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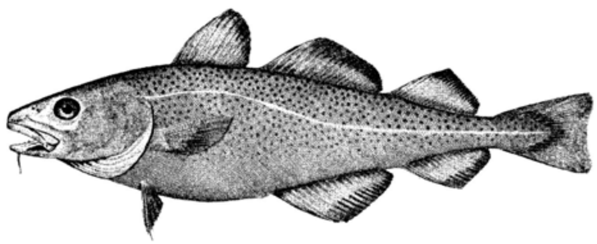
RECOVERY POTENTIAL ASSESSMENT FOR THE LAURENTIAN NORTH DESIGNATABLE UNIT (3Pn, 4RS AND 3Ps) OF ATLANTIC COD (*GADUS MORHUA*)



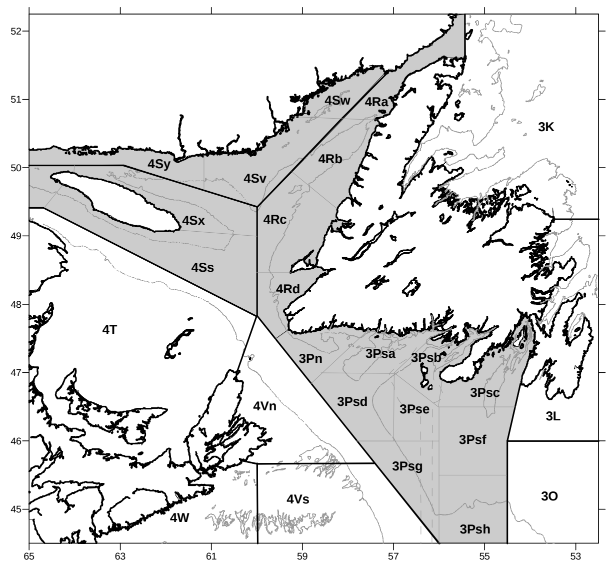


Figure 1: Cod stock management areas NAFO subDivision 3Pn + Divisions 4RS (northern Gulf of St. Lawrence) and subDivision 3Ps (southern Newfoundland) that make up the Laurentian North designatable unit.

Context

In 2003, Laurentian North cod was designated Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) due to the significant decline in abundance, mainly due to overfishing. Its status was revised in April 2010 and Laurentian North cod is now considered Endangered.

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 North DU cod under the Act and developing a recovery strategy.

This science advisory report describes the status of cod populations in 3Pn,4RS (northern Gulf of St. Lawrence) and 3Ps (southern Newfoundland) that make up the Laurentian North designatable unit (DU). Projection results over 36 years for each population in the DU are presented. This scientific advice also addresses the major threats to the survival and recovery of Laurentian North cod and the limiting factors. Measures that can help its recovery are listed.

SUMMARY

- The Laurentian North designatable unit of Atlantic Cod consists of two stocks or management units: northern Gulf of St. Lawrence cod (management units 3Pn,4RS), southern Newfoundland cod (management unit 3Ps).

- The northern Gulf cod population collapsed in the late 1980's / early 1990's. Abundance of mature cod has been stable at a low level since 1997. In contrast, the number of mature cod in 3Ps has been variable since the early 1980's and near the long-term average in 2010.

- Natural mortality (*M)* and fishing mortality (*F)* of northern Gulf cod are approximately 0.4 each for a total mortality of approximately 0.8 in recent years. For 3Ps, estimates of total mortality (ages 4 to 11) over 2005-09 averaged 0.64; *M* is considered to be 0.2 and there is no evidence that it has changed.

- Seal predation is contributing to increased natural mortality of cod in the northern Gulf. Any reduction in natural mortality would promote recovery.

- Weights-at-age and maturity have declined in recent years for both stocks.

- A conservation limit reference point (LRP) has been established for both cod stocks. The LRP for northern Gulf cod is estimated to be 116,000 t. The estimated Stock Spawning Biomass (SSB) has been below the LRP since 1990 and stands at 16,000 t in 2010. For 3Ps cod, the limit reference point (LRP, $B_{Recovery}$) is the 1994 level of SSB and the 2010 SSB is marginally above (7%) the LRP.

- The results of this RPA are mainly based on projections of stock size over 36 years (3 generations). Long-term projections are dominated by process error (uncertainty in recruitment rates, mortality rates, etc.) so that their utility is not in providing probabilities of specific outcomes but rather in defining the uncertainty. The entire range of uncertainty, particularly the lower limits, needs to be considered in any conclusion.

- Projections were undertaken for both stocks and at the DU level. These projections were not intended to be projections of stock status but rather used to estimate the probabilities of achieving the LRP.

- Assuming no fishing and future productivity conditions are similar to those previously observed, the northern Gulf population is projected to increase although 75% of the results remain below B_{lim} after 36 years. For 3Ps, all results are above B_{lim}, with results ranging from 2-4 times above the LRP in 36 years.

- If fishing mortality remains at current levels and future productivity conditions are similar to those previously observed, the northern Gulf population is projected to increase in the short-term but subsequently returns to the 2010 level after 36 years – 15% of LRP (ranging from 4-41% of LRP). In 3Ps, the SSB declines after 2025 and median SSB is 64% of the LRP. Further, the range of outcomes is relatively wide (30-130% of LRP).

- Projected status of the DU was inferred from combining the stock-specific projections. If fishing mortality is reduced to half of current levels or eliminated, the abundance of mature cod increases compared to current levels (with probability 0.60 or 0.98, respectively). If

fishing mortality remains at current levels, the abundance of mature cod is 25% lower than current levels.

BACKGROUND

Rationale for Assessment

As part of this assessment process, scientific information is needed to support the development and assessment of social and economic cost and benefit of potential management 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 SARA. The information will be used to develop a recovery strategy, and if necessary, one or more action plans.

Considering the sharp decline of Laurentian North cod (76-89%) over the last three generations, it was designated as Endangered in April 2010 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC, 2010).

The information contained in this recovery potential assessment (RPA) is primarily from recent peer-reviewed assessments of cod stocks in 3Pn,4RS and 3Ps. Further supporting detail is available in the “pre-COSEWIC” review of all Atlantic Cod stocks (refer to Sources of Information).

The RPA provides scientific information to guide decision making and it provides insight for decisions on whether to add the species to Schedule 1 of SARA.

Species Biology and Ecology

For Atlantic Cod, females reach sexual maturity at about six years of age, although age at first spawning generally varies between five and eight years of age depending on the stock (45-60 cm). Males mature earlier and at a smaller size than females. Cod are very prolific. Females of about 80 cm long produce about 2 million eggs, while those of around 130 cm produce over 11 million eggs. Cod spawn in batches, i.e. they release their eggs in several series over several weeks. The fertilized eggs rise to the surface when ready to hatch. The eggs and resulting larvae are at the mercy of currents and predators. The mortality rate is considerable. The newly hatched larvae (5 mm) feed on the yolk sac for one to two weeks, after which they must begin to feed in the water column. At about 4 cm, young cod begin adopting a demersal behaviour where they feed and remain near the bottom for a period of one to four years. As adults, cod undertake seasonal migrations and movements that characterize the species.

Young cod fry feed mainly on copepods, amphipods, and other small crustaceans in the plankton. Juveniles feed mainly on shrimp, amphipods, euphausiids, and fish, mollusc and shellfish larvae. Adult cod feed mainly on capelin, herring, sand lance, flounders, young Greenland halibut, crabs, shrimp, brittle stars, comb jellies, and a host of other species of fish, molluscs and shellfish. The growth rate of cod varies by region. Differences in the annual growth rate may exist within the same region, according to population density, water temperature and food. The mean weight of specimens averages 2 to 3 kg and measures 60 to 70 cm. Cod does not usually exceed 30 kg.

Laurentian North Designatable Unit

The Laurentian North designatable unit (DU) extends from the northern Gulf of St. Lawrence to the south coast of Newfoundland, covering two DFO stock management units, the northern Gulf of St. Lawrence (3Pn,4RS) and southern Newfoundland (3Ps).

Some individuals from 3Pn,4RS spend the winter along the southwest coast of Newfoundland (3Pn/3Psd), and migrate and disperse in the summer in the northern Gulf of St. Lawrence along the North Shore of Quebec and in the Strait of Belle Isle. Tagging results indicate that a local resident sub-population exists in 3Pn. The population sub-component within 4S has almost disappeared.

The majority of cod in 3Ps spend the winter on the southern slopes of St. Pierre Bank and Halibut Channel. In summer, many migrate to the coastal area of southern Newfoundland. Some 3Ps cod also mix with Northern cod (2J3KL) in summer and fall. Tagging results indicate that the 3Ps stock is a complex mixture of sub-components which may include individuals that migrate seasonally between adjacent areas as well as individuals that perform seasonal migrations between inshore and offshore waters.

ASSESSMENT

Historic and Current Abundance and Trends

3Pn, 4RS Cod

A sequential population analysis model (SPA) was used to integrate the available information from fishery-independent surveys and commercial catches of this stock. The number of adults in the population collapsed over 1983 to 1994, dropping from 200 million to 7 million (Figure 2, left panel). Over the most recent five years, the average number of adults has been 19 million individuals.

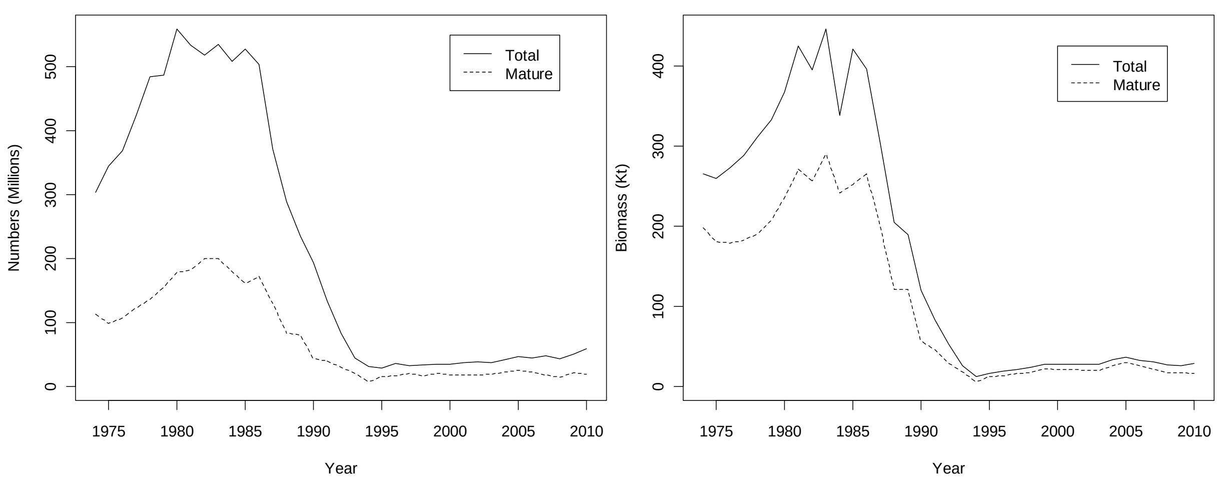


Figure 2: Estimated trends in abundance (left) and biomass (right) of cod in 3Pn,4RS over 1974-2010.

The biomass of the northern Gulf of St. Lawrence stock collapsed during the mid 1980s and early 1990s (Figure 2, right panel). Spawning stock biomass (SSB) declined from approximately 250 Kt in the mid-1980s to the lowest observed in 1994. In the most recent five years, SSB has averaged 19 Kt, well below the LRP of 116 Kt.

3Ps Cod

A survey-based cohort analysis is used to estimate the relative abundance, biomass and also total mortality of 3Ps cod.

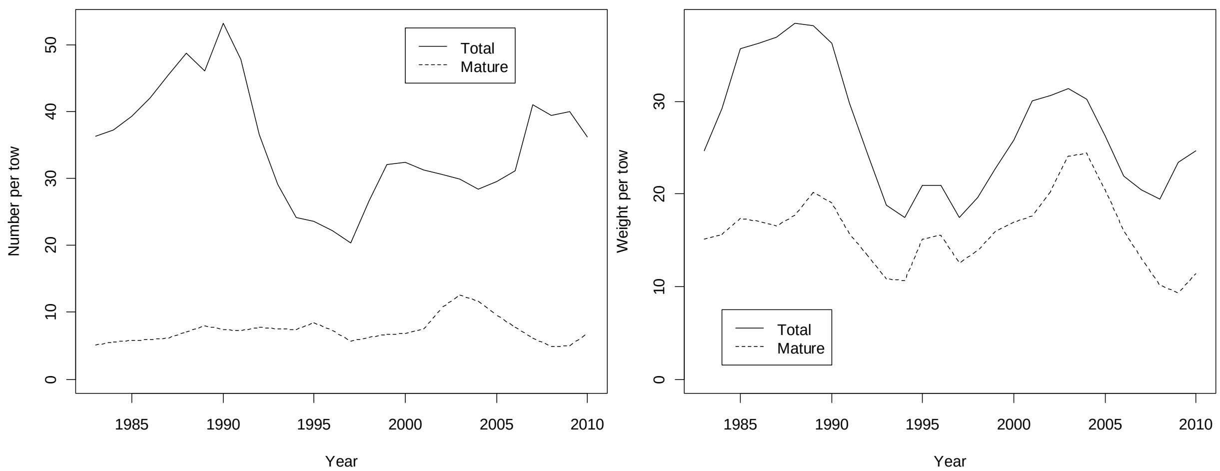


Figure 3: Estimated trends in abundance (left) and biomass (right) of cod in 3Ps over 1983-2010.

Presently, the abundance of mature individuals is approximately 10% below the 1983-2010 average (Figure 3, left panel). However, current SSB is about 30% less than the 1983-2010 average, and is marginally above (7%) B_{lim} (Figure 3, right panel). The LRP for this stock is $B_{Recovery}$, the lowest observed SSB from which the stock has recovered (SSB_{1994}).

The current status of the two stocks which comprise the DU is markedly different. The SSB of 3Pn,4RS cod is estimated to be 85% lower than the B_{lim} level, whereas the SSB of 3Ps cod is currently estimated to be marginally above the LRP (7%).

Historic and Current Distribution and Trends

For cod in 3Pn+4RS, there was a slight decline in area of occupancy and geographic range (D_{95}) from 1990 to 2002 (Figure 4). From 2002 to 2008, the area of occupancy has gone from 40,000 km^2 to 60,000 and the D_{95} an index of geographic range, has risen from 25,000 km^2 to 40,000. Most of this spreading occurs in 4S cod.

Generally, the area of occupancy for cod 1 year old and older (1+) is higher than that of 5 year old and older (5+) cod. This is an indication that the area of occupancy is higher for the stock as a whole than it is for just adult cod.

In 3Ps, the area covered by the survey has varied slightly over the time series as a consequence of strata not sampled, and has generally been in the range of 16,500 to 17,500 nm^2 or 55,000 - 60,000 km^2. The DWAO, a weighted index of occupied area, was lowest over 2002-2005, and reached a minimum of 21,000 km^2 in 1995, approximately 1/3 of the survey area (Figure 5). Outside of this period, values have varied between 35,000 – 45,000 km^2 indicating that cod are widespread through most of the surveyed area.

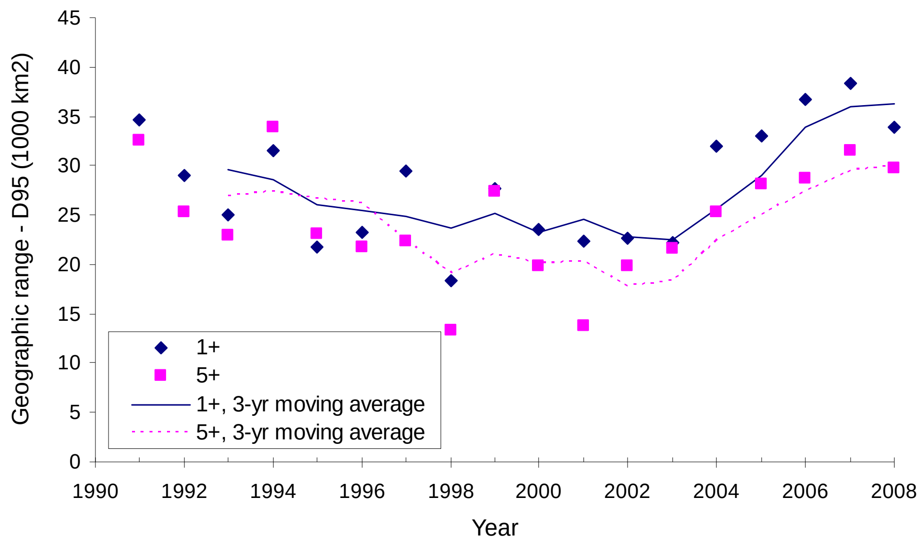


Figure 4: Area of occupancy indicators for 3Pn,4RS cod as geographic range.

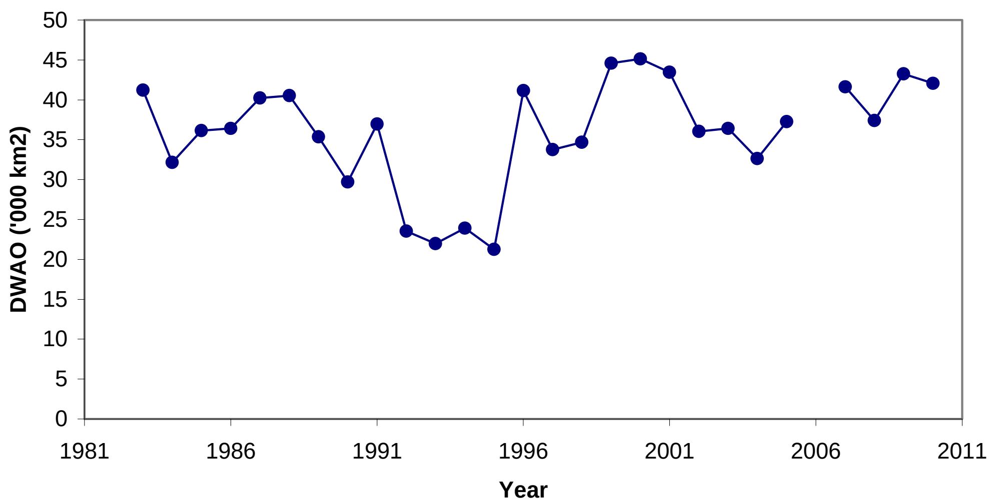


Figure 5: Area of occupancy index (design weighted area occupied; DWAO) for cod in 3Ps.

Life History Parameters

3Pn, 4RS Cod

Growth, condition, size and age at sexual maturity decreased in the mid-1980s and in the early 1990s, periods when oceanographic conditions were unfavourably cold. These changes had a negative impact on fecundity and the reproductive rate of the population. In addition, the natural mortality rate (*M*) has increased (Figure 6). The reasons for this increase are unclear but appear, in some years, to be related to poor fish condition, particularly after spawning. Characteristics related to growth and reproduction improved after the mid-1990s and have returned to levels observed in the early 1980s. However, the mean length-at-age for older fish and age and size at maturity remained at lower levels than in the 1980s.

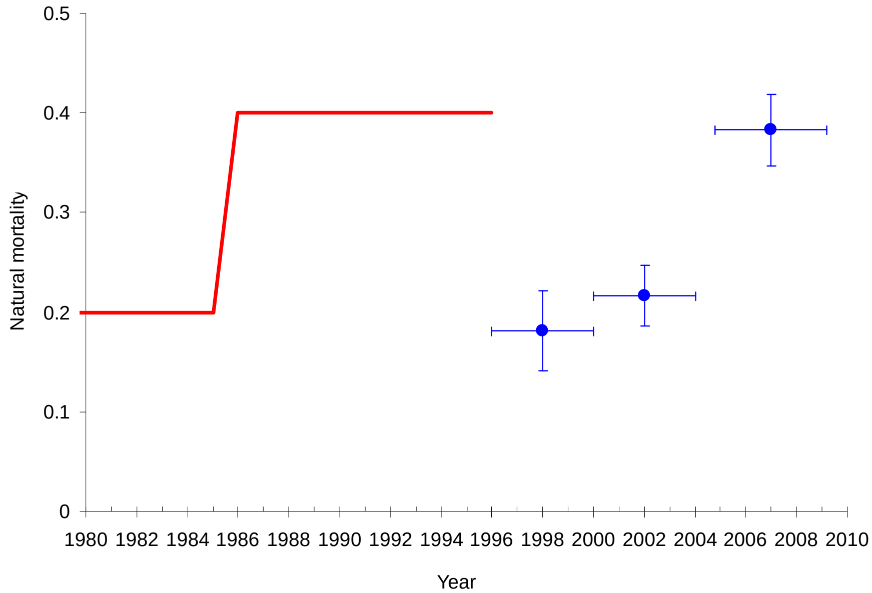


Figure 6: Changes in natural mortality (M) in Northern Gulf cod (solid lines are imposed values of M whereas the crosses are estimated by ADAPT; vertical lines are standard errors, horizontal lines represent time intervals).

In 2009, a significant decrease in age and size at maturity was observed, which affects fecundity. Length at maturity at 50% decreased from 44.6 cm in 2008 to 39.3 cm in 2009. Age at maturity at 50% decreased by almost a year; from 5 years in 2008 to 4.2 years in 2009. A decline in fecundity at age was observed for individuals 7 years of age or less (Figure 7). The seasonal condition cycle in 2009, expressed by the Fulton index, was similar to the 1998-2008 average. Natural mortality is estimated at 0.18 for the 1997-2000 period, 0.22 for 2001-2004 and 0.38 for the 2005-2009 period. The estimate takes into account predation by seals, recreational fishing, and discarding of fish.

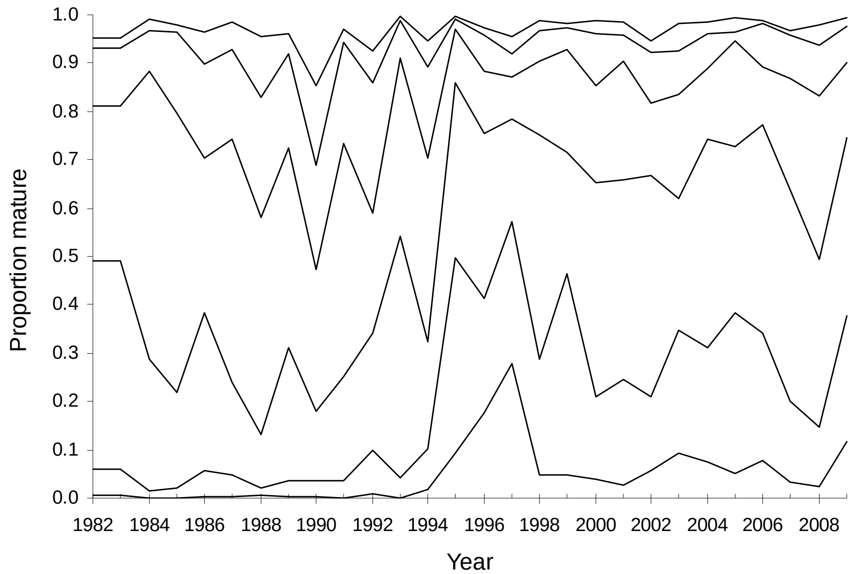


Figure 7: Maturities-at-age for Northern Gulf cod age 3 (lowest line) to age 8 (top line).

Natural mortality and fishing mortality of northern Gulf cod are approximately 0.4 each for a total mortality of approximately 0.8 in recent years. Recruitment has been weak since 1991.

3Ps Cod

The proportion of female cod maturing at younger ages has increased over the last two decades (Figures 8 and 9). The reasons for the change toward earlier age at maturity are not fully understood and have a genetic component but may partly be a response to high levels of mortality. Males generally mature about one year younger than females but show a similar trend over time.

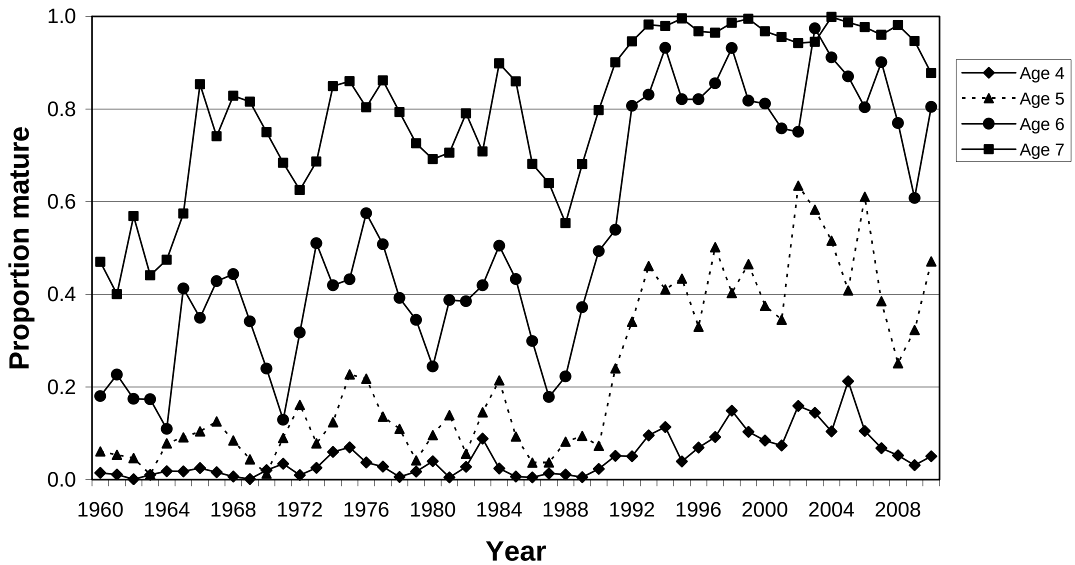


Figure 8: Estimated proportions mature at ages 4-7 for female cod sampled during DFO Research Vessel (RV) bottom-trawl surveys in 3Ps cod.

From the mid-1980s to early-2000s, length-at-age tended to increase at young ages (2-3), and varied with no consistent trend at older ages. Length-at-age for fish sampled in the sentinel surveys, however, has declined since 1998 in fish older than age 4.

Comparison of post-1992 condition with that observed during 1985-1992 is difficult because survey timing has changed. Condition varies seasonally and tends to decline during winter and early spring. In general, the overall condition of cod in the surveys post-1992 shows no consistent trend although the values from 2010 are below average.

Total mortality estimated from the cohort model over 2005-2009 (ages 4-11) averaged 0.60 (45% mortality). This high level of mortality is a concern. Total mortality rates reflect mortality due to all causes, including fishing.

A recruitment index was derived from catch rates of juvenile (age 1-4) cod during the DFO Research Vessel (RV) survey and the industry Groundfish Enterprise Allocation Council (GEAC) trawl survey. The standardized index indicated that the 2006 cohort is estimated to be relatively strong and is expected to fully recruit to the 2011 fishery. The 2007 and 2008 cohorts are estimated to be near the 1994-2008 average.

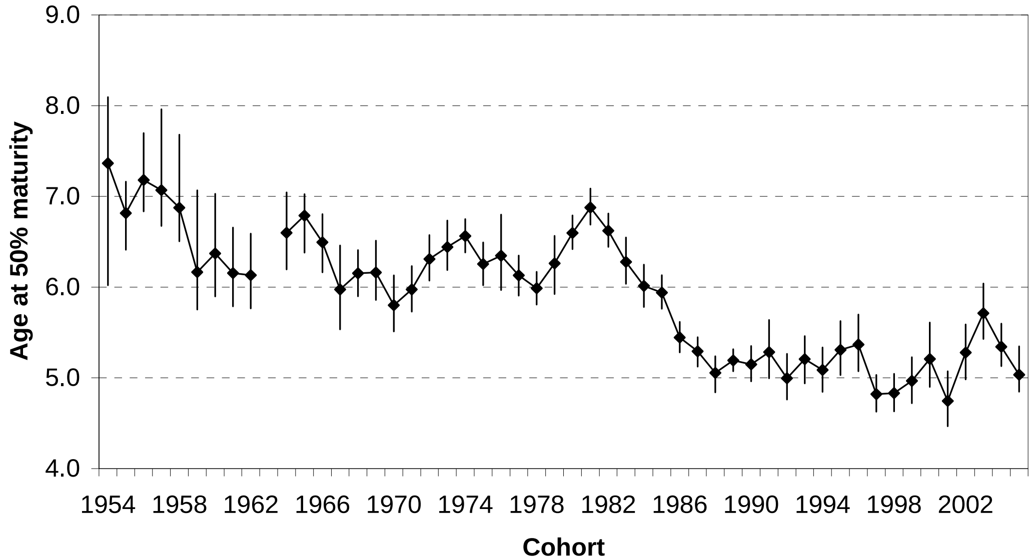


Figure 9: Age at 50% maturity by cohort (1954-2005) for female cod sampled during DFO RV bottom-trawl surveys of 3Ps cod. Error bars are 95% confidence intervals.

Habitat Requirements and Suitability

Residence Requirement

Definition from *Species at Risk Act* 2(1)- 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.

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.

Habitat Properties

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 the 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. In western Atlantic waters, settlement occurs in both coastal and offshore location in the southern portion of the range, whereas in the north it occurs predominantly in coastal areas. For cod in 3Pn,4RS, the west coast of Newfoundland represents a significant concentration area for juveniles. The south coast of Anticosti and the eastern part of the Lower North Shore represent areas of concentration of juveniles. In 3Ps, age 1 and 2 cod are sampled over most of the area covered by the DFO multi-species bottom-trawl survey. In addition, several studies of egg, larval and juvenile distribution have been conducted in both Fortune Bay and Placentia Bay. It appears that area of settlement may be related to temperature conditions, which affect growth.

Within these broader geographic considerations, demersal juvenile cod 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. Inshore, vegetation - eelgrass and macroalgae - is important. In both inshore and offshore areas, pebble-gravel and rock-boulder areas within a patchy marine landscape are significant habitats for demersal juveniles.

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.

Adult

With age, habitat requirements for adult cod become increasingly diverse. Since preferences of older fish for either depth or substrate composition are unclear, distribution of mature cod is probably determined primarily by temperature and food availability. Although they are widely distributed throughout the Laurentian North DU, cod in this region appear to continue to favour areas with structurally complex habitat since this is where prey are concentrated. Overwintering areas tend to be in deeper warmer waters.

Cod from the northern Gulf of St. Lawrence (3Pn,4RS cod) undertake long migrations every year. In the fall, the stock migrates along the west coast of Newfoundland. Homing results suggest that the fidelity of Atlantic Cod to its summer habitat is stable from year to year. In the Strait of Belle Isle, north of Point Riche (Newfoundland) and Blanc Sablon (Quebec), Gulf cod mix with schools of Labrador and eastern Newfoundland cod. Mixing may also occur occasionally in the north-western Gulf with cod from 4TVn. Such mixing occurs every winter in the area of Burgeo Bank with 3Ps cod. A telemetry study conducted from May 2004 to September 2005 to examine mixing of northern Gulf cod (3Pn4RS) into 3Ps showed that 61% of cod implanted with transmitters in the northern Gulf (3Pn4RS) crossed into 3Ps during winter, mixing with local resident cod.

Stock structure and migration patterns of cod in 3Ps are complex. Tagging studies indicate that cod tagged in coastal waters have mostly been recaptured in the same waters, even five to six years after tagging. Some cod tagged offshore were recaptured in summer and fall on the south coast by coastal fishermen using fixed gear. Tagging has also revealed some shifting of cod between 3Ps and adjacent areas (3Pn,4RS, 3KL and 3NO). Spawning is widely distributed throughout 3Ps and takes place both near the coast on Burgeo Bank, St. Pierre Bank and Halibut Channel.

Spawning Adults

Over the species range spawning cod have been observed both in the 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 for coupling of spawning times with 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.

For the Northern Gulf of St. Lawrence, cod spawn in April and May, they move to the Port-au-Port Peninsula, on the west coast of Newfoundland (4R). For the 3Ps stock, spawning occurs at different times and lasts several months. Spawners have been observed particularly from March to August in Placentia Bay.

Spatial Extent of Habitat

The geographic distribution of Atlantic Cod ranges from Cape Hatteras, North Carolina to Greenland on the western Atlantic and the Barents Sea south to Spain and Portugal on the eastern Atlantic. 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.

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 do 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 in the offshore may cause physical disturbance to habitat. Currently there is exploration by seismic surveys in the Old Harry area, an area between the Magdalen Islands and Bay St. George on the west coast of Newfoundland.

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.

SARA and Management Considerations

Two stock recruit models have been accepted as plausible models in order to determine the LRP for 3Pn,4RS cod. The SSB LRP for Northern Gulf cod of 116 Kt is the average of the SSB corresponding to 50% of maximum recruitment from each model. In 3Ps, a LRP has been defined as the lowest observed SSB from which there has been a sustained recovery. This corresponds to the 1994 SSB level.

Recovery targets are presently undefined but should correspond to mature biomass levels in excess of B_{lim}. Consequently, the time required to recover to these targets will exceed the time required to reach B_{lim}.

For both the 3Ps and 3Pn,4RS cod stocks, projections of stock dynamics over 36 years were conducted starting from the most recent population estimates for each stock. A total of six projection scenarios were considered: fishing mortality over 2010-2045 was held constant at values corresponding to reductions of 0%, 25%, 50%, 75%, 95% and 100% of current fishing mortality. The current mortality level for each stock was defined as the average fishing mortality in the most recent three years. To illustrate the range of outcomes, results of the F=Current and F=0 projections are reported below.

3Pn,4RS Cod

For 3Pn,4RS, projections under current levels of fishing mortality (F=0.47; the 2007-2009 average over ages 7-9) indicate an SSB increase of about 50% over 2010 to 2024 (Figure 10; left panel). This recovery results from slight improvements in recruitment and survivorship (reduced natural mortality). However, over the longer term, SSB declines further, and after 36 years, the median projected SSB is 25% of the B_{lim} level.

Under the scenario of no fishing mortality for 36 years, there is some recovery of the SSB (Figure 10; upper right panel). However, more than 75% of outcomes suggest that the stock will not reach B_{lim} by 2046. There are two primary interrelated reasons which yield this outcome: i) recruitment generally remains quite low compared to values when the stock was more productive; and ii) natural mortality remains relatively high in most projection scenarios.

Projections using a demographic model based on the life history characteristics of the stock also indicate declines in spawning stock number (SSN) and SSB over 36 years under current level of F. Projected SSB would be well below B_{lim}. In the absence of fishing, no further decline in SSN and SSB would be observed but the recovery over 36 years would be slow. Depending on the scenario used, the minimum period of time needed to reach B_{lim} would be 32 years.

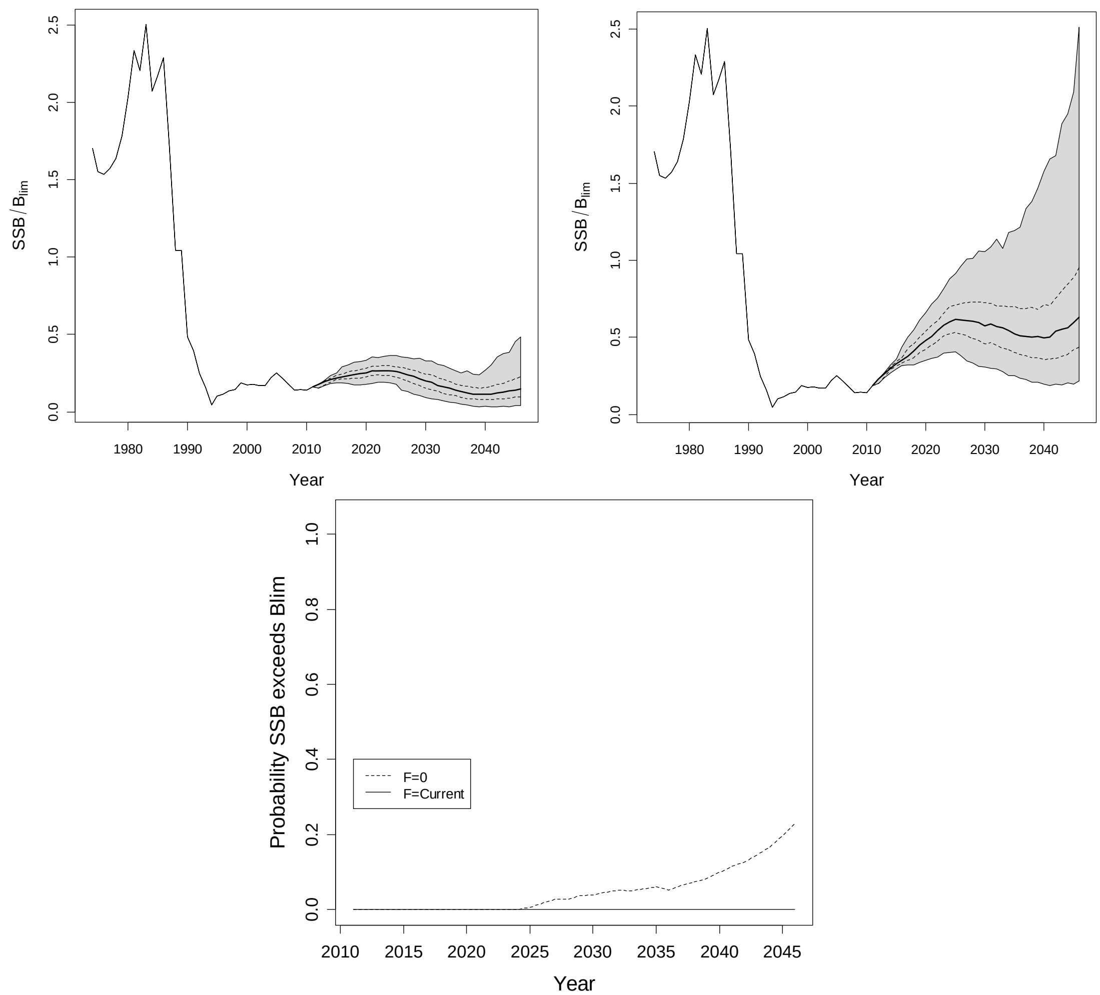


Figure 10: 3Pn,4RS cod — Thirty-six year projection of SSB relative to B_{lim} assuming fishing mortality remains constant at current levels (upper left panel), or is reduced to zero (upper right panel). The 2.5th, 25th, 50th (solid line), 75th and 97.5th percentiles of SSB relative to B_{lim} are shown in the projection period. Lower panel: Probability that projected SSB exceeds the LRP under each scenario (F=0 and F=Current).

3Ps Cod

Under current levels of fishing mortality (F=0.54; 2007-2009 average over ages 6-11), projections indicate a rapid increase in SSB through 2014 (Figure 11; upper left panel). This recovery results from improvements in recent recruitment, primarily the 2006 cohort. Over the longer term, however, the SSB declines with median SSB projected to be below B_{lim} by 2030. At the end of the projection period, the median projected SSB is 35% lower than the B_{lim} level.

If there are no removals (F=0), there is rapid and sustained recovery of SSB (Figure 11; upper right panel). All projections exceed B_{lim} through the entire projection period. After 36 years, the population remains at a relatively high level, with the median projected SSB being about three times the LRP.

There is uncertainty about how to model biological parameters in the projections. A second set of analyses under F=0 using biological conditions from 1994 to 2009 were conducted. For

3Pn,4RS, the outcome was similar; the majority of results indicate that the stock remains below B_{lim}, though there was some increase in the number of cases that actually reach B_{lim}. For 3Ps, differences were trivial, partly because the full window of re-sampling (1983-2009) is only slightly longer than that (1994-2009) in this sensitivity analysis.

The most recent estimate of SSB for cod in 3Pn,4RS is 14% of the B_{lim} level. The stock remains in a collapsed state, and projections of stock dynamics over 36 years indicate a low probability of reaching the LRP even if fishing mortality is eliminated. Conversely, current estimates of the 3Ps cod SSB are marginally above B_{lim}, and all projection scenarios considered indicate short term increases.

To explore the risk of further decline in mature stock numbers, stock specific results presented above were combined to the DU level. DU estimates of SSN were derived as area-weighted averages of the 3Pn,4RS and 3Ps SSN estimates. To account for the different structure of the models used to assess each stock, the estimates for 3Pn,4RS were adjusted to the scale of the 3Ps estimates (survey mean numbers per tow). Results could only be combined over 1983-2010 as 1983 corresponds to the start of the 3Ps time-series. The probability of SSN increase was calculated for each 36 year period, i.e. 1983-2019, 1984-2020, through to 2010-2046.

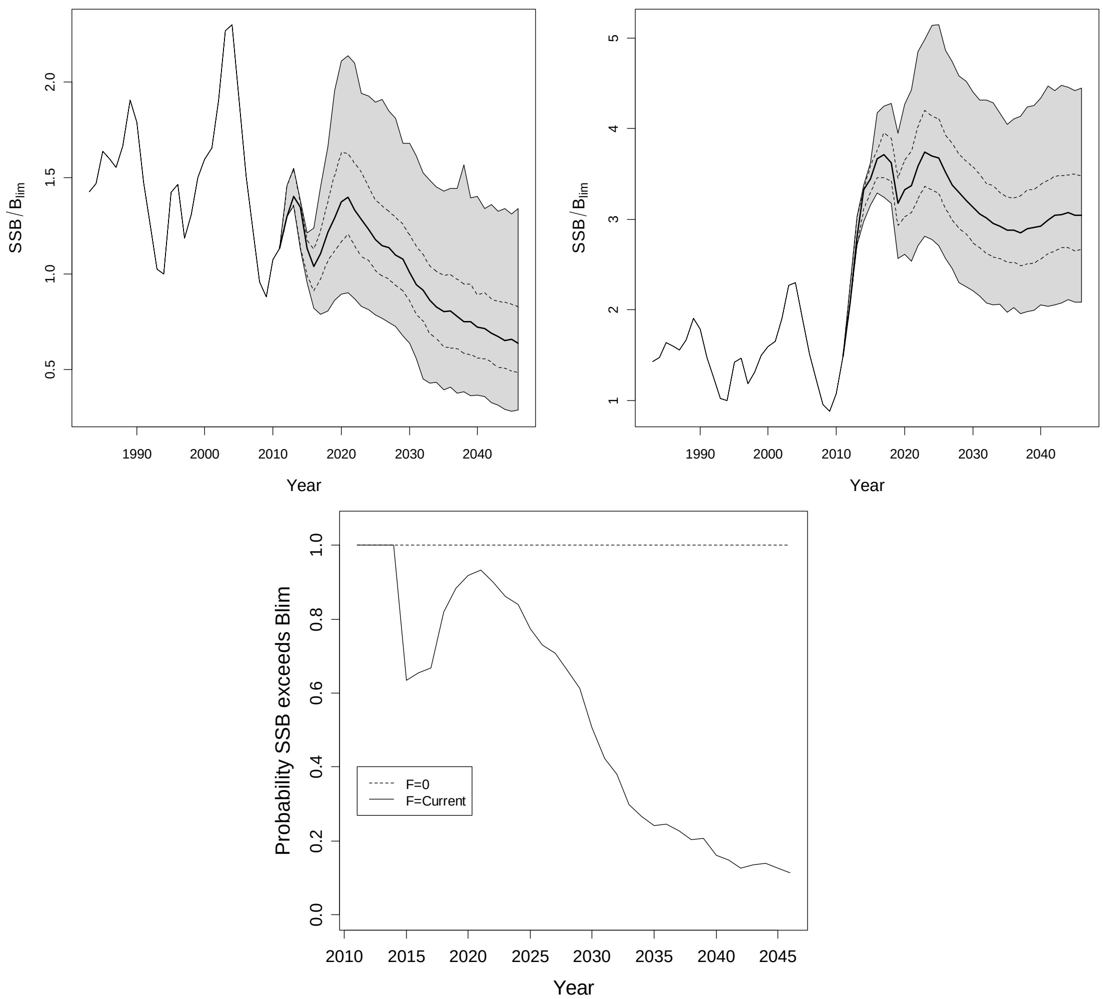


Figure 11: 3Ps cod – Thirty-six year projection of SSB relative to B_{lim} assuming fishing mortality remains constant at current levels (upper left panel), or is reduced to zero (upper right panel). The 2.5th, 25th, 50th (solid line), 75th and 97.5th percentiles of SSB relative to B_{lim} are shown in the projection period. Lower panel: Probability that projected SSB exceeds the LRP under each scenario (F=0 and F=Current).

Laurentian North DU

Assuming F=0 throughout the DU, SSN results indicate that by 2025 median SSN increases to 2.5 times current levels (Figure 12, upper left panel). Subsequently, there is some decline, but the probability of an increase in SSN over 36 years remains high (Figure 12, upper right panel).

If fishing mortality is reduced to half of current levels (currently, F=0.47 for 3Pn,4RS and F=0.54 for 3Ps) the median SSN in 2025 increases by 50% compared to present levels. By the end of the 36-year projection, 60% of the projection results indicate an increase in SSN (Figure 12, middle row).

Under the assumption that fishing mortality remains constant at current levels, the probability that SSN increases generally remains low (Figure 12, bottom row), with median SSN at the end of the projection period decreasing by 25% from current levels.

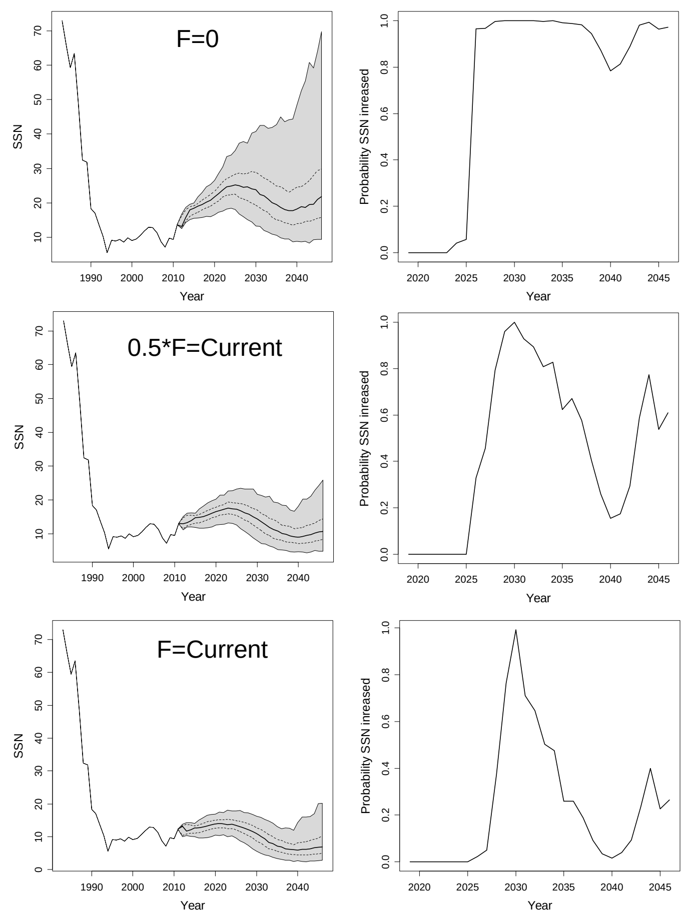


Figure 12: Thirty-six year projections the Laurentian North DU (3Pn,4RS and 3Ps cod combined) illustrating Spawning Stock Numbers (SSN) (left panels) and probability that the SSN has increased (over each 36-year period; right panels) for projections under F=0 (top row), 50% of F=Current (middle row) and F=Current (bottom row). Lines in SSN panels correspond to the 2.5th, 25th, 50th, 75th, and 97.5th percentiles.

Allowable Harm Assessment

Given that SSB of 3Pn,4RS cod declined by over 50% from 2004 to 2010 during a time of small but retrospectively unsustainable catches (the stock is currently at 15% of safe biological levels and natural mortality appears to be increasing), any human induced mortality on the stock will decrease the possibility that the stock biomass will increase, and the recent track record suggests it is likely to decrease. 3Ps cod, though not as severe as 3Pn,4RS cod, has a spawning biomass hovering near the LRP and any human induced mortality on the stock will slow the movement away from this undesirable state. Table 1 summarizes the results by stock and for the DU.

Table 1. Summary of status indicators for allowable harm assessment for each stock and for the DU of Laurentian North.

	3Ps Cod: B_{lim} (11 kg/tow survey SSB) $F_{current}$=0.54		3Pn4RS Cod: B_{lim} (116,000t SSB) $F_{current}$=0.47		LN DU: An increase in SSN over a 36-year period	
Reduction in Fishing Mortality from $F_{current}$	**Year B_{lim} Surpassed**		**Year B_{lim} Surpassed**		**End of 36 year period**	
	with 50% Probability	**with 95% Probability**	**with 50% Probability**	**with 95% Probability**	**with 50% Probability**	**with 95% Probability**
100% (F=0)	*	*	>2046	>2046	2026	2026
50%	*	*	>2046	>2046	2028	2029
0%	*	*	>2046	>2046	2029	2030

*Stock is presently estimated to be above B_{lim}.

The results highlight the different status of each stock comprising this DU. The SSB of 3Ps cod is estimated to be above B_{lim} and is projected to increase in the short term if fishing mortality remains at current levels. Conversely, the SSB of 3Pn4RS is at present only 15% of the B_{lim} level, and under the most optimistic projection scenario of no fishing, SSB 36 years into the future has a low (less than 25%) chance of reaching the LRP.

To provide the species-at-risk context, comparisons of the number of mature individuals in the DU were made over each possible 36-year time period, an approximation of three generations. (As the 3Ps SSB estimates start in 1983, the first 36-year comparison window of 1983-2019 compares the SSN of 1983 to that in 2019.) The time required to have increases projected SSN for the DU is similar across all fishing mortality scenarios. Increases in SSN over 36 years become apparent when the collapsing SSN of the 3Pn4RS stock around 1990 enters the 36-year comparison.

Threats to Survival and Recovery

Laurentian North DU

Natural Mortality

High recent natural mortality is considered to be a high risk for the Northern Gulf component of the Laurentian North DU. Within 3Ps, natural mortality is considered to be 0.2 and there is no evidence that it has changed.

Other potential sources of harm (such as habitat alteration, pollution, shipping, cables and lines, military activities, ecotourism, fisheries on food supplies; scientific research, aquaculture; introductions & transfers) were not specifically quantified in this assessment but are considered to have relatively low impacts on the ability of cod to survive and recover.

Oil and Gas Exploration and Exploitation

There has been oil and gas exploration (seismic surveys and exploratory drilling) in the entire DU since the 1960s. The literature on the effects of seismic energy on fish, molluscs and crustaceans indicates that if seismic surveys have effects on populations of fish, molluscs or crustaceans, these effects are not easily measured because of confounding factors such as natural dispersal, fishing pressure and animal migrations. The possible impacts on the stock or sub-stock, in a particular area or a bay, or in coastal waters, appear to be the primary concern. There is sufficient evidence suggesting the possibility that seismic exploration causes sub lethal effects at the individual level. There is potential for disturbance of particular life stages or disruption of spawning behaviour. Airguns can produce low noise levels at a considerable distance from the source. However, in relation to ambient ocean noise and animal behaviour, the level of noise associated with vessels could have a greater significance. Other possible threats related to oil drilling concern the discharge of oil-based sludge or drill cuttings, drilling fluids, waste from the platform and production waste. Accidental oil spills into the environment, whether from an accident involving an oil tanker or a leak from an oil well, could eventually be a major concern in the Gulf.

Damages to Habitat by Fishing Gear

Fishing gear does 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.

Predators

Anecdotal evidence suggests that grey seal presence is increasing on the West and South Coasts of Newfoundland.

3Pn, 4RS Cod

Fishing

Cod landings in the northern Gulf of St. Lawrence exceeded 100,000 t in 1983 and declined precipitously afterwards until a moratorium was imposed from 1994 to 1996. The fishery resumed in 1997 and since then catches have taken or exceed the annual surplus production such that the stock has remained at low level. Such an exploitation rate did not allow any stock rebuilding and is preventing stock recovery. The SSB is currently about 85% below the B_{lim} level.

The exact discard rate in the cod directed fishery remains unknown and there are no statistics on recreational fishing. Unreported cod catches from the redfish fishery and other fisheries also remain difficult to estimate, but represent another source of mortality. Since the introduction of the Nordmore grate in the shrimp fishery (1993-1994), cod bycatch has decreased considerably and consist mostly of small individuals (bycatch of 1 kg or less). They were estimated at 9 t in 2009 for the entire shrimp fishery in the northern Gulf.

Coastal Eutrophication and Hypoxia

The deep waters of the Gulf of St. Lawrence have low oxygen concentrations. Besides the natural processes affecting oxygen levels, various anthropogenic factors can increase the vertical flux of organic matter that characterizes the process of coastal eutrophication. Current oxygen saturation levels in the head of channels could significantly affect various aspects of the biology and ecology of populations and communities. Studies conducted on cod have established lethal threshold at 28% saturation. Moreover, growth rate is reduced to a rate below 70%. Northern Gulf cod seem to avoid areas with less than 70% dissolved oxygen and they appear absent from areas of less than 30% saturation. Habitat loss appears associated with these low levels of dissolved oxygen.

3Ps Cod

Fishery

Catches from this stock have supported an inshore fixed gear fishery for centuries and are of vital importance to the area. The French islands of St. Pierre and Miquelon are within the 3Ps stock area; hence this resource is managed bilaterally with France. Over the past decade, total catches have ranged between 10,000 - 15,000 t.

Invasive Species

Green Crab (*Carcinus maenas)* is an invasive species found within this DU, notably at the head of Placentia Bay. Through alteration of habitat and bottom cover, they may reduce the survival prospects of juvenile cod.

Limiting Factors for Population Recovery

The cold ocean conditions, from the mid-1980s to early 1990s, could have caused changes in the biological characteristics of cod, including reduced growth, condition and size as well as age at sexual maturity. These changes may have impacted egg production and natural mortality. Presumably, the intensive fishing effort combined with adverse environmental conditions caused the sharp decline of the stock.

Predation is also a limiting factor. The increase of the harp seal population between 1984 and 2006 seems to have brought on an increase in predation of young cod in the Laurentian North. Grey seal predation also appears to have a negative effect on adult cod. Under current productivity conditions, it is possible that predation by seals is affecting the recovery of Laurentian North cod, but the significance of the impact remains difficult to assess.

In the northern Gulf of St. Lawrence between 2003 and 2005, predation was estimated at 75% of total mortality for large cod (+35 cm). Harp and grey seals account for a significant proportion of predation. In small cod (<35 cm) for the same period, predation appears to account for 95% of natural mortality (and total mortality).

Measures for Promoting Recovery

Fishery Management

Mitigation measures for reducing directed fishing mortality include: the implementation of the Precautionary Approach (PA); the development and adoption of harvest control rules and decisions compliant with the PA in the Integrated Fisheries Management Plans for all cod stocks; catch limits for commercial, index or stewardship fisheries; creating zones to protect high concentrations of individuals; limiting participants and/or fishing effort by restricting the number of boats or gear allowed; and, maintaining or creating no fishing zones during certain times of the year in areas where cod spawn.

A number of these mitigation measures are already being considered or have been applied in the Laurentian North DU including seasonal closures.

Bycatch and Discards

Mitigation measures for reducing bycatch and discards of cod include: the application of Bycatch and Small Fish Protocols; measures included in Conservation Harvesting Plans such as gear type, mesh size, percent or weight of allowable incidental catches per trip in certain areas or during certain time of the year; adopting more stringent requirements for the management, control and monitoring of bycatch in other commercial fisheries; increasing at-sea observer coverage when (and where) the catch and discarding of fish is likely to be high to improve estimates of bycatch and discards; conducting a review, in conjunction with industry, of additional measures such as seasonal closures or gear restrictions to address the discarding of fish; recording discards in monitoring documents; increased compliance monitoring activities (such as Dockside Inspections, At-Sea Inspections, expanded use of Vessel Monitoring Systems and Aerial Surveillance).

3Pn, 4RS Cod

Current exploitation rates are reducing the probability that the stock can rebuild. A reduction in exploitation would be necessary to promote rebuilding.

Seal predation is contributing to recent increased natural mortality of cod. Any reduction in natural mortality will promote recovery.

It is important to maintain the seasonal spawning closure to promote spawning success. It is also important to prevent overfishing of local stocks.

3Ps Cod

The 3Ps cod stock is currently estimated to be marginally above the LRP, $B_{Recovery}$. Further, short-term projection results from the most recent assessment indicate that SSB will increase if total mortality rates are similar to current values.

Ecologically and Biologically Significant Areas (EBSA)

The *Oceans Act* authorizes the DFO to increase the protection of marine and coastal areas that are of particular biological and ecological significance. The conservation objective for ecologically and biologically significant areas (EBSA) identified for the Estuary and Gulf of St. Lawrence is to ensure that the characteristics of the EBSA that relate to its uniqueness, that makes the area suitable for the aggregation and/or that ensure the reproduction and survival of species dependent on the area (fitness consequences), are not altered by human activities. Of the 10 areas identified as EBSAs for the Estuary and Gulf of St. Lawrence, the west coast of Newfoundland is the main migration corridor for the northern Gulf cod stock and a concentration area for juveniles.

Sources of Uncertainty

Methods appropriate for long term projections were employed here; therefore, interpretation of these results for only the first few projected years underestimates the uncertainty that would be included for purposes of short term projection.

The assessment method applied to 3Ps cod estimates total annual mortality. The long-term projections conducted to evaluate recovery potential separate these total mortality estimates into natural and fishing mortality, and results are conditional on this assumption. There is no evidence that M has changed over time within 3Ps.

It was noted that the recent increase in natural mortality for the northern Gulf cod stock could be due to missing data from the recreational fishery and discards; these, in fact, are fishing mortalities that could be reduced with proper management actions.

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.

The projections at either the stock or DU level are subject to the uncertainties common to stock assessment: the uncertainty in the current stock size and the factors affecting productivity. These projections differ though from the projections usually seen in stock assessments 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.

The degree to which grey seals contribute to natural mortality is highly uncertain, principally because of inadequate data on the diet and predator behaviour. Grey seal surveys and diet data (i.e., stomach sampling) will need to address these areas in the future.

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This Science Advisory Report is from the Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, Zonal Advisory Process, February 21-25, 2011 on Recovery Potential Assessment (RPA) for Atlantic Cod (Newfoundland and Labrador, Laurentian North, Laurentian South, Southern Designatable Units). 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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