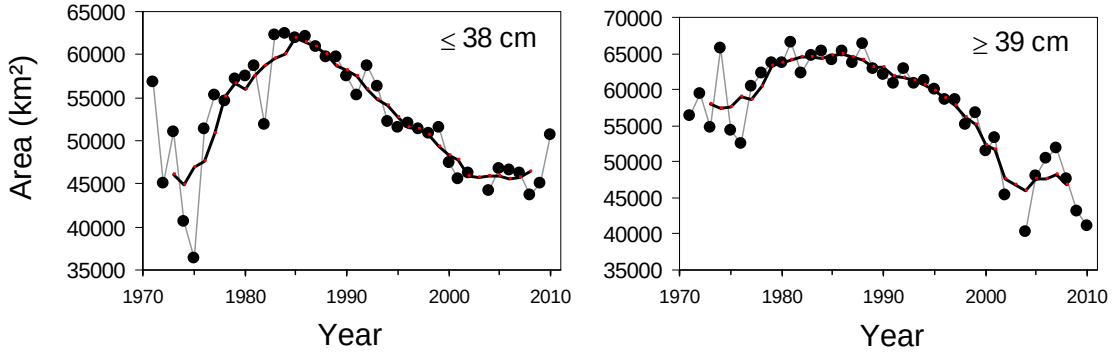


Figure 12: Index of area occupied (km^2) by juvenile (≤38 cm) and adult (≥39 cm) length classes of southern Gulf cod.

4VsW cod

An index of geographic range was calculated based on catches in the summer survey. The area occupied by 4VsW cod was highest in the 1980s and lowest in the 2000s (Fig. 13). For adult cod (≥ 39 cm), area occupied was about 70,000 km^2 until 1992 and then declined to about 25,000 km^2, increasing somewhat in recent years. For juvenile cod (≤ 38 cm), the area occupied changed less; starting at about 50,000 km^2 and falling to a minimum in the early 2000's with a recent increase.

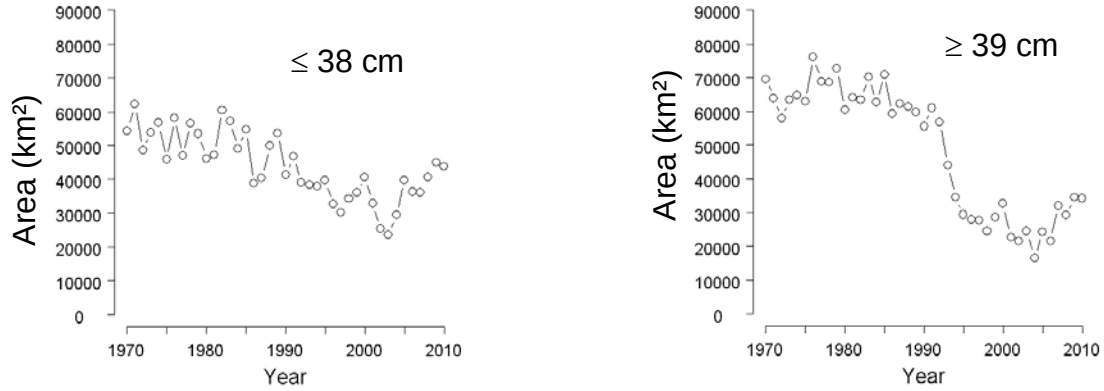


Figure 13: Index of area occupied (km^2) by juvenile (≤38 cm) and adult (≥39 cm) length classes of 4VsW cod.

4Vn cod

An index of geographic range was calculated based on catches in the July research vessel survey. Area occupied did not show any distinct trends for small (≤ 38 cm) fish (Fig. 14). However, a declining trend was observed for larger (≥ 39 cm) fish starting in 1990, with the index falling by about a third.

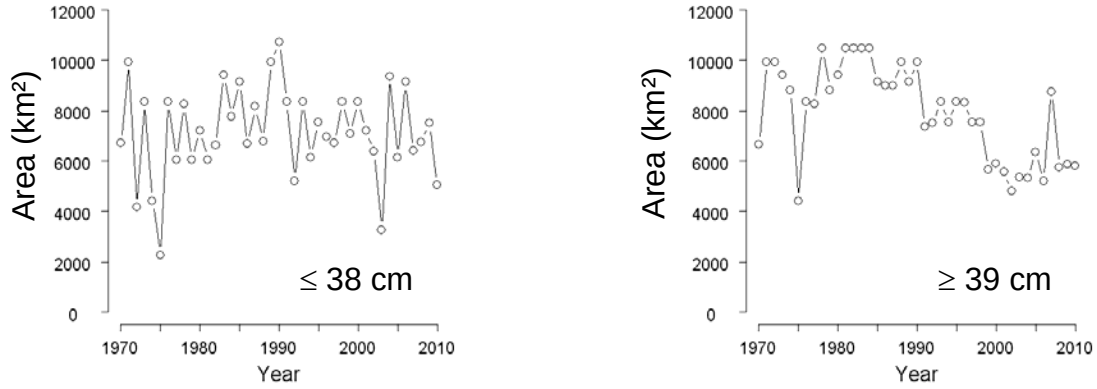


Figure 14: Index of area occupied (km^2) by juvenile (≤38 cm) and adult (≥39 cm) length classes of 4Vn cod from the July research vessel survey, 1970-2010.

Laurentian South DU

At the DU level, area occupied was roughly stable throughout the 1970s and 1980s but then declined in the 1990s (Fig. 15). This decline was considerably greater for the larger adult cod than for smaller cod. Area occupied in the early 2000s (2000-2004) was 73% of the 1980s average for small cod and 55% of the 1980s average for large cod. In the late 2000s, area occupied recovered somewhat, due entirely to increases in the 4VsW component. By 2008-2010, area occupied had increased to 96,000 km^2 for small cod and 82,000 km^2 for large cod.

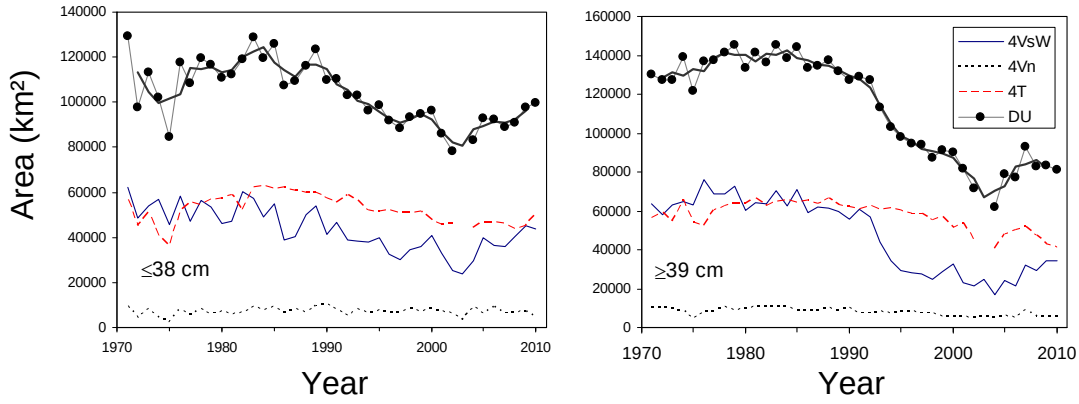


Figure 15: Index of area occupied (km^2) by juvenile (≤38 cm) and adult (≥39 cm) sizes of cod for the Laurentain South DU.

Life History Parameters

Southern Gulf cod

Natural Mortality (M)

Earlier studies estimated the instantaneous natural mortality rate (*M*) of 5+ southern Gulf cod to be between 0.07 and 0.2 in the 1970s and earlier. In the population model a value of 0.15 was assumed for 5+ cod in 1950-1976. There is no independent information on the level of *M* for younger southern Gulf cod. Based on a study that modeled empirical estimates of *M* of marine fish as a function of fish length and growth characteristics, a value of 0.65 was assumed for 2-4 year old cod in 1950-1976. The population model estimated *M* in years after 1976. For young cod, estimated *M* declined in the late 1980s and early 1990s (Fig. 16). For older cod, estimated *M* increased in the late 1970s and early 1980s to a level near 0.35 and then increased further in the late 1980s and early 1990s to a level that fluctuated between 0.6 and 0.75.

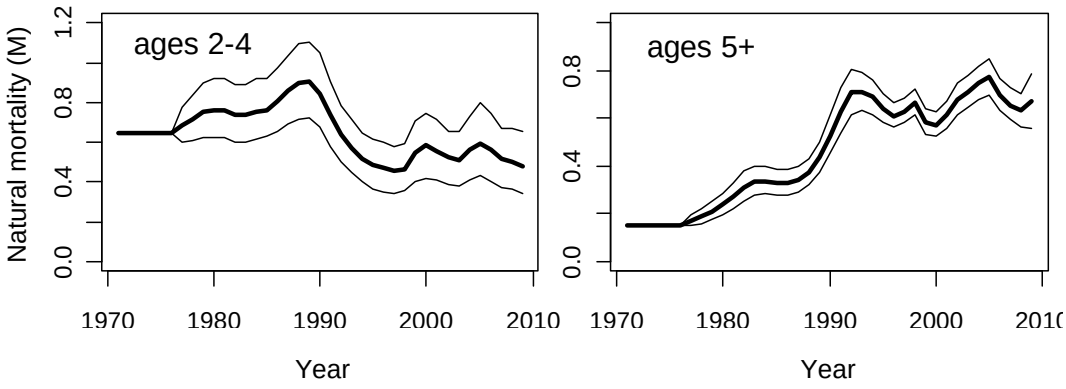


Figure 16: Estimated rate of natural mortality (M) of young (2-4 years) and older (5+) southern Gulf cod. Heavy lines show the median estimates and light lines show the uncertainty (95% probability) around these estimates. Values were assumed to be 0.65 and 0.15 for young and older cod respectively in 1950-1976.

Estimates of *M* from population models also include any mortality due to discarded or unreported catch. The decline in estimated *M* of young cod from the late 1980s to the mid 1990s may partly reflect a decline in discard mortality due to management measures implemented in the late 1980s and early 1990s and to the sharply reduced fishing effort since the mid 1990s.

The sharp increase in estimated 5+ *M* in the late 1980s and early 1990s may be partly due to increases in unreported catch during this period, as suggested by an independent modelling study. However, fishing effort in the southern Gulf declined to very low levels in the mid to late 1990s and in the 2000s, and very little of the high estimated *M* in these periods can be attributed to unreported catch.

Age and size at maturation

Age and length at 50% maturity declined sharply in cohorts of southern Gulf cod produced in the 1950s and 1960s (Fig. 17). This likely represents an evolutionary response to intensified fishing. Maturation schedules changed little among cohorts produced since the early 1970s, despite severe reductions in fishing effort and mortality in the 1990s and 2000s. The high natural mortality of adult cod in the 1990s and 2000s may be a cause of the continued early maturation in this population, now replacing fishing mortality as the agent of selection favouring early maturity.

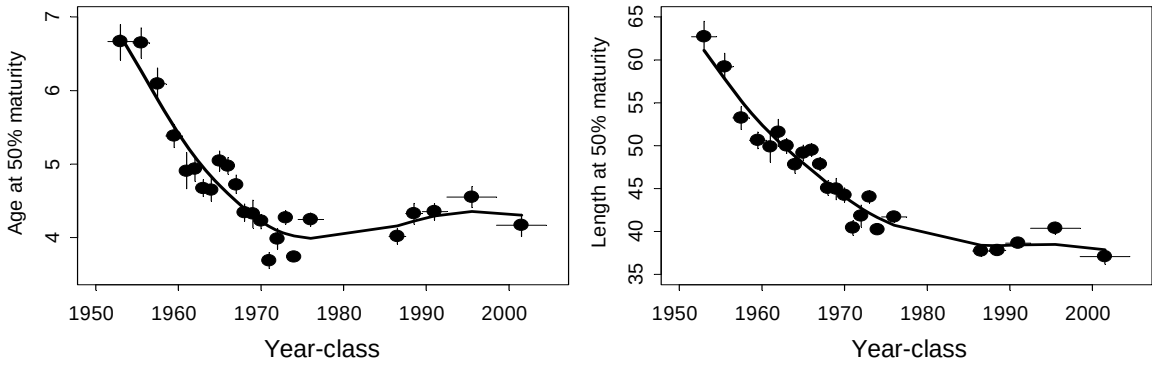


Figure 17: Age and length at 50% maturity of female southern Gulf cod. Vertical lines are 95% confidence intervals. Horizontal lines indicate the range of year-classes grouped together for an estimate. Time trends are summarized by a smoothing spline.

Fecundity

Compared to other cod stocks south of the Laurentian Channel, the southern Gulf stock has high size-specific fecundity, high gonadosomatic index and large eggs. Its higher reproductive allotment may be an adaptation to its slow growth and later maturation. Though estimates of size-specific fecundity can vary significantly from year to year, no long term changes in fecundity at size are evident.

Growth and condition

Weight-at-age of southern Gulf cod dropped sharply in the late 1970s and early 1980s (Fig. 18). This reflected a density-dependent decline in growth rate as cod abundance increased during this period, combined with a change in the direction of size-selective fishing mortality. Weight-at-age has remained low since the mid 1980s, despite good conditions for growth in recent years (i.e., low cod abundance, high prey abundance and relatively warm water temperatures) and a severe reduction in size selection due to fishing. The continued small size-at-age of southern Gulf cod may be partly due to a genetic response to size-selective fishing in the 1980s and early 1990s, or could reflect the phenotypic response to continued size-selective mortality (now natural mortality rather than fishing mortality) or changes in cod behaviour in response to increased risk of predation.

Condition of southern Gulf cod in September was relatively high in the early to mid 1970s, low from the late 1970s to the mid 1980s, near the long term average from the late 1980s to the mid 2000s, and slightly below the long term average in recent years (Fig. 19). Southern Gulf cod feed little in the winter and thus show a strong seasonal cycle in condition, with condition at its lowest level in spring. Condition in the spring, monitored since 1992, tended to be higher in the 2000s than in the 1990s.

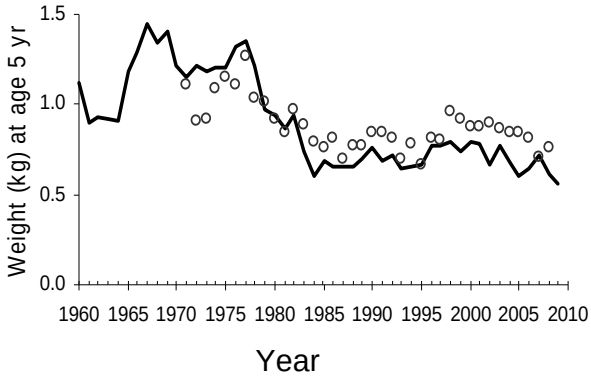


Figure 18: Mean weight (kg) at age 5 years of southern Gulf cod from the September research vessel survey (line) and the fishery (circles).

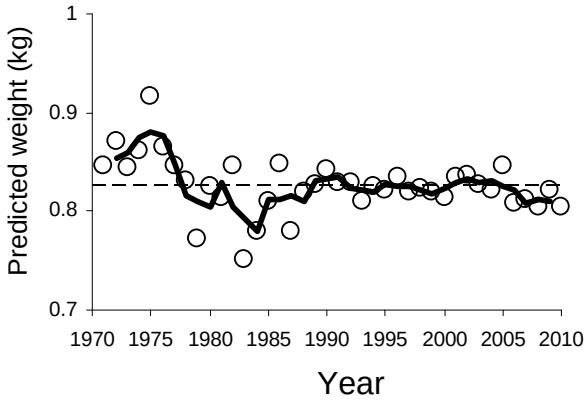


Figure 19: Condition index (predicted weight at 45 cm total length) of southern Gulf cod based on the length-weight relationship of fish caught in September. Heavy line is a 3-yr moving average and dashed line is the 40-yr mean.

Recruitment rate

Year-classes of southern Gulf cod produced in the mid to late 1970s were unusually strong (Fig. 20). The recruitment rate in this period is thought to be abnormally high, reflecting reduced predation on cod eggs and larvae following the collapse of pelagic fish stocks in the southern Gulf in the early 1970s. Pelagic fish stocks recovered in the 1980s, and recruitment rates of cod returned to a lower level.

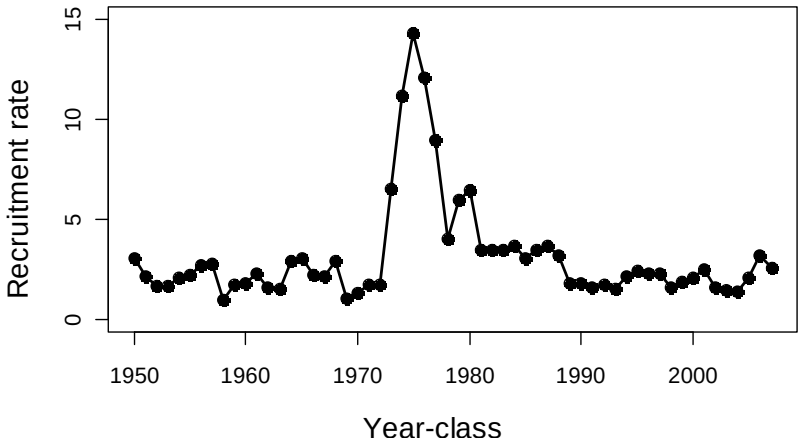


Figure 20: Recruitment rate (abundance at age 2 yr divided by the SSB) of southern Gulf cod.

4VsW cod

Natural Mortality (M)

Natural mortality of 4VsW cod aged 5 years and older (5+) was estimated to be unusually high in the 1990s and early 2000s (peaking at approximately 1.1) but has recently declined to a low of 0.36 (Fig. 21). The mortality on young fish (1-4) has also had several peaks and valleys over the assessment period and fallen to the lowest values in the series recently (Fig. 22). The *M* on these younger fish is much less important on the productivity of the stock because it acts on only a few ages.

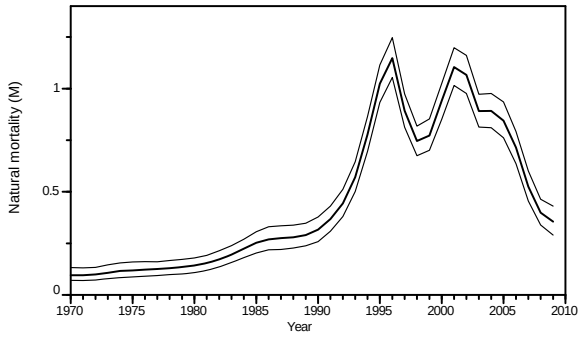


Figure 21: M estimated from VPA for 4VsW cod aged 5+ years. Black line is median estimate and light lines are the 2.5 and 97.5 percentiles.

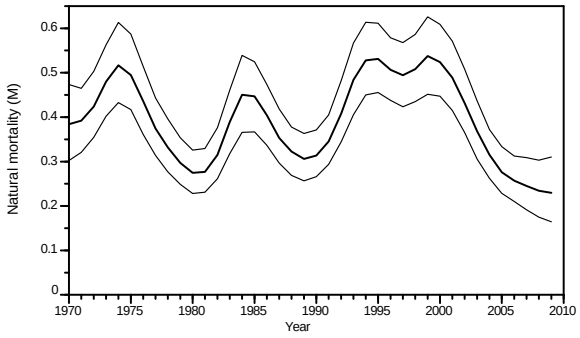


Figure 22: M estimated from VPA for 4VsW cod aged 1-4 years. Black line is median estimate and light lines are the 2.5 and 97.5 percentiles.

Age and size at maturation

Age and length at 50% maturity of female 4VsW cod have shown reductions since the beginning of the time series (1950s). Age at 50% maturity has declined from greater than 5 years of age for cohorts in the 1950s to less than 4 years in recent years (Fig. 23). Length at 50% maturity has fallen from about 50 cm for cohorts in the 1950s to less than 40 cm in recent years (Fig. 24). The causes for these declines are unknown.

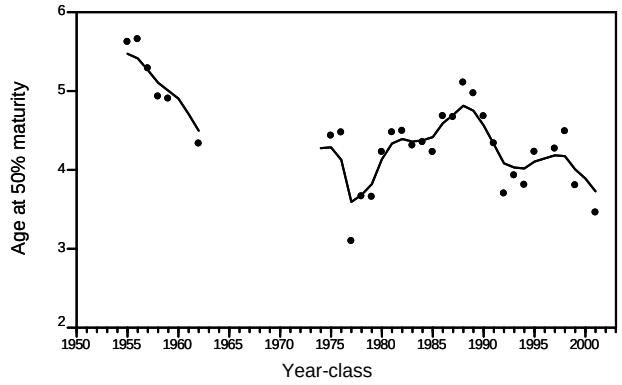


Figure 23: Age at 50% maturity by year-class of female cod in 4VsW from spring surveys.

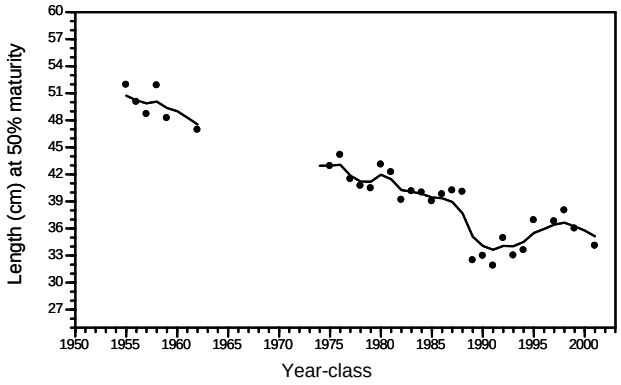


Figure 24: Length (cm) at 50% maturity for year-classes of female cod in 4VsW from spring surveys.

Fecundity

There are very few data on fecundity of 4VsW cod. Available information suggests that size-specific fecundity of cod is lower in 4VsW than the southern Gulf of St. Lawrence (4T) or Sydney Bight (4Vn).

Growth and condition

Weight-at-age of 4VsW cod declined from the 1970s through the 1990s with recovery to the long term mean by the end of the series (Fig. 25). Similarly, there was a general trend of decreasing condition from the 1970s until the early 1990s with a slight recovery thereafter (Fig. 26).

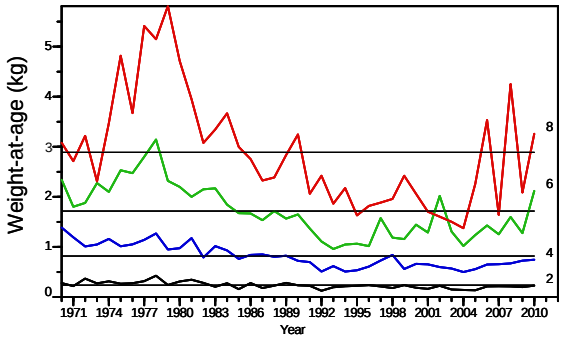


Figure 25: Weight-at-age for ages 2, 4, 6, and 8 years old 4VsW cod from the July survey. The horizontal lines are the means for each age.

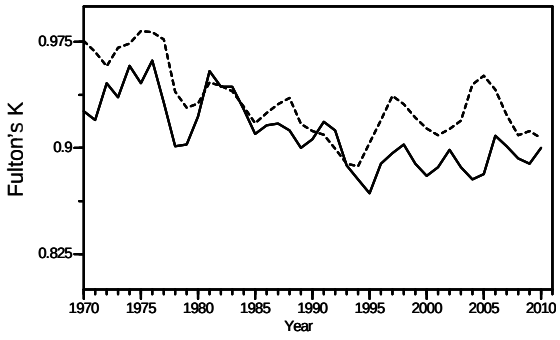


Figure 26: Condition expressed as Fulton's K for 30 cm (solid line) and 45 cm (dashed line) 4VsW cod. Data have been smoothed with a 3 year moving average.

Recruitment rate

Recruitment rate peaked in the 1970s, fell, and then increased to the highest levels observed in the 2000s (Fig. 27).

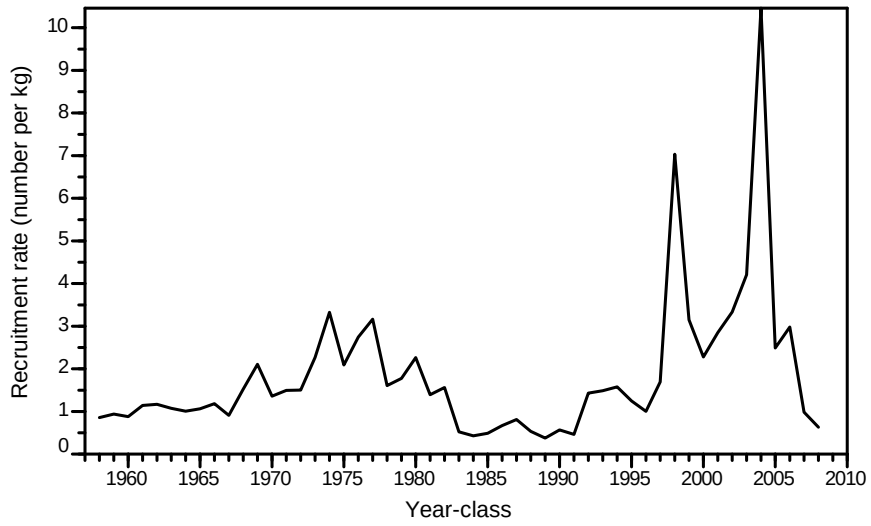


Figure 27: Recruitment rate (age-1 abundance divided by the SSB producing the year-class) of 4VsW cod.

4Vn cod

Natural Mortality (M)

Natural mortality rates have not been estimated for this stock. Based on estimates of total mortality (*Z*) from the July research vessel survey, *Z* increased in the mid 1980's for older ages (Fig. 28). *Z* for younger fish increased from the early 1990's onwards, and currently is in the same range as the older fish. As catches were substantially reduced with the closure of the fishery in 1993, these high estimates of total mortality indicate that natural mortality is high.

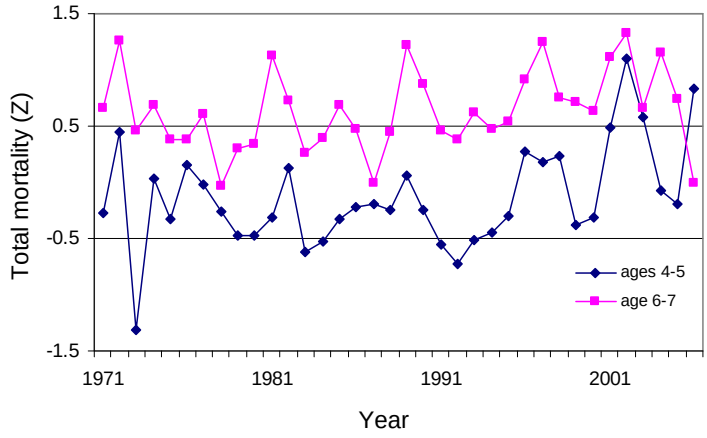


Figure 28: Estimates of total mortality (Z) of 4Vn cod by age groups.

Fecundity

Limited information collected in the late 1990's indicates that fecundity at length for the 4Vn stock is similar to that of the southern Gulf cod stock.

Growth and condition

Condition (predicted weight at length) for both large (50 cm) and small (30 cm) fish was highest in the 1970's, but declined subsequently (Fig. 29). While considerable variability is seen in the time series, condition for large cod has been without trend since 1980, while condition of 30 cm cod has shown a decline.

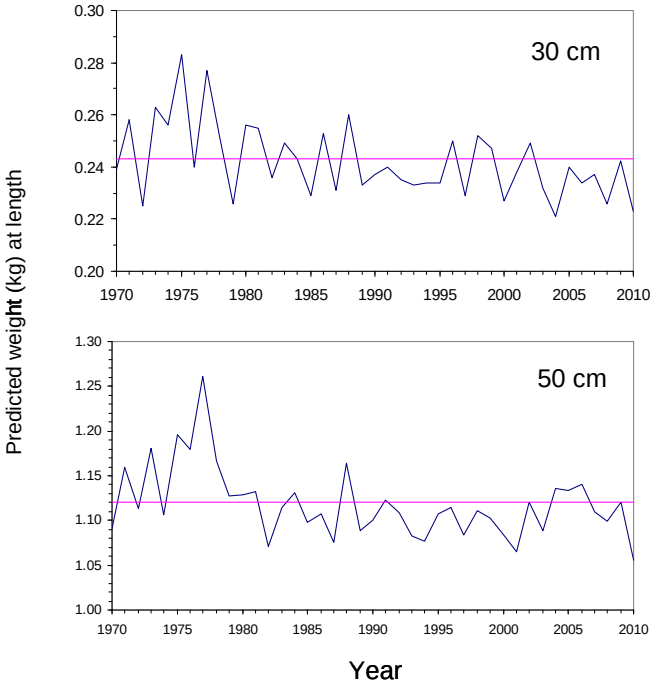


Figure 29: Condition (predicted weight at length) for 30 cm (upper panel) and 50 cm (lower panel) total length of 4Vn cod, from July research vessel survey.

Length-at-age for older (ages 4-7) fish was highest from the mid-1970's, but declined subsequently (Fig. 30). Some improvement has been seen in recent years. Length at younger ages shows little trend over the time series.

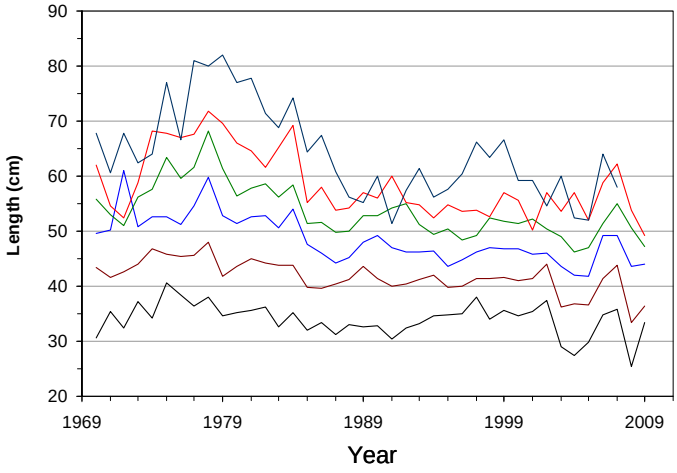


Figure 30: Length-at-age for 4Vn cod from the July research vessel survey. Ages 2 though 7 are shown.

Recruitment rate

The sum of age 2-4 fish over a year-class from the July research vessel survey is used as a recruitment index. Recruitment rate (the recruitment index divided by SSB) was relatively low for the early part of the time series (Fig. 31). However, since 1998 recruitment rate has been sharply higher.

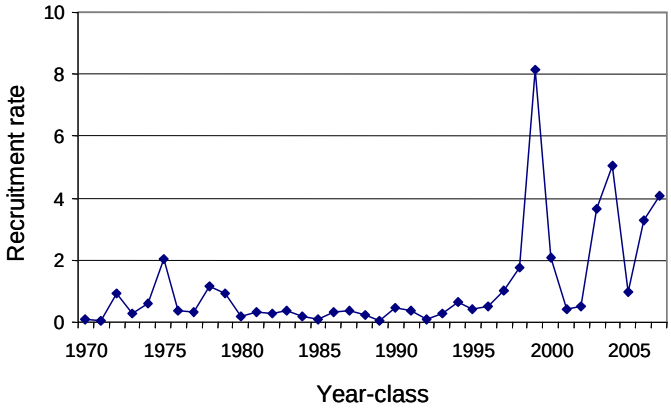


Figure 31: Recruitment rate index (year-class abundance at ages 2-4 / SSB) for 4Vn cod.

Habitat Requirements and Suitability

Habitat use by Atlantic Cod varies significantly by life stage and size. Latitudinal gradients in development rates (spawning times, egg development rates, and growth rates of all life stages), influence habitat use patterns in the species. Physical habitat associations are the strongest at the demersal juvenile stage (4 - 35 cm long).

Eggs and larvae

Egg and larval distributions are determined by the spawning locations of adult cod and subsequent action by prevailing oceanographic currents and non-density dependant forces. Eggs are typically found in the upper surface layers of water column. There is no evidence to suggest that they are associated with particular physical habitat features.

Juveniles

Cod assume more active control of their movements at the pelagic juvenile stage. It remains unknown to what extent individuals exhibit directional movements which might determine where they settle to the seabed. Prevailing evidence suggests that oceanographic currents and retention mechanisms have a dominant role on distribution.

The demersal juvenile stage is the most habitat-dependant period in the life-cycle of Atlantic Cod. Association with specific habitat features and habitat components is of greater importance in demersal juveniles after settlement to the seabed. Settlement locations vary by latitude and ambient near-bottom temperatures in potential areas of settlement. In western Atlantic waters, settlement occurs in both coastal and offshore locations in the southern portion of the range, whereas in the north it occurs predominantly in coastal waters. In the Laurentian South DU, juveniles tend to occur in shallow inshore areas in the southern Gulf and in 4Vn, and in the inshore and on the offshore banks in 4VsW, suggesting that settlement occurs in these areas.

Studies in other areas indicate that demersal juveniles associate with seabed habitats which provide cover from predators - physically complex habitats among those available. There is evidence to suggest that structurally complex habitat reduces mortality rate and is preferred by demersal juveniles. These complex habitats include pebble-gravel and rock-boulder areas within patchy marine landscapes and, in inshore areas, macroalgae and eelgrass beds.

There is evidence that juvenile cod do saturate local habitat and their densities affect recruitment to subadult life stages. Therefore, the amount of habitat likely defines an upper threshold carrying capacity within the life stage.

Adults

Adult and subadult cod are widely distributed in the southern Gulf, occupying a range of depths, temperatures and bottom types. The depths and temperatures occupied by southern Gulf cod vary seasonally. The median temperatures occupied by southern Gulf cod generally vary between about 1 and 3.5°C in summer (depending on age and time period) and 5 and 6°C in winter. Southern Gulf cod are generally distributed at intermediate depths (25-100 m) on the Magdalen Shallows during the summer feeding season and in deeper water (200-350 m for ages 4+) along the southern slope of the Laurentian Channel in winter. In summer, cod are distributed in inshore areas and on the banks in 4Vn and 4VsW, moving into deeper water in winter.

Given the broad distribution of waters suitable for cod in the southern Gulf, Cabot Strait, and Eastern Scotian Shelf, habitat is not considered to be limiting for the populations in this DU.

Spawning Adults

Over the species range, spawning cod have been observed both in offshore and inshore waters in large aggregations at all times of the year depending on location. Most spawning occurs in a two to three month long period, which may be specific to location. Individuals are batch-spawners. There is little consistency in spawning depth among areas. There is no correlation of location or timing of spawning to temperature. There is evidence that spawning time may be linked to periods of high secondary productivity.

The specific seabed habitat features that influence affinity to a specific area are not well known. Spawning locations are thought to be associated with oceanographic features such as gyres or currents that retain eggs and larvae, or distribute them to locations where conditions are generally good for the early life-history stages. Specific spatial locations which are stable in time suggest there are distinctive features about these locations leading spawners to choose them repeatedly. We do not currently know what constitutes "the habitat" for spawning cod, other than it quite often happens in the same place annually.

The main spawning area of southern Gulf cod is located in the western Magdalen Shallows in the area of the Gaspé Coast, Miscou Bank, the Shediac Valley, and the western coast of the Magdalen Islands. Spawning by southern Gulf cod generally occurs from April to September, with peak spawning in May-June.

4Vn cod spawn primarily from May to early July, in an area between Cape Smoky and the Bird Islands, know as ‘The Gutter’, although the appearance of 0-group fish at other times of the year suggest sporadic spawning occurs year round. These spawning aggregations are temporally and geographically distinct from aggregations in the southern Gulf and 4VsW.

In 4VsW, cod spawning has been documented to occur both in spring (April/May) and fall (November/December) with the distribution of spawners closely matching that of other mature individuals. Though rare, spawners have been observed during the March RV survey on the edge of Western Bank, the Gully, the Laurentian Channel, and in deeper waters northwest of Banquereau Bank. Unfortunately, there has been no fall research vessel survey since 1984 to examine this component of the resource.

Spatial Extent of Habitat

The geographic distribution of Atlantic Cod ranges from Cape Hatteras, North Carolina to Greenland in the western Atlantic and the Barents Sea south to Spain and Portugal in the eastern Atlantic. Older juveniles and adults are widespread throughout the Canadian portion of the historical range of the species, indicating suitable habitat exists throughout their range. However, very little information is currently available at the appropriate spatial resolution to identify the extent of the habitat available to demersal juvenile Atlantic Cod – such as gravel and cobble, eelgrass beds or macroalgae – especially in the offshore. There is no indication that the amount of suitable habitat is currently limiting recovery of cod.

Activities that Might Threaten Habitat

In general, potential for anthropogenic disturbance is highest in the coastal zone and with proximity to human population centers and industrial activity. Natural mortality of demersal juveniles can increase significantly with loss of habitat structure. Habitat alteration in the form of physical disturbance to structural components of habitat such as complex living habitat (e.g., corals, eelgrass and macroalgae) and some physical seabed features (e.g., fine scale geological bedforms) can reduce its function of providing cover from predators, therefore decreasing its value.

Mobile bottom-contact fishing gears have impacts on benthic populations, communities, and habitats. The effects are not uniform, but depend on at least the specific features of the seafloor habitats, including the natural disturbance regime; the species present; the type of gear used, the methods and timing of deployment of the gear, and the frequency with which a site is impacted by specific gears; and the history of human activities, especially past fishing, in the area of concern.

Other gears including those that do not contact the bottom may still have an effect but the severity of any impact will depend on the nature of the impact (i.e. what is impacted and in what way); the location and scale of the fishery and how the gear is rigged, deployed, and retrieved.

Eutrophication is a threat in areas of the nearshore and also in some areas of the inshore. Eelgrass beds and macroalgae can be impacted by anthropogenic eutrophication, sedimentation, and contaminants.

Oil and gas development may cause physical disturbance or contamination of habitat.

Impact of Potential Habitat Changes

Limitations in the quantity of habitat available and interannual variation in predator and prey abundance can create bottlenecks to demersal juvenile survival.

Juvenile cod mortality rate is very high in non-complex habitat, compared to complex habitats nearby. The ecological significance of complex habitat on survival of demersal juvenile cod cannot be overstated. Complex habitat represents a buffering effect on populations, especially at low abundance. Evidence that demersal juvenile cod can attain a carrying capacity limit has been demonstrated at local scales in coastal waters; however, this appears to be rare and is unlikely to be a common occurrence across an entire DU.

Reduced landscape complexity in eelgrass beds leads to reduced demersal juvenile densities and carrying capacity within habitat. The impact of reduced landscape complexity for other habitat components is unavailable.

Spatial Configuration Constraints

Spatial configuration constraints such as connectivity and barriers to access are not a current limiting factor for Atlantic Cod recovery.

Amount of Suitable Habitat

Older juveniles and adults are widespread throughout the Canadian portion of the historical range of the species, indicating that some amount of suitable habitat exists within this range. However, very little information is currently available at the appropriate spatial resolution to identify the extent of the habitat available to demersal juvenile Atlantic Cod – such as gravel and cobble, eelgrass beds or macroalgae – especially in the offshore. There is no indication that the amount of suitable habitat is currently limiting recovery of cod.

Feasibility of Habitat Restoration

It is technically feasible to undertake restoration of coastal habitat in localized areas. However, there is no indication that such restoration is required for population recovery.

Habitat restoration to higher values would likely be focused in shallow environments (e.g., coastal environment). Introduced materials (e.g., rocky reefs) and restored shoreline and eelgrass restorations and transplants have been successful in other countries and also in Canada. Natural expansion of some vegetated habitat is known to be accompanied by increased demersal juvenile density. Therefore, it is possible to consider such options on small local scales.

Risks Associated with Habitat “Allocation” Decisions

The degree to which a habitat can be defined as a discrete area with clear edges or a gradient of features in the marine environment has not been identified. The associated risks of habitat allocation decisions have not been evaluated for Atlantic Cod. However, as noted earlier, there is no indication that the amount of suitable habitat is currently limiting recovery of cod.

Impact of Threats on Quality and Quantity of Available Habitat

Older juveniles and adults are widespread throughout the Canadian portion of the historical range of the species, indicating that some amount of suitable habitat exists within this range.

Habitat alteration, especially physical alteration or loss of structurally complex seabed habitat will reduce its value. Threats to cod habitat include physical disturbance to complex living

habitat and physical seabed features, eutrophication, invasive species and shoreline development.

Natural mortality of demersal juveniles can increase significantly with loss of habitat structure. Habitat alteration in the form of physical disturbance to structural components of habitat such as complex living habitat (e.g., corals, eelgrass and macroalgae) and some physical seabed features (e.g., fine scale geological bedforms) can reduce its function of providing cover from predators, therefore decreasing its value. Due to the current lack of knowledge of distribution and quantity of structurally complex habitat, especially in the offshore, we have little understanding of how much these habitats may have been altered by human and natural disturbances in the past. The specific effects of any particular threat on productivity of cod habitat are even less clear. There is no indication that the amount of suitable habitat is currently limiting recovery of cod.

The permanent loss of some habitat components will have a disproportionate negative effect on cod populations. Eelgrass is a DFO-Ecologically Significant Species. It is known to be important in near shore areas for small demersal juvenile cod in much of its range. The impact of loss of this habitat is known to be high. Impacts of possible losses for other habitat components have not yet been determined.

Fishing gears and eutrophication also affect the quality and quantity as described under the section above ‘Activities that Might Threaten Habitat’.

Invasive species present a significant local threat in some areas in which they have been observed. Invasive green crab (*Carcinus maenas*) is a known threat in shallow coastal waters. The species can destroy eelgrass beds by uprooting the plants. Other invasive species can overgrow marine vegetation, reducing its function of providing cover from predators, therefore decreasing its value. There have been no specific threats to cod habitat identified in offshore areas.

Sensitive Areas

Cod in the southern Gulf population are highly aggregated at certain times of year and would be especially vulnerable to disturbance at these times. Southern Gulf cod are highly aggregated on the overwintering grounds (e.g., in the vicinity of St. Paul’s Island in November to January), during the migrations in spring (April and early May) and fall (early November) through the Cape Breton Trough and along the southern slope of the Laurentian Channel, and on the spawning grounds.

4Vn cod migrate offshore in winter to deeper water in the Laurentian Channel, where they mix with southern Gulf cod, although the population size of the 4Vn resident stock is very small relative to that of that of the southern Gulf. Although both fisheries are closed at present, a fishery conducted in the Laurentian Channel during the period when the two stocks are mixed has the potential to overfish the 4Vn stock.

4Vn cod are known to form spawning aggregations in the area between Cape Smoky and the Bird Islands, where they were heavily fished in the past.

Residence

The *Species at Risk Act* 2(1) defines a residences as “a dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating”.

Laurentian South cod do not have any known dwelling-place similar to a den or nest during any part of their life-cycle. Therefore, the concept of residence does not apply.

SARA and Management Considerations

Limit Reference Point

The limit reference point (LRP) for recruitment overfishing is the SSB below which the stock is considered to have suffered serious harm (because the probability of good recruitment is low). A LRP has been established for each of the populations in the Laurentian South DU.

Southern Gulf cod

The LRP was established for this population in 2002, based on the lowest historical SSB from which the stock readily recovered and on a variety of methods based on stock-recruit relationships. The estimated LRP is 80,000 t of SSB. The stock is estimated to have been below the LRP since 2003. Estimated SSB in 2010 is 49% of the LRP.

4VsW cod

The LRP is based on the spawning stock biomass producing maximum sustainable yield (BMSY) during a productive period, defined here as the period up to 1990. The LRP was defined as 40% of BMSY and is estimated to be 50,000 t of SSB. SSB has been beneath the LRP since 1992 except the most recent year (2009) which was 25% above it.

4Vn cod

A LRP, based on the minimum SSB from which the stock has readily recovered, was determined based on area-expanded mature survey biomass from July. This limit corresponds to the 1973-1978 period, with a mean value of about 8,400 t. Currently (2004-2009) the biomass is about 2,250 t, or about 25% of the LRP.

Projections at current productivity

Long-term stochastic projections were undertaken to examine the consequences of current productivity conditions, defined here as the conditions that occurred between 1994 and 2009 (i.e., since the initial closure of cod-directed fisheries in September 1993). These projections should not be interpreted as forecasts of future stock status because they depend on assumptions about future productivity. Future productivity conditions are very uncertain, and the probability of current conditions continuing for a long period of time is unknown. The southern Gulf and 4VsW populations were projected forward over 36 years, taking into account uncertainty in estimated abundance at age and uncertainty and variability in estimated components of productivity in the current period. Projections are illustrated using the median and the 2.5^{th} and 97.5^{th} percentiles. The full range of uncertainty should be considered when

interpreting these projections. Projections could not be undertaken for the 4Vn resident population which lacks a population model.

Southern Gulf cod

Productivity of southern Gulf cod has been low for the past 20 years. If these productivity conditions persist in the future, the population would be expected to continue to decline, even with no fishery removals. The fully-recruited fishing mortality *F* that resulted from the bycatch-only fishery in 2009 is estimated to be 0.014. This level of F has no detectable effect on the projected population trajectory. During the small directed fisheries in 2007 and 2008 (total allowable catch of 2000 t), *F* is estimated to have averaged 0.106 for fully recruited ages (9-10). At this level of *F* the projected population declines are noticeably steeper. Under current productivity conditions, the probability of achieving the LRP over the next 40 years is zero for this population for all levels of *F*, including *F* = 0.

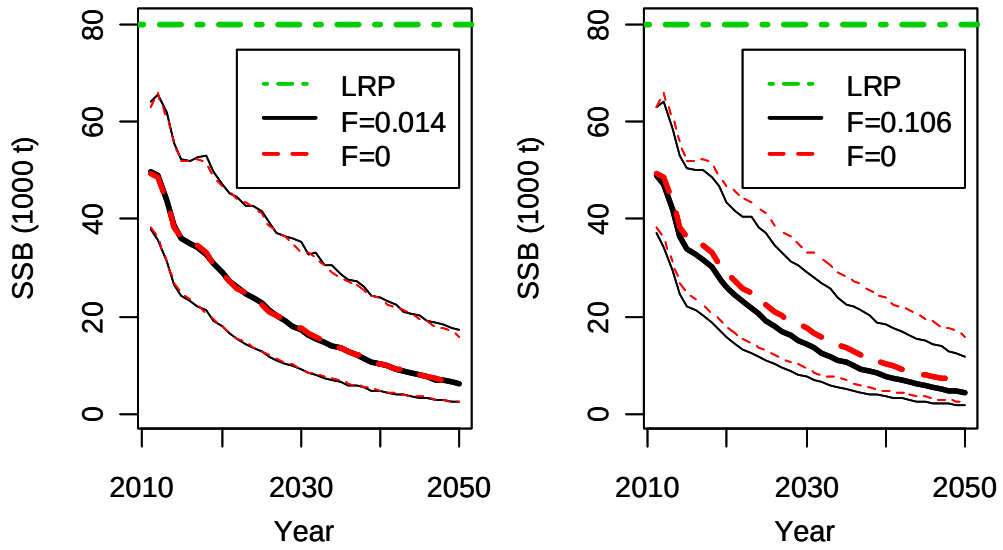


Figure 32: Projected SSB of southern Gulf cod relative to the LRP, assuming that current producivity conditions were to persist in the future and at current bycatch F (left panel) and at directed fishery F of 2007 and 2008 (right panel). Heavy lines show the median projection and light lines the 2.5th and 97.5th percentiles.

4VsW cod

If current productivity conditions (as defined by the period 1994-2009) were to persist in the future, the population would be expected to continue to decline, even with no fishery removals. The average fishing mortality on older fish (5-15) has been around 0.01 for the last few years. This level of *F* has no detectable effect on the projected population trajectory (Fig. 33). The recent strong year-classes persist in the projections for a few years and then the stock settles to a low equilibrium size. Under these conditions, the probability of reaching the LRP is zero.

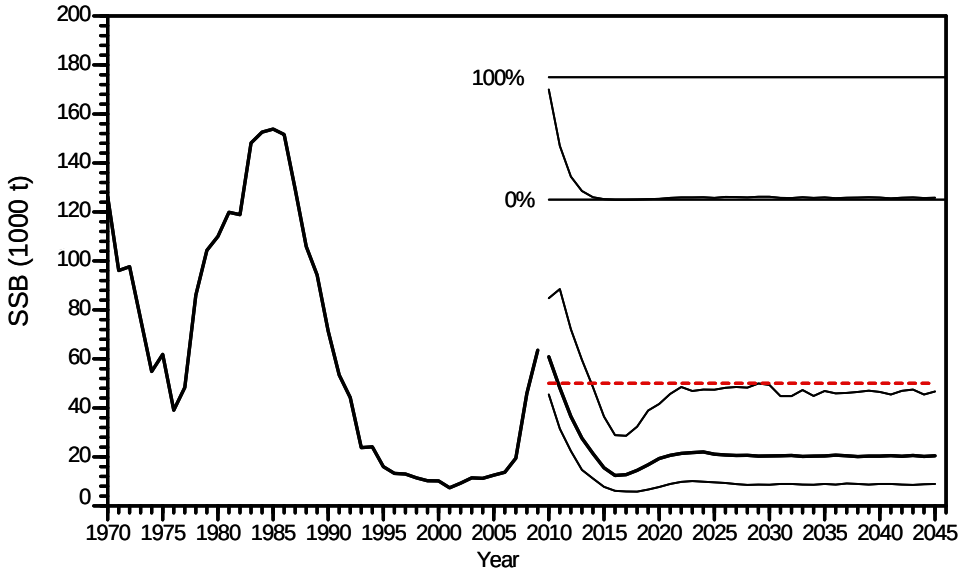


Figure 33: SSB projections with F = 0.01. The thin lines are the 2.5 and 97.5 percentiles. The horizontal dashed line is the LRP (50,000 t). The inset graph is the probability of exceeding the LRP.

Laurentian South DU

According to projections, the combined mature abundance of the southern Gulf and 4VsW stock components would be expected to decline if current productivity conditions were to persist. For each year of the projection, the probability of exceeding mature abundance 36 years (3 generations) earlier was calculated. A high probability of exceeding this level of abundance might be considered an indication that the level of risk has declined for this DU. The probability of exceeding mature abundance 36 years earlier is initially high because mature abundance was very low 36 years in the past (the mid 1970s) (Fig. 34). However, the probability of reaching this level falls to zero early in the projection.

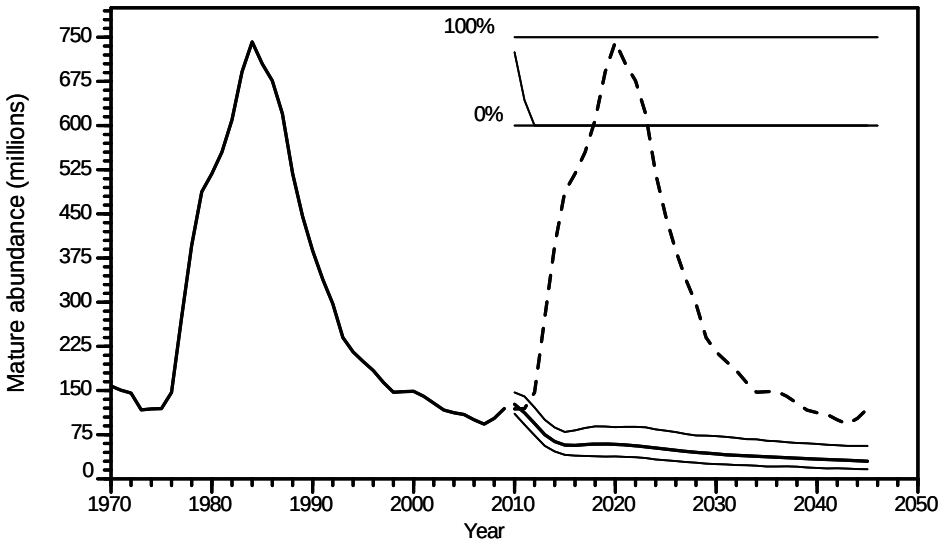


Figure 34: Combined history (1970 to 2009) and projections (2010 to 2045) of mature abundance for the southern Gulf and 4VsW stock components of the Laurentian South DU. The median of the projection is the heavy line; light lines show the 2.5th and 97.5th percentiles. The inset graph is the annual probability that mature abundance will exceed the level observed 36 years earlier (the dashed line).

Projections at other levels of productivity

Southern Gulf cod

Projections were also conducted at lower levels of 5+ *M* in order to determine the reduction in 5+ *M* required to obtain stable or increasing SSB at current levels of the other components of productivity (Fig. 35).

If other components of productivity were to remain at their current levels in the future and if *F* were 0, a reduction in 5+ *M* to 75% of the current level would be required to halt declines in SSB while a reduction to 70% of the current level would produce increasing SSB. With a reduction to 65% or 60% of the current level, the probability of exceeding the LRP in 20 years would be 60% or 90% respectively, given the productivity conditions used in these projections and the uncertainties in the estimates of abundance at age and natural mortality. Values of 5+ *M* that are 80% or less of the average current (1994-2009) level have not been observed since the 1980s and are not expected under current ecosystem conditions.

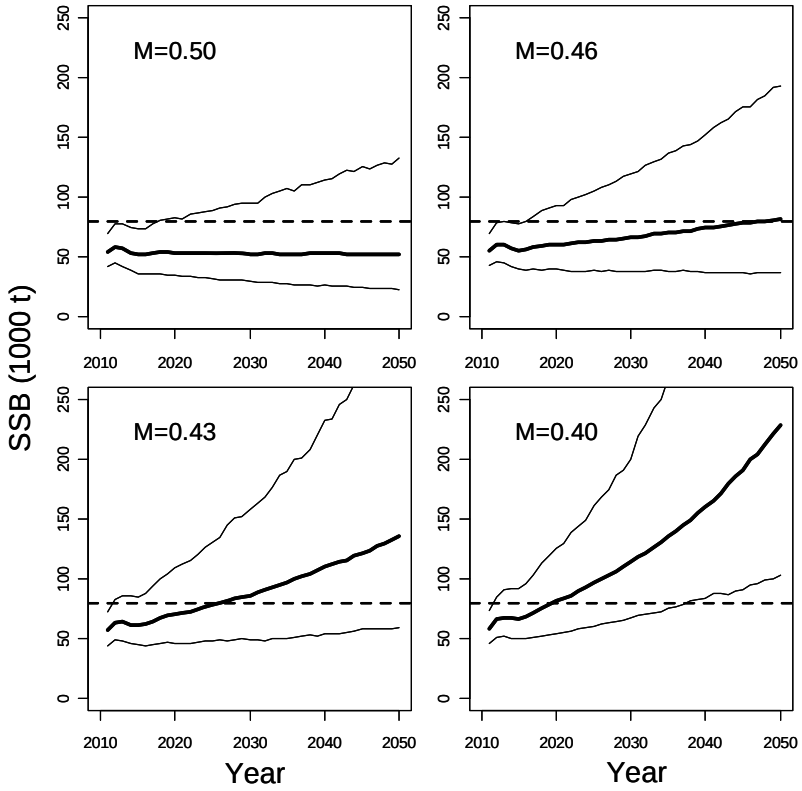


Figure 35: Projected spawning stock biomass (SSB) of southern Gulf cod at various levels of 5+ M with other components of productivity at current (1994-2009) levels. M levels are 75% (upper left), 70% (upper right), 65% (lower left), and 60% (lower right) of the average current level. Heavy lines show the median projection and light lines the 2.5th and 97.5th percentiles. The dashed line is the LRP.

4VsW cod

Projections were carried out at 10 levels of adult *M* ranging from the lowest to the highest seen in the assessment period (Fig. 36). All other aspects of productivity are sampled from the 1994-2009 window. The spawning biomass in the last 10 years of the 36 year projections was

averaged as a summary of the final state. Because most aspects productivity, especially natural mortality, have changed recently for this stock, it is not possible to anticipate future productivity except to say that the near future would probably be like the recent past. Similarly, conditions that pertained to the relatively productive period before the 1990s, are less likely than those from the more recent period.

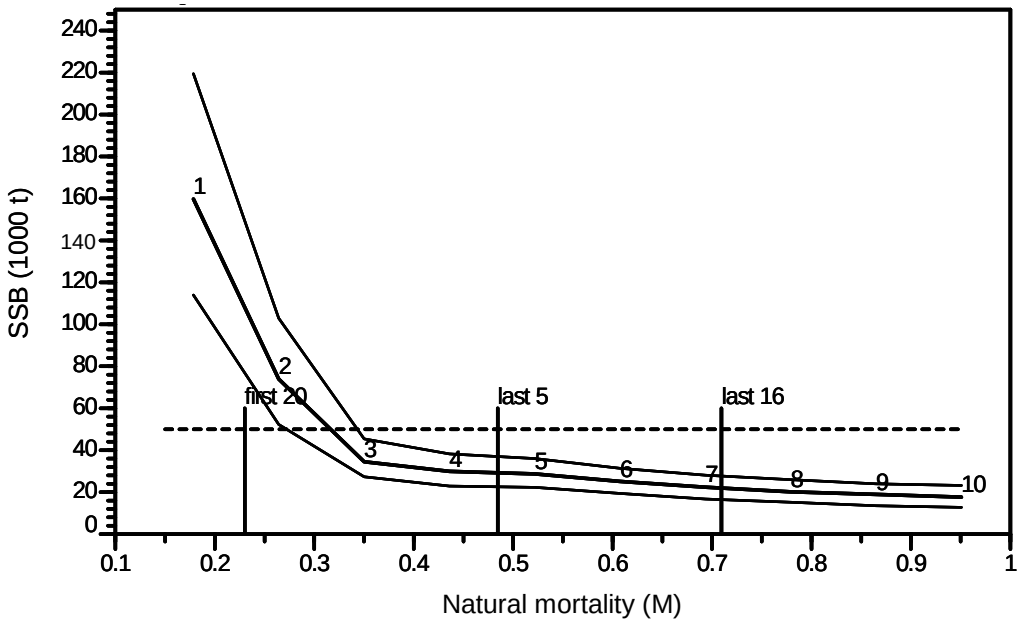


Figure 36: Projections at ten levels of 5+ M while the M(ages 1-4) and other projection parameters are set at the recent average. The Y-axis is the average SSB over the last 10 years of the 36 year projection with the black line being the median estimate and the light lines are the 2.5 and 97.5 percentiles. The horizontal dashed line is the 50,000 t SSB LRP. The average M for the first 20 years (1970-1989), the most recent 5 years and the period 1994-2009 are included for reference.

Threats to Survival and Recovery

Southern Gulf cod

Fishing

Increasing fishing mortality from the early 1950s to the mid 1970s resulted in the first collapse of this stock. Following its recovery in the late 1970s due to exceptional recruitment, increasing fishing mortality in the late 1980s and early 1990s contributed to its second collapse. SSB stabilized at a low level during the moratorium on directed fishing in 1994-1997. However, during the directed fisheries in 1998-2002 and 2004-2008, fishing mortality, though relatively low, was still too high for the stock to sustain given its high and increasing level of 5+ *M*, and SSB declined further to record low levels (Fig. 37). On the other hand, estimated fishing mortality since the closure of cod-directed fishing in 2009 has been negligible compared to natural mortality and has no detectable effect on the stock trajectory. Since 2009, the estimates of fishing mortality include mortality due to bycatch in fisheries for other groundfish and due to catch in scientific monitoring programs. Recreational and aboriginal food and ceremonial catches amount to an additional 15 t or less and are thus also negligible. Bycatches of cod, particularly older 5+ cod, in invertebrate fisheries in the southern Gulf are also considered to be very small, with a negligible impact on the stock trajectory.

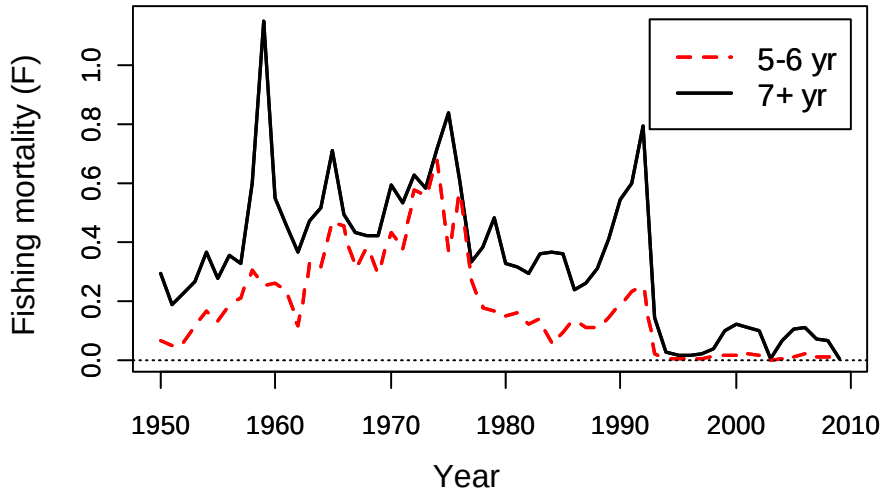


Figure 37: Estimated rates of fishing mortality of southern Gulf cod.

Natural mortality

The lack of recovery and continued decline of southern Gulf cod is primarily due to high natural mortality of older (5+) cod. A comprehensive suite of hypotheses for the causes of this elevated mortality was examined at a zonal assessment meeting (DFO 2010b). The hypotheses examined were: unreported catch, emigration, disease, contaminants, poor fish condition, life-history change, parasites and predation (in particular predation by grey seals). No support was found for any of these hypotheses except the following:

1. A significant portion of the losses attributed to *M* in the late 1980s and early 1990s may instead be due to unreported catch, but the contribution of unreported catch to estimated *M* from the mid 1990s to the present can only be negligible.

2. Life-history change (early maturation) in combination with poor fish condition may have contributed to moderate increases in *M* (by 0.1-0.2) in the early to mid 1980s, but *M* due to these causes would have declined when fish condition subsequently improved. Neither life history change (early maturation, early senescence) nor poor fish condition are supported as important factors in the current high level of *M* in the 2000s.

3. The hypothesis most strongly supported by the weight of evidence is that a major component of the current high *M* of 5+ southern Gulf cod is due to predation by grey seals.

Other factors

Climate change, habitat alteration, coastal eutrophication and hypoxia are considered to represent low risks for this stock at present. Oil and gas exploration is presently occurring in the Gulf of St. Lawrence and represents a potential risk to southern Gulf cod.

4VsW cod

Fishing

There is no directed fishery for 4VsW cod at this time. Bycatch mortality is very small and is negligible relative to natural mortality (Fig. 38).

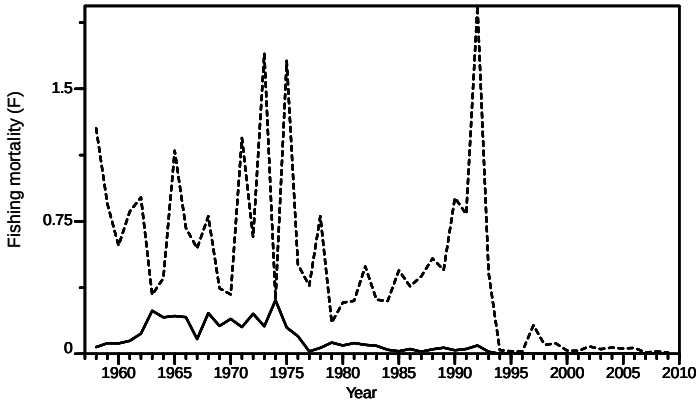


Figure 38: Estimated fishing mortality (F) for two age groups 1-4 (solid line) and 5-15 (dashed line) of 4VsW cod.

Natural mortality

Natural mortality of 4VsW cod aged 5 years and older (5+) was estimated to be unusually high in the 1990s and early 2000s (averaging 0.8 in 1990-2004) but in the last five years the average fell to 0.6. Predation by grey seals is considered to be a significant component of natural mortality but its relative contribution is of unknown magnitude.

4Vn cod

Fishing

Catches for this component of the DU declined from 1985 until closure of the fishery in September 1993. After closure, catches were restricted to a number of sentinel surveys as well as a small amount of bycatch in other fisheries. Sentinel catches were highest in the commercial index (CI) fishery (100 – 270 t). The CI was discontinued in 2007, and since then landings have been restricted to bycatch only, which is very small relative to natural mortality.

Relative *F* is calculated from total biomass from the July research vessel survey and landings data (Fig. 39). Based on this index, exploitation rate was relatively high in the early to middle 70's and again from 1987 to 1991. Exploitation rate was generally low following the closure of the fishery in 1994, although the 2004 point appears anomalous.

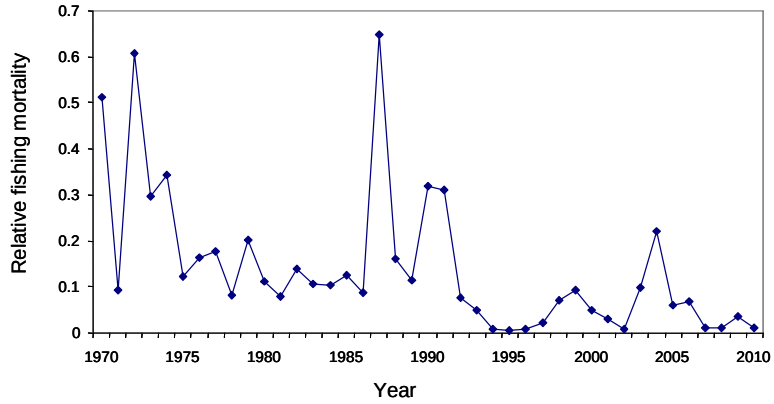


Figure 39: Relative fishing mortality for 4Vn cod.

Natural mortality

Estimates of total mortality were calculated from the July research vessel survey data, by age group. Although noisy (even with smoothing), *Z* increased in the mid 1980's for older ages. *Z* for younger fish increased from the early 1990's onwards, and currently is in the same range as the values for older fish.

Despite the closure of the fishery in 1993, *Z*'s have been high subsequently, particularly for older fish. Given the low levels of catch, this implies natural mortality has been high during the recent period. The possible causes of this increased natural mortality are not understood.

Limiting Factors for Population Recovery

Southern Gulf cod

Weight-at-age

Weight-at-age of southern Gulf cod has been low since the mid 1980s. This low weight-at-age contributes to the production deficit currently experienced by this stock. The causes of continued low weight-at-age in this stock are unclear (see above). Possible explanations include a genetic response to the strong selection against fast growth imposed in the 1980s and early 1990s, on-going selective predation of fast-growing behavioural types by grey seals, and/or behavioural changes associated with increased risk of predation.

Recruitment rate

Recruitment rate is currently low compared to the levels observed from the mid 1970s to the early 1980s, and thus contributes to the current low productivity of this stock. The exceptional recruitment rates in the earlier period are thought to be unusually high, resulting from reduced predation on cod eggs and larvae by pelagic fish (which had collapsed in the mid 1970s). Pelagic fish, in particular fall-spawning herring, are currently at a relatively high level of abundance in the southern Gulf, providing one explanation for the lower rates now than in the 1970s. Nonetheless, some increase in recruitment rate at low stock size might be expected due to density-dependent compensatory effects, but this has not been observed.

4VsW cod

During the 1990s and early 2000s, natural mortality of 4VsW cod aged 5 years and older (5+) was estimated to be unusually high and other components of productivity such as weight-at-age and condition were at their lowest values for the time series. As a result, reduced productivity might have been considered a factor limiting population recovery. However, more recently, there have been improvements in productivity that, if maintained, would be favourable for population growth.

4Vn cod

Reduced productivity

Given this fishery is closed and bycatches are very small, limits to the recovery of the population are high natural mortality and reduced recruitment. Declines are noted in growth and condition. However, these are relatively small and have stabilized or shown some improvement in recent years, and are not likely to contribute substantially to reduced production.

Recruitment rate

Recruitment rate was low for the early part of the time series. However, since 1998 recruitment rates have been relatively high and no longer appear to be a factor limiting recovery.

Measures for Promoting Recovery

Southern Gulf cod

Following the closure of the directed cod fishery in 2009, removals by the commercial fishery have been reduced to a very low level (< 150 t) and have no detectable effect on the probability of survival or recovery of this stock. However, measures should be in place to ensure that, if fishing effort for other groundfish increases, bycatch does not increase to levels that would affect the probability of survival and recovery. These measures could include increased observer coverage, improvements to the Dockside Monitoring Program, mandatory hail out, completion of log books, vessel monitoring systems, bycatch limits (e.g., percent or weight of allowable incidental catches per trip), season/area closures and increased compliance-monitoring activities (such as Dockside and At-Sea inspections). Many of these measures are currently in place. Recreational catches are also thought to have a negligible impact on this stock; nonetheless, monitoring of recreational catches could be improved by measures such as the establishment of a marine recreational licence system.

Given the negligible level of fishing mortality since the closure of the cod-directed fishery in 2009, the only additional action that can be taken to improve the chances for recovery of this stock would appear to be action to reduce the rate of natural mortality of adult (5+) cod, the main factor contributing to the continued stock decline. A review of the weight of evidence for potential causes of the high 5+ *M* of southern Gulf cod supported a conclusion that predation by grey seals was likely the greatest contributor to the current elevated mortality of large (5+) cod.

Due to significant potential biases in the diet information for grey seals, it was not possible to quantify their consumption of large cod. Thus, it was not possible to provide a quantitative estimate of their contribution to *M*. Nonetheless, a number of scenarios were examined regarding the grey seal removals that would be required to reduce 5+ *M* to a level that would

allow recovery. In one scenario it was assumed that predation by grey seals accounted for about 10% of 5+ *M*. In this scenario, seal removal could not reduce *M* to a level that would allow recovery. In another scenario it was assumed that predation by grey seals accounted for about 50% of 5+ *M*. In this scenario, seal removal could reduce *M* to levels that would allow recovery, but the necessary removals were substantial. To reduce *M* to a level that would permit recovery to the LRP in 20 years with a high probability (70%, given the assumptions of the projections), the number of grey seals foraging in the areas occupied by southern Gulf cod would need to be reduced by 70% to an estimated 31,000 animals. If seal predation contributes a higher proportion of *M*, or if particular seals specialize in predation on cod and it is possible to target those seals, the necessary removals would be lower.

4VsW cod

Though grey seal predation is a major contributor to natural mortality, the size of this component relative to all components of mortality is very difficult to quantify. Various estimates have been published and several were presented at a recent zonal assessment meeting (DFO 2010b). Estimates of the component of total mortality by seal predation generally range between 10 to 50% on cod less than 9 years old. Even without establishing the degree of causality, it is noted that the Sable Island grey seal population was under 50,000 animals when 4VsW cod was productive; the current Sable Island herd size is around 300,000, six times larger.

4Vn cod

The commercial fishery for this component was closed in September 1993. Since the closure, catches have been restricted to a number of Industry sentinel activities as well as a small amount of bycatch in other fisheries. Sentinel catches were highest in the commercial index (CI) fishery (100 – 270 t). The CI fishery was discontinued in 2007. Since then landings have been restricted to bycatch and the sentinel survey. These landings are very small relative to natural mortality.

Although at present bycatch of cod is small in fisheries directing for other species, fishing effort in these fisheries should be monitored to ensure levels of bycatch do not rise significantly.

Allowable Harm Assessment

Under 1994-2009 productivity conditions, there is no possibility that the southern Gulf cod stock will recover to its LRP. Conclusions are the same for 4VsW cod once recent strong year-classes are lost from the population. For these two stocks, the extent to which various levels of fishing mortality would jeopardize survival was assessed by comparing projected population trajectories at these levels of *F* to the trajectory with *F*=0 (e.g., Figure 32).

Southern Gulf cod

The third closure of the directed fishery for southern Gulf cod began in 2009. Removals of cod due to bycatch in fisheries directing for other species and by scientific monitoring programs resulted in very low fishing mortality in 2009 (fully recruited $F = 0.014$). The effect of this level of *F* on the projected population trajectory and thus on the probability of population survival is negligible. The probability of SSB falling below various thresholds differs negligibly between this level of *F* and $F = 0$ (closure of all fisheries). For example, the probability that projected SSB will fall below 5,000 t by 2050 is 32% at this level of *F* and 33% at $F = 0$, i.e. no difference (Fig. 40). Removals at the small level of the cod directed fisheries in 2007 and 2008 (TAC of 2,000 t)

resulted in a fully recruited *F* of 0.106. This level of *F* accelerated projected population declines and thus decreased the probability of population survival. For example, the probability that projected SSB will fall below 5,000 t by 2050 is 63% at this higher level of *F*, about twice the probability given *F*=0 or *F* due to bycatch only.

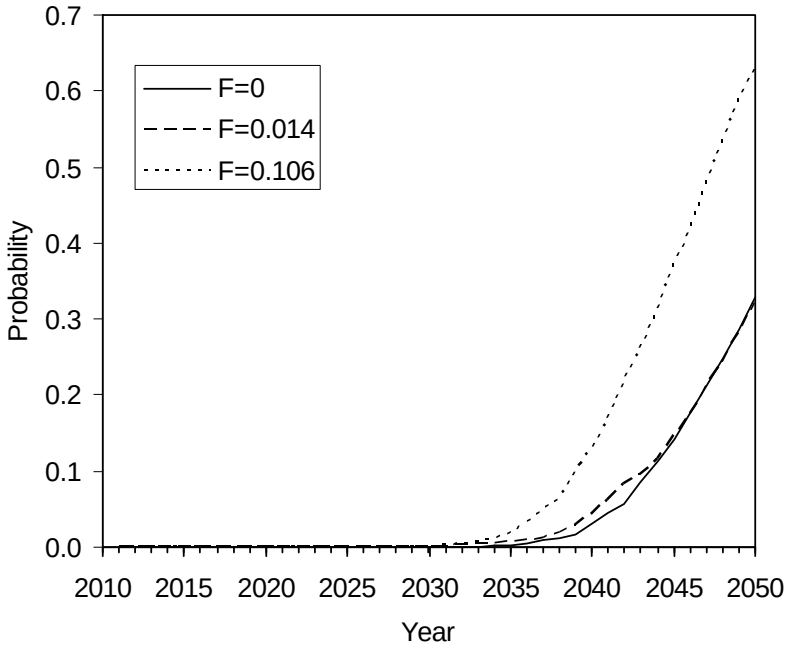


Figure 40: Probability that the projected SSB of southern Gulf cod will fall below 5,000 t at various levels of fully-recruited F.

4VsW

Following the closure of the directed cod fishery in 1993, fishing mortality due to cod bycatch in other groundfish fisheries and scientific monitoring programs has been low, on the order of a few percent. Because the recent bycatch of cod represents an F of about 0.01, there is no detectable effect on the probability of survival or recovery of this stock. However, there is no clear threshold when bycatch would be considered a factor affecting the projected status. Furthermore, at recent biomass levels, catch corresponding to an F of 0.01 would amount to several hundred tons.

4Vn

This fishery was closed in September 1993. After closure, catches were restricted to a number of industry sentinel activities and bycatch in other fisheries. Currently removals (15 – 25 t per year) are restricted to bycatch only and likely have little effect on survival or recovery of the stock given their very low level relative to natural mortality.

Sources of Uncertainty

The projections at either the stock or DU level are subject to the uncertainties common to stock assessments: the uncertainty in the current stock size and the factors affecting productivity. These projections differ though from the projections usually seen in stock assessment because of the requirement to project for 36 years. The factors affecting production (reproduction,

mortality, growth) have been seen to vary over time and are difficult to predict. However, they tend to change slowly and the recent past is probably the best indication of the near future. The level of uncertainty increases as projections move further into the future.

Natural mortality, and its change over time, is the biggest contributor to the productivity changes seen for the stocks in this DU. As fishing pressure is very low, mitigation is only possible through changing other sources of mortality. The degree to which grey seals contribute to natural mortality is highly uncertain, principally because of inadequate data on diet and predator behaviour.

Knowledge of the amount and spatial distribution of available habitat for demersal juvenile Atlantic Cod is currently unavailable at the spatial scales with which juveniles are likely to be using it. The spatial resolution of most of our available seabed habitat knowledge is on the order of tens of kilometers. In contrast, demersal juvenile cod are known to associate with seabed habitats at scales of hundreds of meters and less – a mismatch on the order of 100 to 1 in scope at best, especially in the offshore. Therefore, it is not known how much habitat is available for juvenile cod at present.

SOURCES OF INFORMATION

This Science Advisory Report has resulted from a Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, zonal advisory process meeting, Feb. 21-25, 2011 on Recovery Potential Assessment (RPA) of Atlantic Cod). Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

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