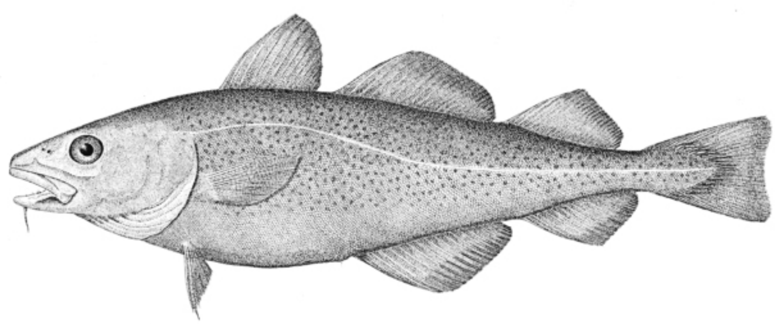
COSEWIC
Assessment and Status Report

on the

Atlantic Cod
Gadus morhua

Laurentian North population
Laurentian South population
Newfoundland and Labrador population
Southern population
Arctic Lakes population
Arctic Marine population

in Canada



Laurentian North population - ENDANGERED
Laurentian South population - ENDANGERED
Newfoundland and Labrador population - ENDANGERED
Southern population - ENDANGERED
Arctic Lakes population - SPECIAL CONCERN
Arctic Marine population - DATA DEFICIENT
2010

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

COSEWIC. 2010. COSEWIC assessment and status report on the Atlantic Cod *Gadus morhua* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xiii + 105 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

Previous report(s):

COSEWIC. 2003. COSEWIC assessment and update status report on the Atlantic Cod *Gadus morhua* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 76 pp.

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Atlantic Cod — Line drawing of Atlantic Cod *Gadus morhua* by H.L. Todd. Image reproduced with permission from the Smithsonian Institution, NMNH, Division of Fishes.

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COSEWIC
Assessment Summary

Assessment Summary – April 2010

Common name
Atlantic Cod - Laurentian North population

Scientific name
Gadus morhua

Status
Endangered

Reason for designation
Populations in this designatable unit (DU) have declined 76-89% in the past 3 generations. The main cause of the decline in abundance was overfishing and there is no indication of recovery. This DU includes the cod management units 3Ps and 3Pn4RS. A limit reference point (LRP) has been estimated for the 3Pn4RS management unit. The abundance for this management unit has been relatively stable over the past decade, but it is well below the LRP, and directed fisheries continue. Abundance in southern Newfoundland (3Ps) is declining. The assessment indicates that this management unit is at the LRP, and directed fisheries continue.

Occurrence
Atlantic Ocean

Status history
The species was considered a single unit and designated Special Concern in April 1998. When the species was split into separate populations in May 2003, the Laurentian North population was designated Threatened. Status re-examined and designated Endangered in April 2010.

Assessment Summary – April 2010

Common name
Atlantic Cod - Laurentian South population

Scientific name
Gadus morhua

Status
Endangered

Reason for designation
Populations in this designatable unit (DU) have declined by 90% in the past 3 generations. The main cause of the rapid decline in abundance during the early 1990s was overfishing. Commercial fisheries were curtailed in 1993 and the abundance stabilized for a number of years. However, increased natural mortality and continued small catches have caused the abundance to decline again. Quantitative analysis of population demographic parameters indicate the population will continue to decline in the absence of fishing if the current elevated level of natural mortality persists. This DU includes the cod management units 4TVn (November – April), 4Vn (May – October) and 4VsW. A limit reference point (LRP) has been estimated for the 4TVn management unit and the current status is assessed to be well below the LRP. An LRP has not been estimated for the 4VsW management unit; however, it is considered to be at a critically low level.

Occurrence
Atlantic Ocean

Status history
The species was considered a single unit and designated Special Concern in April 1998. When the species was split into separate populations in May 2003, the Maritimes population was designated Special Concern. When the Maritimes population was further split into two populations (Laurentian South population and Southern population) in April 2010, the Laurentian South population was designated Endangered, and the original Maritimes population was de-activated.

Assessment Summary – April 2010

Common name
Atlantic Cod - Newfoundland and Labrador population

Scientific name
Gadus morhua

Status
Endangered

Reason for designation
This designatable unit (DU) includes the cod management units 2GH, 2J3KL and 3NO, located in the inshore and offshore waters of Labrador and eastern Newfoundland, and the Grand Banks. Cod in this area have declined 97-99% in the past 3 generations and more than 99% since the 1960s. The area of occupancy declined considerably as the stock collapsed in the early 1990s. The main cause of the decline in abundance was overfishing, and there has been a large reduction in the fishing rate since 1992. However, the population has remained at a very low level with little sign of substantive recovery. The most recent surveys indicate an increase in abundance over the past 3 years; however, this change in abundance is very small compared to the measured decline over the past 3 generations. The extremely low level of abundance and contracted spatial distribution makes the population vulnerable to catastrophic events, such as abnormal oceanographic conditions. Threats from fishing, predation, and ecosystem changes persist. There is no limit reference point (LRP) for the 2J3KL management unit but the population in this area is considered to be well below any reasonable LRP value. The offshore 2J3KL fishery is under moratorium and there is an inshore stewardship fishery with no formal total allowable catch (TAC). The fishery in the 3NO management unit is also under moratorium. There is an LRP for this management unit and the population is well below this value.

Occurrence
Atlantic Ocean

Status history
The species was considered a single unit and designated Special Concern in April 1998. When the species was split into separate populations in May 2003, the Newfoundland and Labrador population was designated Endangered. Status re-examined and confirmed in April 2010.

Assessment Summary – April 2010

Common name
Atlantic Cod - Southern population

Scientific name
Gadus morhua

Status
Endangered

Reason for designation
Populations in this designatable unit (DU) have declined by 64% in the past 3 generations and the decline is continuous. Commercial fishing is ongoing and is an important contributor to the decline. As well, there is evidence of an unexplained increase in natural mortality in the 4X portion of the DU. Rescue from the US population is unlikely given the low abundance of the species in that area. This DU includes the cod management units 4X5Y and 5Zjm. There is a directed fishery for the species in the 4X5Y area, and although there is no limit reference point (LRP), recent fishery management advice indicates that this management unit is at a critically low level. There is also a directed fishery in the 5Zjm management unit and this fishery is co-managed with the United States.

Occurrence
Atlantic Ocean

Status history
The species was considered a single unit and designated Special Concern in April 1998. When the species was split into separate populations in May 2003, the Maritimes population was designated Special Concern. When the Maritimes population was further split into two populations (Laurentian South population and Southern population) in April 2010, the Southern population was designated Endangered, and the original Maritimes population was de-activated.

Assessment Summary – April 2010

Common name
Atlantic Cod - Arctic Lakes population

Scientific name
Gadus morhua

Status
Special Concern

Reason for designation
This designatable unit (DU) exists in 3 isolated lakes on Baffin Island, Nunavut. The combined surface area of the 3 lakes is less than 20 km^2. Rescue from other DUs is not possible. One of the lakes, Ogac Lake, is accessible for fishing and large numbers of the species may be removed from the lake if fishing increases.

Occurrence
NU

Status history
The species was considered a single unit and designated Special Concern in April 1998. When the species was split into separate populations in May 2003, the Arctic population was designated Special Concern. When the Arctic population was further split into two populations (Arctic Lakes population and Arctic Marine population) in April 2010, the Arctic Lakes population was designated Special Concern, and the original Arctic population was de-activated.

Assessment Summary – April 2010

Common name
Atlantic Cod - Arctic Marine population

Scientific name
Gadus morhua

Status
Data Deficient

Reason for designation
Information to establish any COSEWIC status category with assurance is not available. Data on distribution, abundance, habitat, and changes over time are insufficient.

Occurrence
Arctic Ocean, Atlantic Ocean

Status history
The species was considered a single unit and designated Special Concern in April 1998. When the species was split into separate populations in May 2003, the Arctic population was designated Special Concern. When the Arctic population was further split into two populations (Arctic Lakes population and Arctic Marine population) in April 2010, the Arctic Marine population was designated Data Deficient, and the original Arctic population was de-activated.

COSEWIC
Executive Summary

Atlantic Cod
Gadus morhua

Laurentian North population
Laurentian South population
Newfoundland and Labrador population
Southern population
Arctic Lakes population
Arctic Marine population

Species information

Class:	Actinopterygii
Order:	Gadiformes
Family:	Gadidae
Latin binomial:	*Gadus morhua* Linnaeus 1758

Common names: English – Atlantic Cod
French – morue franche
Inuktitut – ogac (Nunavut); ovak, ogac (Ungava Bay); uugak, ugak (Innu, Labrador) (McAllister *et al*. 1987)

Distribution

Atlantic Cod inhabit all waters overlying the continental shelves of the Northwest and the Northeast Atlantic Ocean. On a global scale, the historical distribution of cod probably differs relatively little from that of its present distribution. In Canada, Atlantic Cod are found contiguously along the east coast from Georges Bank and the Bay of Fundy in the south, northward along the Scotian Shelf, throughout the Gulf of St. Lawrence, around the island of Newfoundland, and finally along the eastern shores of Labrador and Baffin Island, Nunavut. There are also three landlocked populations of Atlantic Cod on Baffin Island. Outside Canadian waters in the Northwest Atlantic, cod can be found on the northeast and southeast tips of Grand Bank and on Flemish Cap, lying immediately northeast of Grand Bank, and in the waters east of Baffin Island extending to western Greenland.

Habitat

During the first few weeks of life, cod exist as eggs, and then as larvae, in the upper 50 metres of the ocean. The primary factors affecting habitat suitability for cod during these early stages of life are probably the oceanographic retention of pelagic eggs and larvae, food availability, and temperature. The most essential habitat characteristics for Atlantic Cod may be those required during the juvenile stage when cod have settled to the bottom for the first 1 to 4 years of their lives. Evidence suggests that a heterogeneous habitat, notably in the form of vertical structures, such as eelgrass, *Zostera marina*, in nearshore waters, is favoured by juvenile cod because it reduces the risk of predation and may also allow for increased growth. As adults, the habitat requirements of cod become increasingly diverse. Indeed, it is not clear that older cod have particular depth or bottom-substrate requirements. The primary factors affecting the distribution and habitat of older cod are probably temperature and food supply. From a spawning perspective, it is not known if cod have specific habitat requirements. Cod spawn in waters ranging from tens to hundreds of metres in depth. Perhaps the factor most beneficial to the survival of offspring is the presence of physical oceanographic features that would serve to entrain the buoyant eggs and prevent them from being dispersed to waters poorly suited to larval cod, e.g., waters off the continental shelf. Currently, it is highly unlikely that spawning habitat is limiting for Atlantic Cod.

Biology

The life history of cod varies a great deal throughout the species' range. In the relatively warm waters at the southern end of its Canadian range (Georges Bank, off the state of Maine) and in the Bay of Fundy, cod commonly attain maturity at 2 to 3 years of age. By contrast, cod inhabiting the Northeast Newfoundland Shelf, eastern Labrador, and the Barents Sea typically mature between ages 5 and 7 yr. Size at maturity ranges from between 35 to 85 cm in length. The number of eggs produced by a single female in a single breeding season typically ranges from between 300,000 and 500,000 at maturity to several million eggs for females greater than 75 cm in length. Egg diameter, which can show a weak, positive association with body size, ranges between 1.25 and 1.75 mm.

Atlantic Cod typically spawn over a period of less than three months in water that may vary in depth from tens to hundreds of metres. Cod are described as batch spawners because of the observation that only 5 to 25% of a female's egg complement is released at any given time (approximately every 2 to 6 days) during a 3- to 6-week spawning period. During the larval stage, the young feed on phytoplankton and small zooplankton in the upper 10 to 50 metres of the water column. After the larval stage, the juveniles swim, or 'settle', to the bottom, where they appear to remain for a period of 1 to 4 years. These settlement areas are known to range from very shallow (< 10 m to 30 m) coastal waters to moderately deep (50 to 150 m) waters on offshore banks. After this settlement period, it is believed that the fish begin to undertake the often-seasonal movements (apparently undirected swimming in coastal waters) and migrations (directed movements to and from specific, highly predictable locations) characteristic of adults.

Populations and designatable units

Estimates of the size of the breeding part of the population for Atlantic Cod are available from two sources: (1) abundance estimates of the mature part of the population, as derived from a fisheries-dependent model called a Virtual Population Analysis (VPA), and (2) catch rates of fish of reproductive age as determined from fisheries-independent research surveys. Surveys provide an index which must be scaled to get the true population size. Models like VPA may extend further back in time and have the potential to smooth trends (year effects) and scale the index using catch data. Fisheries and Oceans Canada (DFO) is the primary source of these abundance data.

Based on COSEWIC's guidelines for assigning status below the species level, six DUs are identified in the present report and, when data are available, trends in the numbers of breeding individuals are described for each. Each of the DUs includes cod from one or more management unit, as delineated by geographical areas defined by the Northwest Atlantic Fisheries Organization (NAFO). These areas are used to identify the cod stocks managed by Fisheries and Oceans Canada.

Arctic Lakes DU

Cod in this DU are confined to coastal lakes along the eastern coast of Baffin Island, Nunavut (three have been documented) that receive intermittent tidal intrusions of salt water. These are Ogac Lake, Qasigialiminiq Lake and Tariujarusiq Lake.

Arctic Marine DU

Cod in this DU inhabit the marine environment east and southeast of Baffin Island, Nunavut (NAFO 0A, 0B). Although little is known about cod inhabiting the marine waters in this area, they are rarely caught in abundance, and may be an extension of cod stocks found in the waters around western Greenland.

Newfoundland and Labrador DU

Cod in this DU inhabit the waters ranging from immediately north of Cape Chidley (the northern tip of Labrador) southeast to Grand Bank off eastern Newfoundland. For management purposes, cod in this DU are treated as three separate stocks by DFO: (1) Northern Labrador cod (NAFO 2GH), (2) "Northern" cod, i.e., those found off southeastern Labrador, the Northeast Newfoundland Shelf, and the northern half of Grand Bank (NAFO 2J3KL), and (3) Southern Grand Bank cod (NAFO 3NO). Approximately 75 to 80% of the Atlantic Cod in Canadian waters were located within this population in the early 1960s.

Laurentian North DU

Cod in this DU combine the stocks identified for management purposes by DFO as (1) St. Pierre Bank (NAFO 3Ps) and (2) Northern Gulf of St. Lawrence (NAFO 3Pn4RS). These stocks are located north of the Laurentian Channel, bordering the south and west coast of Newfoundland and south coast of Quebec.

Laurentian South DU

Cod in this DU comprise three DFO-recognized management units (1) Southern Gulf of St. Lawrence (NAFO 4TVn Nov. to April), (2) Cabot Strait (NAFO 4Vn May to October), (3) Eastern Scotian Shelf (NAFO 4VsW). These stocks range from the southern Gulf of St. Lawrence to the eastern Scotian shelf and many overwinter along the southern slope of the Laurentian Channel.

Southern DU

Cod in this DU combine two stocks identified for management purposes by DFO: (1) Bay of Fundy/Western Scotian Shelf (NAFO 4X and the Canadian portion of NAFO 5Y), and (2) Eastern Georges Bank ($5Z_{jm}$). The latter stock is transboundary and is managed jointly by Canada and the USA. Geographically, this DU is located in the waters adjacent to Nova Scotia and New Brunswick, extending from southern Nova Scotia and the Bay of Fundy, to the Canadian portion of Georges Bank 5Z.

Limiting factors and threats

The primary historical cause of the reduction of Atlantic Cod range-wide was over-exploitation. The rate of decline was likely exacerbated by life history changes such as reductions in individual growth and age at maturation. Current threats to the stability and recovery of Atlantic Cod populations associated with exploitation include directed commercial fishing (quota-regulated harvest), recreational or “food fisheries”, indirect fishing (a consequence of illegal fishing, catch misreporting, discarding), and bycatch from other fisheries for bottom-dwelling species (e.g., Greenland halibut, northern shrimp, haddock, lobster, winter flounder). However, increased natural mortality of older cod now surpasses exploitation as the primary threat and source of mortality south of the Laurentian Channel particularly in the Laurentian South DU. Sources of high natural mortality remain unknown but may include changes to the magnitude and types of species interactions, and unfavourable environmental conditions. Selection against late maturity and rapid growth rate, induced by previously high rates of exploitation, may also be contributing to the higher mortality and slower growth observed in some areas today. The influence of marine climatic variation on cod population productivity remains poorly understood, but it seems likely that periods of cold water and high North Atlantic Osciliation anomalies are associated with reduced productivity in some populations.

DU status and trends

The report suggests that, for designation purposes, Atlantic Cod in Canada be recognized as six DUs, in accordance with known genetic, ecological, and demographic data, and in accordance with the guidelines detailed by COSEWIC (Nov. 2008). Regarding the assignment of risk, the primary cause of the reduction in Atlantic Cod (fishing) has not ceased in any of the DUs (although it is restricted in some regions). In the Laurentian North DU, excessive fishing mortality has reduced the breeding part of the population, particularly in the Northern Gulf section of this DU. In the Laurentian South DU and Southern DU, high natural mortality rates and not fishing pressure seem the dominant threat and are resulting in projections of unprecedented declines and functional extinction within decades. For the Newfoundland and Labrador DU, it is evident, based on harvest rates estimated by Fisheries and Oceans Canada, that fishing may be a significant impediment to recovery in parts of this population’s range and increasing declines in others. The populations, their 3-generaton rates of decline, and threats to their recovery are summarized in the table below.

Designatable Unit	NAFO Areas	Three-Generation Rate of Decline (VPA/RV)	Threats
1.Arctic Lakes		Unknown	Increased angling pressure in some lakes.
2.Arctic Marine	0A and 0B	Unknown	Bycatch, though magnitude of stock and threat remains unknown.
3.Newfoundland and Labrador	2G, 2H, 2J, 3K, 3L, 3N, 3O	97% / 99%	1. Fishing (including legal, illegal, and unreported catches). 2. Fishing-induced and natural changes to the ecosystem, resulting in altered levels of inter-specific competition and predation, notably predation by Harp Seals and fish on northern cod. 3. Marine climatic variation and its correlation with population productivity. 4. Alteration of bottom habitat by fishing gear and genetic changes to life history represent potential but unevaluated threats.
4.Laurentian North	3Ps, 3Pn, 4R, 4S	89% / 76%	1. Fishing (including legal, illegal, and unreported catches), representing a greater threat to Northern Gulf cod. 2. Fishing-induced and natural changes to the ecosystem, resulting in altered levels of inter-specific competition and predation, notably predation by Harp Seals and fish on Northern Gulf cod. 3. Marine climatic variation and its correlation with population productivity. 4. Alteration of bottom habitat by fishing gear and genetic changes to life history represent potential but unevaluated threats.
5.Laurentian South	4T, 4Vn, 4Vs, 4W	90% / 90%	1. Fishing-induced and natural changes to the ecosystem, resulting in elevated levels of natural mortality through inter-specific competition and predation, notably Grey Seal predation. 2. Fishing (including legal, illegal, and unreported catches). 3. Marine climatic variation and its correlation with population productivity. 4. Alteration of bottom habitat by fishing gear and genetic changes to life history represent potential but unevaluated threats.
6. Southern	4X, Canadian portions of 5Y and 5Z	64% / 67%	1. Fishing (including legal, illegal, and unreported catches). 2. Fishing-induced and natural changes to the ecosystem. 3. Marine climatic variation and its correlation with population productivity. 4. Alteration of bottom habitat by fishing gear and genetic changes to life history.

Special significance of the species

Given its historical and contemporary importance to society, few species have been of greater significance in Canada. After the short-lived Viking-based settlements on Newfoundland’s Northern Peninsula in the late tenth century, it was cod that brought the first Europeans to Newfoundland waters in the late fifteenth century, an economic venture that spawned one of the first permanent settlements in British North America (1612; Cupids, Newfoundland). Until the early 1990s, Atlantic Cod was the economic mainstay for Newfoundland and Labrador, as it was for a large part of the population in the Maritimes and along Quebec’s north shore and Gaspé Peninsula. From a biological perspective, the Atlantic Cod, which numbered approximately 2.5 billion spawning individuals as recently as the early 1960s, was one of the top predators of the marine food web in the Northwest Atlantic.

Existing protection or other status designations

In Canada, the Atlantic Cod is protected federally by the *Fisheries Act* and by the *Oceans Act*. At present, Conservation Harvesting Plans are in place for the Southern Gulf of St. Lawrence, and three Federal/Provincial Cod Action Teams have been established (Newfoundland and Labrador, Maritimes, Quebec) with a mandate to promote recovery. In addition, several of the cod DUs in Canadian waters are managed jointly with other countries. For example, the Eastern Georges Bank cod stock is jointly managed by Fisheries and Oceans Canada and the National Marine Fisheries Service in the United States; and cod in the NAFO 3Ps area of the Laurentian North DU are managed bilaterally by Canada and France (on behalf of Saint Pierre and Miquelon). In most regions, quotas as well as seasonal and gear restrictions have been incorporated into the management framework (Worcester *et al*. 2009). Although biologically relevant reference points for stock abundance have been identified in several areas, these are currently not used in the management of these stocks, and fisheries management can essentially be described as ad hoc with respect to the setting of annual TACs. At present, several stocks remain under commercial moratoria and the remaining are under quota restrictions with respect to historic levels.

Other Status Designations for Atlantic Cod

IUCN: Vulnerable
Global Heritage Status Rank: G5

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS
(2010)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.

** Formerly described as "Not In Any Category", or "No Designation Required."

*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994. Definition of the (DD) category revised in 2006.

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The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

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in Canada

2010

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SPECIES INFORMATION

Name and classification

Class:	Actinopterygii
Order:	Gadiformes
Family:	Gadidae
Latin binomial:	*Gadus morhua* Linnaeus 1758

Common names: English – Atlantic Cod
French – morue franche
Inuktitut – ogac (Nunavut); ovak, ogac (Ungava Bay); uugak, ugak (Innu, Labrador) (McAllister *et al*. 1987)

Morphological description

The Atlantic Cod is a medium to large marine fish (Figure 1), inhabiting cold (10° to 15° C) and very cold waters (less than 0° to 5° C) in coastal areas and in offshore waters overlying the continental shelf throughout the Northwest and Northeast Atlantic Ocean (Figure 2). Morphologically, the feature that distinguishes them from most other fishes (a feature shared by other gadids) is the presence of three dorsal fins and two anal fins. Otherwise, cod have the “classic”, streamlined, fusiform shape characteristic of fish that are able to sustain moderate speed over relatively long distances. The colour of cod varies a great deal throughout Canadian waters, having been described by fishermen as near-black, brown, and red, depending on the location of capture (Neis *et al*. 1999). The flesh of cod is comprised of firm, non-oily, white tissue that deteriorates relatively slowly after death, and is easily preserved by drying, salting, or some combination thereof.

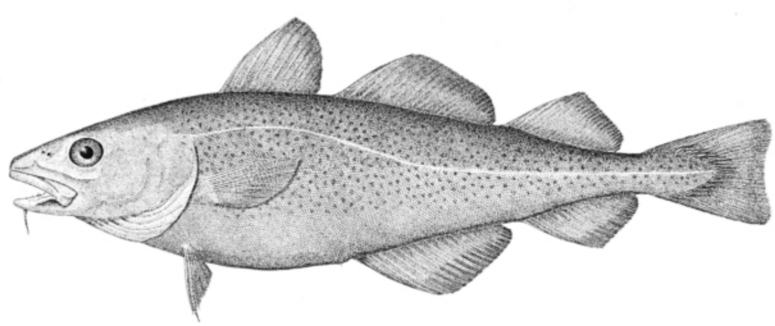

Figure 1. Line drawing of Atlantic Cod, or morue franche, *Gadus morhua*, by H.L. Todd. Image reproduced with permission from the Smithsonian Institution, NMNH, Division of Fishes.

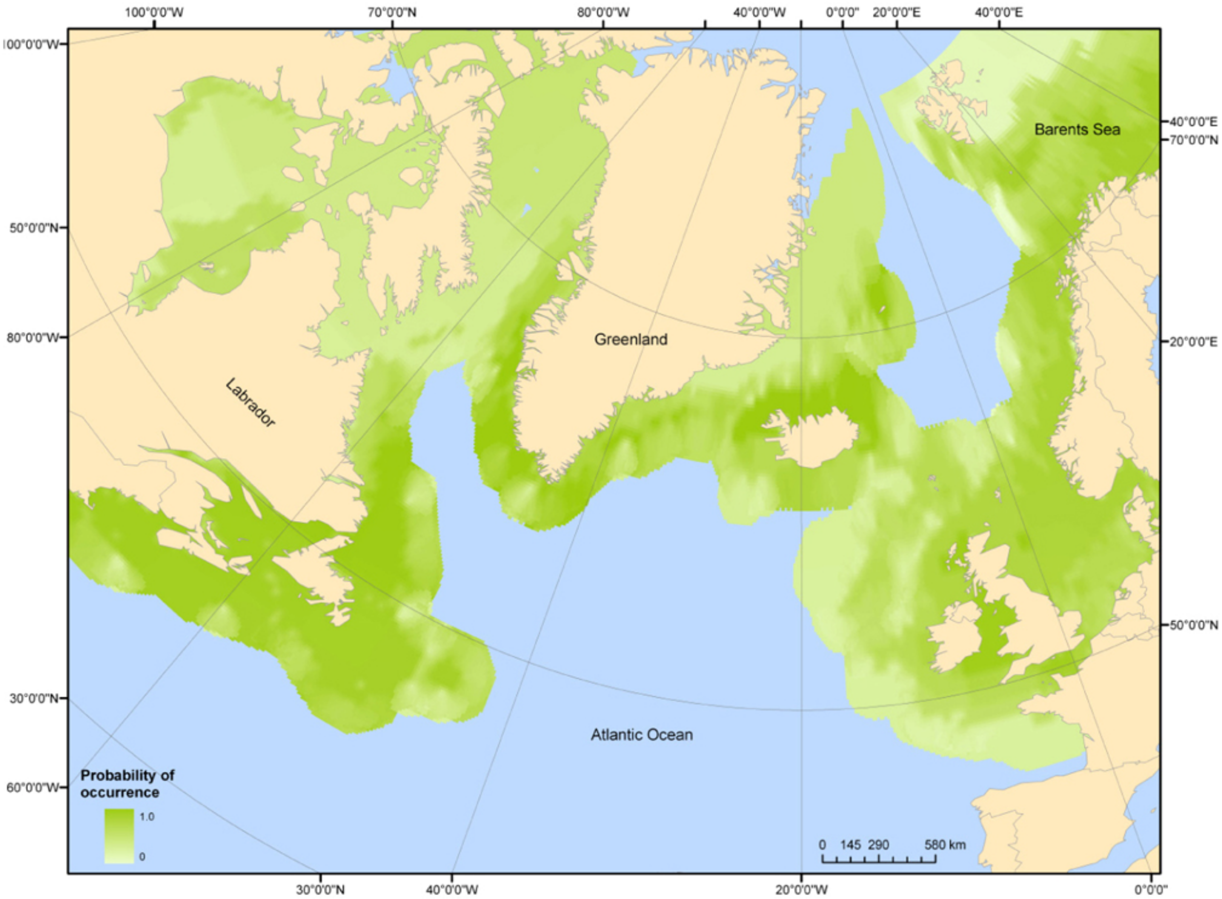

Figure 2. Global distribution of Atlantic Cod, *Gadus morhua*. Data from Fishbase.org.

Spatial population structure

The approach for defining the level of spatial structuring recognized by COSEWIC for Atlantic Cod has changed over the last decade. Presently, COSEWIC defines a DU by two criteria: 1) it must be substantially reproductively isolated from other populations, as evidenced by genetic distinctiveness, spatial disjunction, or occupation of different ecogeographic regions, and 2) it must represent a significant component of the evolutionary legacy of the species (Waples 1991). Accordingly, DUs are generally more reproductively isolated over a longer period of time than are the subpopulations within them, and multiple types of information (e.g., genetic structure, life history variation) are often required to address both significance and discreteness. In 1998, COSEWIC assigned cod to the Special Concern (Vulnerable) category and assigned a single designation to cod throughout their entire Canadian range. For a single designation to be valid, this requires the absence of significant variation in genetic and life history or adaptive variation throughout the species' range. However, as recent genetic and ecological data are consistent with the hypothesis that Atlantic Cod can be distinguished as separate DUs, in 2003 COSEWIC identified 4 designatable units (DUs) for cod in Canadian waters. Integrating information from genetic, ecological, and life history research, there is substantial evidence of population differentiation among Atlantic Cod in the Northwest Atlantic. However, while differences among recognized cod stocks are sufficiently high to warrant their separate treatment from a management perspective, it is not clear how populations might best be designated from an evolutionary perspective, given that genetic and life history data are not available for all stocks. Nonetheless, there is ever-increasing and substantive evidence of restricted dispersal and adaptive differences among cod at spatial scales considerably smaller than the geographical range of the species in Canada. From the general perspective, relevant studies include those on:

1. Genetic analyses of neutral genetic variation: Bentzen *et al*. 1996; Ruzzante *et al*. 1996, 1997, 1998, 1999, 2000a,b, 2001; Pogson *et al*. 1995, 2001; Beacham *et al*. 2002; Lage *et al*. 2004; Hardie *et al*. 2006; Bradbury *et al*. submitted; Bradbury *et al*. unpublished. In addition see Carr *et al*. 1995; Carr and Crutcher 1998; Carr and Marshall 2008 for mtDNA analyses.

2. Tagging studies such as mark-recapture, telemetry data, and natural tags: Thompson 1943; McKenzie 1956; McCracken 1959; Martin and Jean 1964; Templeman 1962; Lear 1984; Taggart *et al*. 1995; Hunt *et al*. 1999; Campana *et al*. 1999; Green and Wroblewski 2000; Swain and Frank 2000; Cote *et al*. 2001; Robichaud and Rose 2004; Windle and Rose 2005; Brattey *et al*. 2008a.

3. Spatio-temporal variation in reproduction: such as spawning period, location and the distribution of early life history stages (Hjort 1919; Frost 1938; Bulatova 1962; Postolaky 1974; Gagne and O'Boyle 1984; O'Boyle *et al*. 1984; Campana *et al*. 1989; Suthers *et al*. 1989; Frank *et al*. 1994; Myers *et al*. 1993; Hutchings *et al*. 1993; Lough *et al*. 1994; DeYoung and Davidson 1994; Pepin and Helbig 1997; Bradbury *et al*. 2000, 2002, 2008; Bradbury and Snelgrove 2001).

4. Life history variation: Pinhorn 1984; Trippel *et al*. 1997; McIntyre and Hutchings 2003; Fudge and Rose 2008.

5. Spatial differences in vertebral number variation demonstrated to have a genetic basis in fishes (e.g., Billerbeck *et al*. 1997) and to be adaptively significant (e.g., Templeman 1962; Templeman 1981; Swain 1992; Swain *et al*. 2001).

6. Genetically based adaptive differences: Puvanendran and Brown 1998; Goddard *et al*. 1999; Purchase and Brown 2000; Purchase and Brown 2001; Marcil *et al*. 2006a; Marcil *et al*. 2006b; Hutchings *et al*. 2007; Bradbury *et al*. submitted.

7. Geographical correlations and differences in demography (i.e. recruitment, natural mortality and growth): Myers *et al*. 1995; Swain and Castonguay 2000.

Designatable units and populations

COSEWIC identifies DUs as discrete and evolutionarily significant units, where "significant" means that the DU is important to the evolutionary legacy of the species as a whole and if lost would likely not be replaced over ecological time scales. Discreteness is considered of primary importance, and may refer to genetic isolation, habitat discontinuity, or ecological isolation. Significance may refer to deep phylogenetic divergence (e.g., glacial races), adaptive (e.g., life history variation), or ecological uniqueness, and its inclusion in the definition reflects the opinion that isolation in and of itself is not deemed sufficient for designation. In this context, it is important to acknowledge that a DU may contain multiple smaller subpopulations, each of which may be connected by some migration (McElhany *et al*. 2000), but migration is not necessary, as discrete subpopulations which lack demonstrable adaptive differences (i.e. significance) may be combined to a single DU. It is also worth noting that as the data are collected as part of the regular Fisheries and Oceans Canada (DFO) assessment process, the finest scale available for designation is at the scale of the DFO-recognized stock on which assessments are based. Nonetheless, these management units have a long history and generally represent a finer spatial scale than most major demographically independent populations. Therefore, evolutionarily significant structure below this scale seems unlikely, but also remains to be tested in many instances. Based on COSEWIC's guidelines for assigning status below the species level, six designatable units are identified in the present report and, when data are available, trends in the numbers of breeding individuals are described for each. Each of the DUs includes cod found in more than one management unit (with the exception of the Arctic Lakes DU), as delineated by NAFO (Northwest Atlantic Fisheries Organization) Divisions (Figure 7). These divisions also identify the cod stocks managed by Fisheries and Oceans Canada.

Arctic Lakes DU

Cod in this DU are those confined to coastal lakes along the eastern coast of Baffin Island, Nunavut (three have been documented) that receive intermittent tidal intrusions of salt water. These are Ogac Lake, Qasigialiminiq Lake and Tariujarusiq Lake.

Arctic Marine DU

Cod in this DU inhabit the marine environment east and southeast of Baffin Island, Nunavut (NAFO 0A, 0B). Although little is known about cod inhabiting the marine waters in this area, they are rarely caught in abundance, and may be an extension of cod stocks found in the waters around western Greenland.

Newfoundland and Labrador DU

Cod in this DU inhabit the waters ranging from immediately north of Cape Chidley (the northern tip of Labrador) southeast to Grand Bank off eastern Newfoundland. For management purposes, cod in this DU are treated as three separate stocks by DFO:

(1) Northern Labrador cod (NAFO 2GH), (2) “Northern” cod, i.e., those found off southeastern Labrador, the Northeast Newfoundland Shelf, and the northern half of Grand Bank (NAFO 2J3KL), and (3) Southern Grand Bank cod (NAFO 3NO). Approximately 75 to 80% of the Atlantic Cod in Canadian waters were located within this DU in the early 1960s.

Laurentian North DU

Cod in this DU combine the stocks identified for management purposes by DFO as (1) St. Pierre Bank (NAFO 3Ps) and (2) Northern Gulf of St. Lawrence (NAFO 3Pn4RS). These stocks are located north of the Laurentian Channel, bordering the south and west coast of Newfoundland and south coast of Quebec.

Laurentian South DU

Cod in this DU comprise three DFO-recognized management units (1) Southern Gulf of St. Lawrence (NAFO 4TVn Nov. to April), (2) Cabot Strait (NAFO 4Vn May to Oct.), (3) Eastern Scotian Shelf (NAFO 4VsW). These stocks range from the southern Gulf of St. Lawrence to the eastern Scotian shelf and many overwinter along the southern slope of the Laurentian Channel.

Southern DU

Cod in this DU combine two stocks identified for management purposes by DFO: (1) Bay of Fundy/Western Scotian Shelf (NAFO 4X and the Canadian portion of NAFO 5Y), and (2) Eastern Georges Bank ($5Z_{jm}$). The latter stock is transboundary and is managed jointly by Canada and the USA. Geographically, this DU is located in the waters adjacent to Nova Scotia and New Brunswick, extending from southern Nova Scotia and the Bay of Fundy, to the Canadian portion of Georges Bank 5Z.

Scientific Basis for Distinguishing the Newfoundland & Labrador, Laurentian North, Laurentian South and Southern Dus

These DUs can be identified as “distinct” and “significant” by a combination of different types of available data. These include age at maturity, maximum population growth rate (r_{max}), temporal trends in abundance, tagging returns, genetic variability at selectively neutral loci, and genetic differences among selectively important traits.

Age at maturity

Age at maturity (represented as the age at which 50% of females are reproductive) differs among the populations, and it likely reflects both environmental (e.g., temperature), and genetic influences and may be subject to strong selection associated with fishing pressure. To compare ages at maturity, the average pre-collapse age across all stocks within each DU was calculated, weighting the average age for each stock by the highest estimated abundance of mature individuals in that stock (as determined by VPA abundance data; see POPULATION SIZES AND TRENDS below). Cod are oldest at maturity in the Newfoundland & Labrador DU in which both stocks mature at 6 years, and youngest in the Southern DU in which the 2 stocks mature at 2.5 years (Figure 3). The clearest difference in age at maturity occurs in the Southern DU where cod mature at 2-3 yrs, considerably younger than in other DUs.

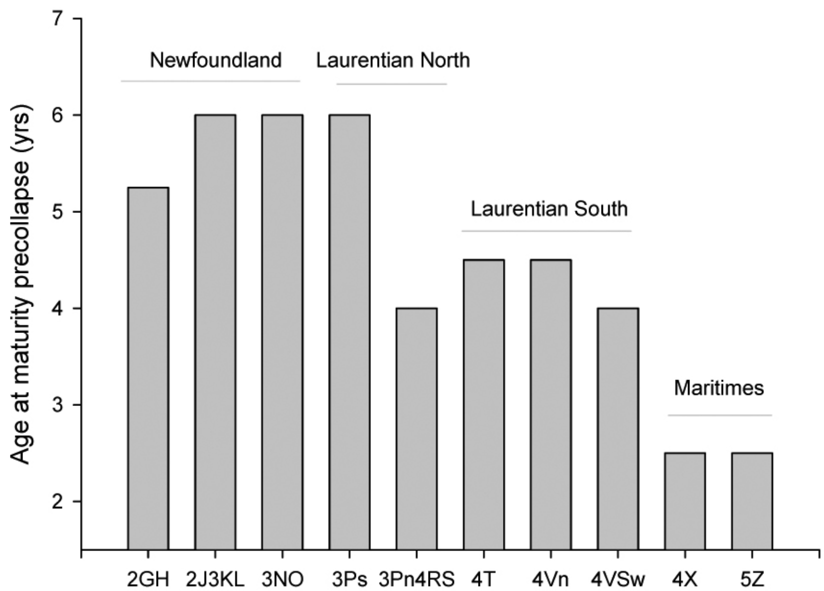

Figure 3. Age at maturities (pre-collapse) for each of the 10 recognized stocks of Atlantic Cod in Canadian waters.

Designatable Unit	**Number of stocks**	**Age at maturity (range among stocks)**	**Reference(s)**
Newfoundland & Labrador	2	6.0 (6-6 yr)	Lilly *et al*. (2001); Trippel *et al*. (1997); Stansbury *et al*. (2001); COSEWIC 2003
Laurentian North	2	4.5 (4-6 yr)	Brattey *et al*. (2001a); COSEWIC 2003
Laurentian South	3	4.5 (4.0-4.5 yr)	Doug Swain, personal communication 2009; Worcester *et al*. 2009
Southern	2	2.5 (2.5-2.5 yr)	Trippel *et al*. (1997); Hunt and Hatt (2002)

Maximum population growth rate (r_{max})

Based on data available in the mid-1990s, one can compare estimates of maximum population growth for the population identified here. The estimate for northern cod is available from Hutchings (1999); the remaining estimates are reported by Myers *et al*. (1997a; revised Table 1; pers. comm.). Estimates of r_{max} are made using the slope of the stock-recruitment relationship near the origin and subject to the caveat that r_{max} may have changed since the mid-1990s as has been observed in some regions (e.g., Swain and Chouinard 2008). However, what is important here is the question of whether r_{max} is likely to differ among the DUs, even for data restricted to the pre-collapse and immediate post-collapse periods for each stock. To compare r_{max} among populations, the average r_{max} across all stocks within each DU was calculated, weighting the r_{max} estimate for each stock by the highest known abundance of mature individuals in that stock (as determined by VPA abundance data; see POPULATION SIZES AND TRENDS below). As predicted based on their differences in age at maturity, the Newfoundland & Labrador DU has a lower maximum population growth rate than its more southerly counterparts. Note, under recent productivity conditions the Laurentian South DU has exhibited extremely low productivity even though it extends farther south than some of the other populations (see Shelton *et al*. 2006).

Designatable Unit	**Number of stocks**	**Maximum population growth rate, r_{max} (range among stocks)**	**Reference(s)**
Newfoundland & Labrador	2	0.15 (0.13-0.35)	Myers *et al*. (1997a, revised Table 1); Hutchings (1999)
Laurentian North	2	0.32 (0.29-0.39)	Myers *et al*. (1997a, revised Table 1)
Laurentian South	3	0.36 (0.24-0.50)	Myers *et al*. (1997a, revised Table 1)
Southern	2	0.51 (0.47-0.67)	Myers *et al*. (1997a, revised Table 1)

Temporal abundance trends

Myers *et al*. (1995) examined the spatial scale of correlation in recruitment to the various Canadian stocks and observed correlations at scales <500km. Accordingly, certain stocks have displayed similar rates of decline. For instance, stocks that comprise the Newfoundland & Labrador DU (2J3KL and 3NO) have experienced steady declines across most of the time period of available data (>90% declines, see POPULATION SIZES AND TRENDS below).

Tagging and Telemetry Data

Tagging studies have been conducted in Canadian waters on cod since the 1930s. The general consensus is that tagged individuals rarely move more than 500 km. An evaluation of almost 50 years of tagging experiments off Newfoundland (Taggart 1995, see Movements/Dispersal section) indicates a clear decline in straying rates with distance and high rates of annual site fidelity (Figure 4A). Furthermore, across studies the evidence for strong site fidelity of cod in Canadian waters is accumulating (Green and Wroblewski 2000; Cote *et al*. 2001; Windle and Rose 2005; Brattey *et al*. 2008a). Brattey *et al*. (2008a) document annual rates of homing to Smith Sound Trinity Bay ranging from 65-100%. Robichaud and Rose (2004) suggest that 40% of all cod stocks worldwide are resident non-migratory populations. Moreover, although some stocks undergo large-scale migrations, such as in the Gulf of St. Lawrence, the degree of mixing and straying may be quite limited (e.g., Campana *et al*. 1999).

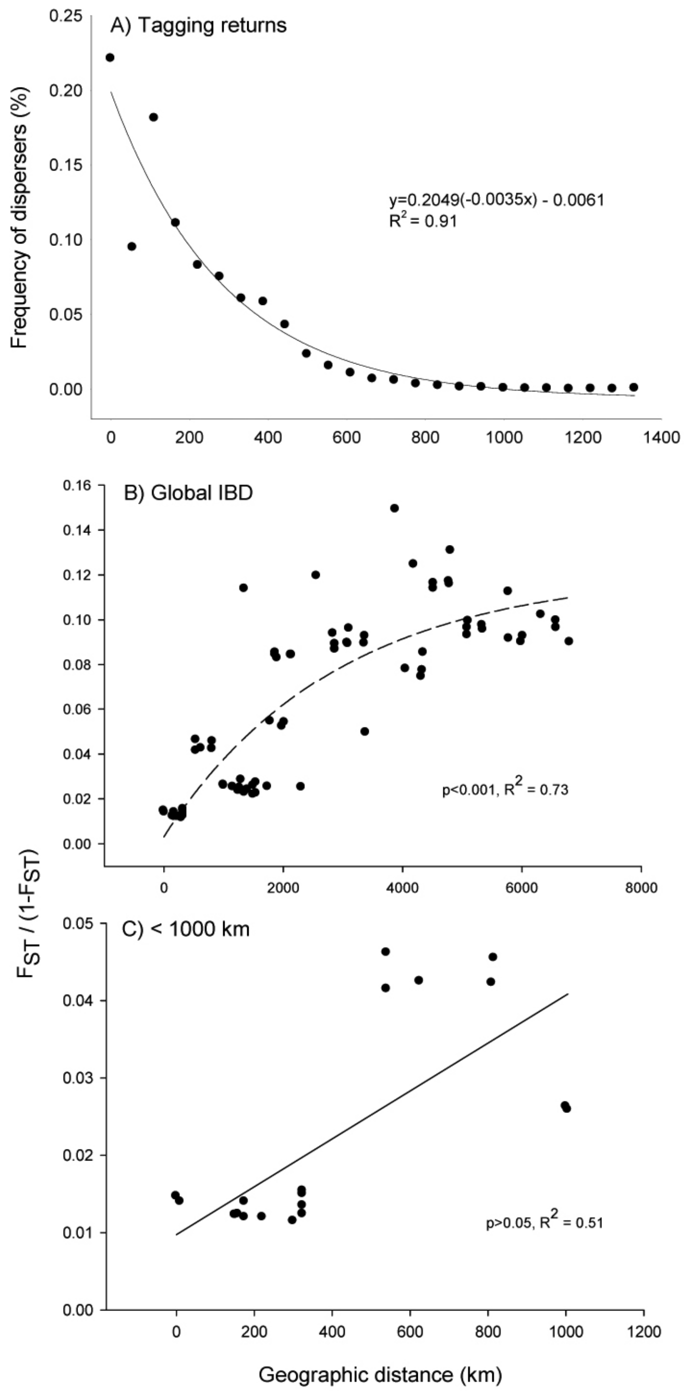

Figure 4. (A) Relationship between frequency of tag returns and geographic distance for cod tagged in Newfoundland waters 1954 to 1993 and genetic isolation by distance for both large (B) and small (C) scales from an analysis of 1405 single nucleotide polymorphisms (Bradbury *et al*. submitted).

Tagging studies can be used to examine straying rates across proposed DU boundaries and corroborate estimates of gene flow based on molecular markers. Brattey *et al*. (2008a) and Lawson and Rose (2000) document movements of 3Ps fish northward along the Avalon Peninsula rarely farther than Conception Bay. The Laurentian Channel, which is likely the main topographic barrier in Canada waters, separates the Laurentian North and Laurentian South DUs. Templeman (1962) reported "there do not appear to be any migration tracks or any considerable intermingling across channel and stocks on each side of the channel are thus separate." Estimates of trans-channel movements suggests crossing rates of <3% (Thompson 1943; McKenzie 1956; McCracken 1959; Martin and Jean 1964). Recent estimates using otolith elemental tags (Campana *et al*. 1999) or vertebral counts (see below, Swain *et al*. 2001) support the earlier conclusions of a low rate of cross channel mixing.

Summary of the evidence for trans-Laurentian Channel movements based on tagging studies from Templeman (1962).

Total Recoveries	Trans-Laurentian Channel Recoveries	%	Reference in Templeman (1962)
984	2	0.20	Thompson (1943)
670	2	0.30	Templeman and Fleming (1962)
2200	33	1.50	McKenzie (1957)
277	3	1.08	McCracken (1957)
215	0	0.00	McCracken (1957)
1022	18	1.76	McCracken (1959)
185	5	2.70	Martin (1959)

Wthin DUs, tagging studies suggest large spatial overlap, often associated with season migrations. Analysis of overwintering distributions along the slope of the Laurentian Channel suggest significant overlap among cod from 4T, 4Vn, and 4VsW along the southern slope, and 4PnRS and 3Ps along the northern slope consistent with their separation into the Laurentian North and Laurentian South DUs (Campana *et al*. 1999; Swain *et al*. 2001). Moreover, in contrast to the Laurentian Channel, straying rates across the Fundian Channel, which separates NAFO 4X and 5Z suggest that it is not a large impediment to movement (5-15% straying, e.g., Hunt *et al*. 1999) and support the formation of a Southern DU.

<u>Genetic differentiation at selectively neutral loci</u>

There is strong evidence of significant genetic differentiation at selectively neutral loci among the DUs (Table 1). In light of large populations, and likely post-glacial range expansions, it is not surprising that spatial differentiation in cod is often low, as is typical of marine fishes. Nonetheless, significant structuring has been observed in multiple studies, usually associated with physical isolation or barriers to gene flow. Bentzen *et al*. (1996) using microsatellite loci, observed significant structuring among Newfoundland, the Flemish Cap, and cod from the Scotian Shelf (Table 1). Similarly, Ruzzante *et al*. (1998) documented significant structuring at the bank scale, again suggesting significant differentiation across the Laurentian Channel (Table 1). Pogson *et al*.'s (2001) analysis of 10 nuclear restriction-fragment-length-polymorphism (RFLP) loci also revealed significant genetic differences among cod sampled from the DUs, particularly between the Newfoundland and Laurentian South DUs. Strong signatures of genetic isolation have also been observed associated with Gilbert Bay Labrador (Ruzzante *et al*. 2001; Beacham *et al*. 2002) and several Arctic lakes (Hardie *et al*. 2006) both of which are characterized by restricted access to the coastal ocean (Table 1). In the absence of obvious barriers to gene flow, evidence of the limits of dispersal are still observed through the presence of genetic isolation by distance. Pogson *et al*. (2001) reported a highly significant negative association between gene flow and geographic distance among cod sampled in Canadian waters from the Newfoundland & Labrador and mainland stocks. A similar association was also reported by Beacham *et al*. (2002) from their analysis of 7 microsatellite loci and the Pantophysin (*Pan*I) locus (Table 1). Recently, Bradbury *et al*. (unpublished data) observed strong isolation by distance both range-wide and at small spatial scales (Figure 4B,C, see below for further details). These negative associations at spatial scales often less than 700 km imply that the greater the geographical separation of cod, the lower their genetic affinity. Moreover, significant isolation by distance at spatial scales <700 km corroborates both the declines in straying observed with tagging returns and the scale of differentiation observed in life history traits and demographic data (see above).

Microsatellite differentiation can further provide insight into gene flow associated with DU boundaries. Ruzzante *et al*. (1998) and Beacham *et al*. (2002) observed significant differentiation between Laurentian North and Newfoundland and Labrador cod supporting the separation of these DUs. Furthermore, significant differentiation was observed (Ruzzante *et al*. 1998, 2000) both across the Laurentian Channel, and between the Southern and the Laurentian South DUs supporting the designation of these boundaries and the formation of the Laurentian South DU. Within DUs at smaller spatial scales, spatial structure is generally absent (Bentzen 1996; Ruzzante *et al*. 1998; Beacham *et al*. 2002) with the exception of the above-noted instances of strong geographic isolation (e.g., Gilbert Bay). Evidence for genetic differentiation among the DUs at selectively neutral loci is summarized in Table 1. It is worth noting that many of the studies which reveal significant structuring included a specific microsatellite locus (Gmo132, Table 1), which has been identified as potentially under natural selection (Nielsen *et al*. 2006). This trend towards the reliance on non-neutral loci or traits for the resolution of isolation and adaptive significance in marine fishes is continuing with work using expressed DNA sequences (Bradbury *et al*. submitted) and common garden experiments (e.g., Hutchings *et al*. 2007), both of which are revealing evidence of fine scale (<500 km) adaptation in cod (see below).

Table 1. Summary of genetic estimates of differentiation from published literature.

Reference	Areas Compared		Marker Type	# Loci	Average Sample Size	Significant	F_{ST}
Bentzen *et al*. 1996	2J	3K	microsatellite	6	60	yes	0.007
Ruzzante *et al*. 1998	2J3KL	2J3KL	microsatellite	5	93	yes	0.001
Bentzen *et al*. 1996	2J3KL	4VSW	microsatellite	6	60	yes	0.003
Bentzen *et al*. 1996	2J3KL	4VSW	Gmo132	1	60	yes	0.021
Pogson *et al*. 1995	2J3KL	4X	RFLP	17	95	yes	Not given
Ruzzante *et al*. 1997	2J3KL (inshore)	2J3KL (offshore)	microsatellite	5	60	yes	0.0014
Ruzzante *et al*. 1997	2J3KL (inshore)	2J3KL (offshore)	microsatellite	5	60	yes	0.0015
Ruzzante *et al*. 2000	3K	3NO	microsatellite (with Gmo132)	5	148	yes	0.005
Hardie *et al*. 2006	3PS	4T	microsatellite	7	84	No	-0.0008
Pepin & Carr 1993	3O	3L	mtDNA	1		No	-0.0122
Carr *et al*. 1995	3L	3L	mtDNA	1	47	No	0.00
Hardie *et al*. 2006	3PS	4W	microsatellite	7	84	No	0.0025
Hardie *et al*. 2006	3PS	4X	microsatellite	7	84	No	-0.0008
Ruzzante *et al*. 2000	4RS	2J3KL	microsatellite (with Gmo132)	4	148	yes	0.025
Ruzzante *et al*. 1998	4RS	4T	microsatellite	5	93	yes	0.008
Hardie *et al*. 2006	4T	4W	microsatellite	7	84	No	0.0026
Hardie *et al*. 2006	4T	4X	microsatellite	7	84	No	0.0004
Hardie *et al*. 2006	4W	4X	microsatellite	7	84	No	-0.0005
Ruzzante *et al*. 1998	4W (Offshore)	4X (Offshore)	microsatellite	5	93	yes	0.004
Ruzzante *et al*. 2000	4X	$5Z_{jm}$	microsatellite (with Gmo132)	5	148	yes	0.007
Pogson *et al*. 2001	4XVsXw	4XVsXw (~600km)	RFLP	10	95	yes	not given, strong IBD
Lage *et al*. 2004	5Z	4X and Nantucket Shoals	pan	1	68	No	-0.0052
Lage *et al*. 2004	5Z	4X(Browns Bank)	microsatellite	5	68	No	0.0012
Lage *et al*. 2004	5Z	4X(Browns Bank)	Gmo132	1	68	No	0.0124
Ruzzante *et al*. 1998	5Z and 4X (Bay of Fundy)	4VSW	microsatellite	5	93	yes	0.011
Hardie *et al*. 2006	Gilbert Bay	3PS	microsatellite	7	84	yes	0.0576
Hardie *et al*. 2006	Gilbert Bay	4T	microsatellite	7	84	yes	0.0558
Hardie *et al*. 2006	Gilbert Bay	4W	microsatellite	7	84	yes	0.0526
Hardie *et al*. 2006	Gilbert Bay	4X	microsatellite	7	84	yes	0.051
Beacham *et al*. 2002	Newfoundland locations		micro (and Pan)	7	275	yes	0.008
Hardie *et al*. 2006	Ogac Lake	3PS	microsatellite	7	84	yes	0.1407
Hardie *et al*. 2006	Ogac Lake	4T	microsatellite	7	84	yes	0.1291
Hardie *et al*. 2006	Ogac Lake	4W	microsatellite	7	84	yes	0.1359
Hardie *et al*. 2006	Ogac Lake	4X	microsatellite	7	84	yes	0.1299

Reference	Areas Compared		Marker Type	# Loci	Average Sample Size	Significant	F_{ST}
Hardie *et al*. 2006	Ogac Lake	Gilbert Bay	microsatellite	7	84	yes	0.1966
Hardie *et al*. 2006	Ogac Lake	Qasigialiminiq Lake	microsatellite	7	84	yes	0.1952
Hardie *et al*. 2006	Ogac Lake	Tariujarusiq Lake	microsatellite	7	84	yes	0.2381
Hardie *et al*. 2006	Qasigialiminiq Lake	3PS	microsatellite	7	84	yes	0.0934
Hardie *et al*. 2006	Qasigialiminiq Lake	4T	microsatellite	7	84	yes	0.0913
Hardie *et al*. 2006	Qasigialiminiq Lake	4W	microsatellite	7	84	yes	0.0806
Hardie *et al*. 2006	Qasigialiminiq Lake	4X	microsatellite	7	84	yes	0.0834
Hardie *et al*. 2006	Qasigialiminiq Lake	Gilbert Bay	microsatellite	7	84	yes	0.1563
Hardie *et al*. 2006	Qasigialiminiq Lake	Tariujarusiq Lake	microsatellite	7	84	yes	0.2234
Hardie *et al*. 2006	Tariujarusiq Lake	3PS	microsatellite	7	84	yes	0.1432
Hardie *et al*. 2006	Tariujarusiq Lake	4T	microsatellite	7	84	yes	0.1295
Hardie *et al*. 2006	Tariujarusiq Lake	4W	microsatellite	7	84	yes	0.1456
Hardie *et al*. 2006	Tariujarusiq Lake	4X	microsatellite	7	84	yes	0.1324
Hardie *et al*. 2006	Tariujarusiq Lake	Gilbert Bay	microsatellite	7	84	yes	0.2141

In contrast to the studies noted above, studies of mtDNA variation indicate that "essentially none of the genetic variance in the Northwest Atlantic is attributable to subdivision among samples" (Carr and Crutcher 1998). See also Carr *et al*. (1995); and Carr and Marshall (2008).

<u>Genetic differentiation among selectively important traits</u>

In addition to differences at selectively neutral loci, there is increasing evidence that cod in the Northwest Atlantic differ from one another at loci or traits that are under selection reflecting local adaptation. This inference is drawn both from the examination of non-neutral molecular loci exhibiting elevated differentiation and from experiments in which differences among cod populations have been documented after the effects of the environment have been removed from the analysis.

Molecular loci may reflect selection and adaptive divergences if they are linked to expressed sequences under selection, as may be the case for microsatellite loci, or if they are expressed themselves and directly experience selection. Both Bentzen *et al*. (1996) and Ruzzante *et al*. (1998) reported significant structure among the DUs which was largely driven by a single locus, Gmo132. The locus has since been shown (Nielsen *et al*. 2006) to be experiencing elevated divergence associated with hitch-hiking selection (i.e. linkage to a gene under selection). Similar observations of elevated divergence associated with the Pantophysin locus have been made in Canadian waters, though the structure is much lower than observed in the eastern Atlantic (Beacham *et al*. 2002). Bradbury *et al*. (submitted) have examined 1641 expressed single nucleotide polymorphisms (SNPs) in cod from 19 locations throughout Canadian and adjacent waters (Fig. 4 & 5). Principal Component Analysis (PCA) and Bayesian clustering indicated the presence of six significant groups (Figure 5a). Twenty-five SNPs displayed clear trends in allele frequency (Figure 5b), elevated divergence, and are highly correlated with ambient temperature (r=0.93) suggesting local adaptation associated with ocean climate. The major transition in allele frequencies at these temperature-associated SNPs occurs between the Laurentian South and the Southern DUs (Figure 5b) consistent with large adaptive differences.

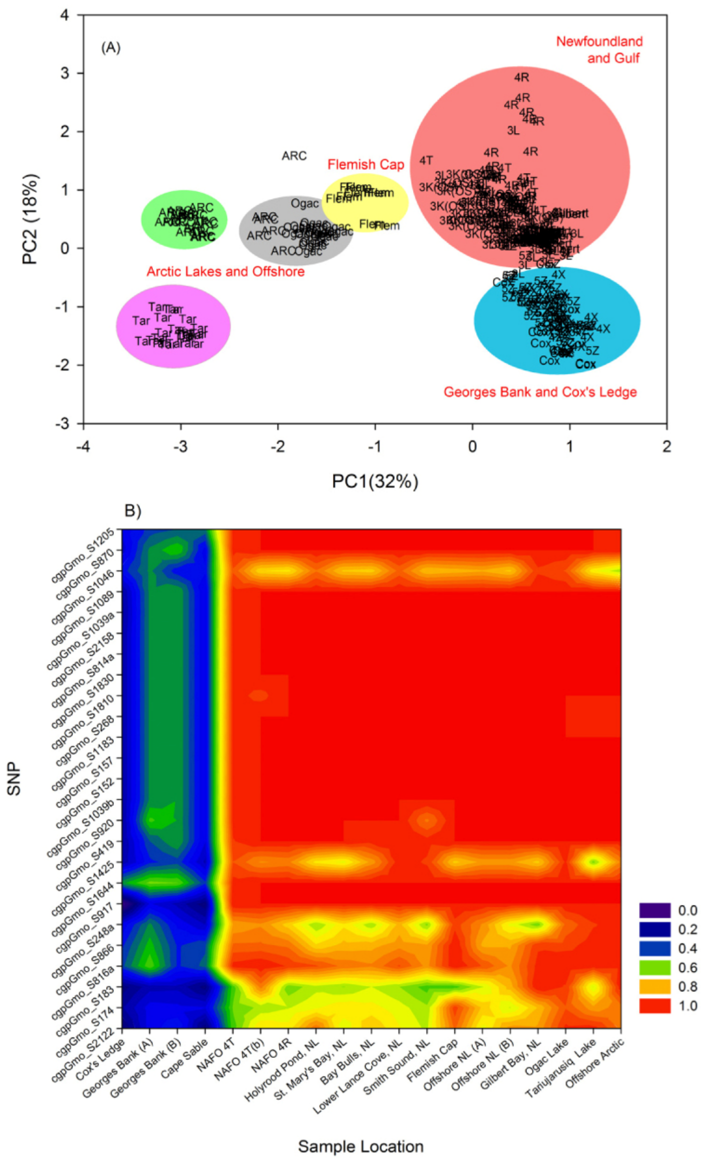

Figure 5. (A)Principal Components Analysis of 1405 single nucleotide polymorphisms (SNP) for 19 samples of Atlantic Cod from throughout Canadian and adjacent waters. Coloured ellipses represent genetic clusters identified using a Bayesian Clustering analysis. (B) Average allele frequencies at 25 SNPs associated with ocean temperature (R^2=0.88, Bradbury *et al*. submitted). Sites identified by NAFO region except, Cox= Cox's Ledge; Ogac = Ogac Lake; ARC = Arctic marine; 3K(OS)=offshore 3K; TAR= Tariujarusiq Lake; Flem=Flemish Cap).

Experimental studies often employing common rearing environments to remove environmental effects, suggest large adaptive differences among many populations. Initial work comparing cod from the Southern and Laurentian South DUs with those from the Newfoundland & Labrador documented genetic differences in juvenile growth rate (Purchase and Brown 2000), food conversion efficiency (Gulf of Maine, Purchase and Brown 2001), and in the influence of light intensity on survival and growth in early life (Laurentian South DU, Puvanendran and Brown 1998). This has been expanded in a series of common garden experiments (Marcil *et al*. 2006a,b, Hutchings *et al*. 2007) which documented clear genetic differences among traits of importance to fitness between cod from the Laurentian North and Southern DUs, the Laurentian South and Newfoundland and Labrador DUs, the Laurentian North and Newfoundland and Labrador DUs, and the Laurentian South and Southern DUs (Hutchings *et al*. 2007). Morphological variation associated with these experiments further indicate differences between all compared DUs (Marcil *et al*. 2006a,b). Overall, these experiments revealed significant main and interaction effects of temperature, food, and population on larval growth, survival, and morphological variation consistent with genetically based differences and the presence of locally adapted populations.

In summary, it seems likely based on the best current information that cod in Canadian waters represent six DUs using the criteria of isolation (as identified using tagging returns or neutral molecular markers) and evolutionary significance (expressed or non-neutral genetic markers; common garden experiments; life history traits; population growth rates). For details regarding population comparisons see table below. These six DUs display significant genetic differences, observed either with microsatellites and/or expressed single nucleotide polymorphisms consistent with significant isolation. Observed adaptive differences are strongest between DUs inhabiting water masses of contrasting water temperatures such as between the Southern DU and populations to the north or between the Northern Gulf DU and Newfoundland and Labrador DU. However, significance is also present through clear habitat discontinuities such as across the Laurentian Channel, or associated with the Arctic Lakes. Although data on the significance of the Arctic Marine DU is lacking, this DU displays the highest expressed genetic differentiation of any other marine Canadian cod population, and given its extreme habitat and evidence of genetic affinities of fish from NAFO 0A to the eastern Atlantic, the evidence for significance seems strong. It should also be noted that the coastal population of cod inhabiting Gilbert Bay, Labrador also displays excessively high genetic differentiation consistent with strong isolation. However, at present, data on the significance of this population are lacking, and as these coastal populations are found elsewhere (e.g., Holyrood Pond, NL), it seems at present it does not fit the DU criteria. Admittedly, the visible isolation presents a clear conservation priority and its DU status may change with additional life history information.

Summary of the evidence for genetic differentiation among the Newfoundland & Labrador, Laurentian North, Laurentian South and Southern DUs based on studies of selectively neutral loci and selectively important traits.

Designatable Unit	Laurentian North	Laurentian South	Southern
Newfoundland & Labrador	1. Seven microsatellite loci and pantophysin locus (Beacham *et al*. 2002) 2. Five microsatellite loci (Ruzzante *et al*. 1998) 3. Six microsatellite loci (Ruzzante *et al*. 2000) 4. Larval growth and survival (Hutchings *et al*. 2007) **5.** Morphological divergence (Marcil *et al*. 2006a)	1. Larval growth and survival (Hutchings *et al*. 2007) 2. Morphological divergence (Marcil *et al*. 2006a) 3. Six microsatellite loci (Bentzen *et al*. 1996) 4. Seventeen nuclear restriction-fragment-length-polymorphism (RFLP) loci (Pogson *et al*. 1995) 5. Ten nuclear restriction-fragment-length-polymorphism (RFLP) loci (Pogson *et al*. 2001) 6. Six microsatellite loci (Ruzzante *et al*. 2000) 7. Influence of light on survival and growth (Puvanendran and Brown 1998).	1. Five microsatellite loci (Ruzzante *et al*. 1998) 2. Morphological divergence (Marcil *et al*. 2006a,b) 3. Single nucleotide polymorphisms (n=1641) Bradbury *et al*. submitted.
Laurentian North	NA	1. Five microsatellite loci (Ruzzante *et al*. 1998) 2. Morphological divergence (Marcil *et al*. 2006a)	1. Six microsatellite loci (Ruzzante *et al*. 2000) 2. Five microsatellite loci (Ruzzante *et al*. 1998) 3. Larval growth and survival (Hutchings *et al*. 2007) 4. Morphological divergence (Marcil *et al*. 2006a) 5. Single nucleotide polymorphisms (n=1641) Bradbury *et al*. submitted. 6. Larval growth rate (Purchase and Brown 2000) and juvenile food conversion efficiency (Purchase and Brown 2001)
Laurentian South	NA	NA	1. Five microsatellite loci (Ruzzante *et al*. 1998) 2. Larval growth and survival (Hutchings *et al*. 2007) 3. Morphological divergence (Marcil *et al*. 2006a) 4. Single nucleotide polymorphisms (n=1641) Bradbury *et al*. submitted.

DISTRIBUTION

Global range

Atlantic Cod inhabit all waters overlying the continental shelves of the Northwest and the Northeast Atlantic Ocean. In the west, cod extend from waters just south of Georges Bank northward to Baffin Island, Nunavut, Canada (Figure 2). In the Northeast Atlantic, cod range from the North Sea northward through the Norwegian Sea to the Barents Sea off Norway and northern Russia. Cod are also found in abundance in the Skaggerak and Kattegat, the strait separating Norway and Sweden from Denmark, and in the southern parts of the Baltic Sea. On a global scale, the historical distribution of cod probably differs relatively little from that of its present distribution (Bigg *et al*. 2007).

Canadian range

In Canadian waters, Atlantic Cod are found contiguously along the east coast from Georges Bank and the Bay of Fundy in the south, northward along the Scotian Shelf, throughout the Gulf of St. Lawrence, around the island of Newfoundland, and finally along the east coasts of Labrador and Baffin Island, Nunavut (Figures 2, 6, 7). There are also three landlocked populations of Atlantic Cod on Baffin Island (McLaren 1967; Patriquin 1967; Hardie *et al*. 2006, 2008). Outside Canadian waters, cod can be found on the northeast and southeast tips of Grand Bank and on Flemish Cap, lying immediately northeast of Grand Bank.

In addition to these offshore waters (typically at depths less than 500 metres), cod can also be found throughout the coastal, inshore waters of Atlantic Canada. The best-studied of these is probably the small, resident Gilbert Bay population in southern Labrador (Green and Wroblewski 2000; Morris and Green 2002), a population that is geographically and genetically distinct from cod inhabiting the offshore waters in this area (Ruzzante *et al*. 2000; Beacham *et al*. 2002). A similar scenario of isolation has been noted in Holyrood Pond, Newfoundland (Bradbury *et al*. 2009). Local ecological knowledge, based on interviews with fishermen conducted by the Fisheries and Oceans Canada in concert with the Fishermen and Scientists Research Society in the Maritimes, suggests that local, inshore spawning aggregations of cod along coastal Nova Scotia were fewer in number in the late 1990s compared to earlier years.

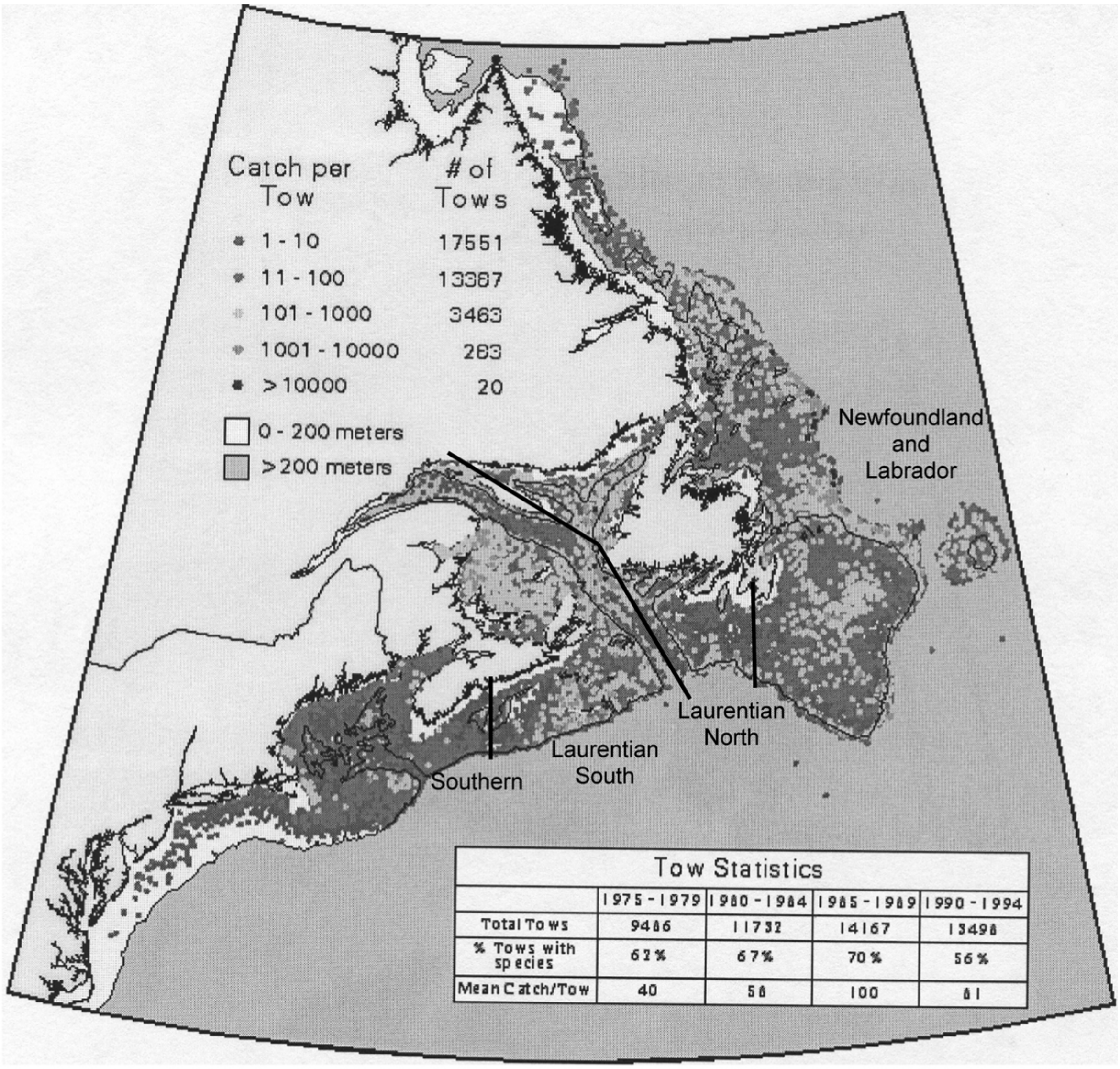

Figure 6. Distribution of Atlantic Cod in North America from the southern extreme of the species' range to northern Labrador, as determined from fisheries-independent surveys conducted by the Canadian Department of Fisheries and Oceans and the National Marine Fisheries Service in the United States. Dots represent survey catch rate data from 1975 to 1994. Solid lines mark DU boundaries. Arctic DUs not shown.

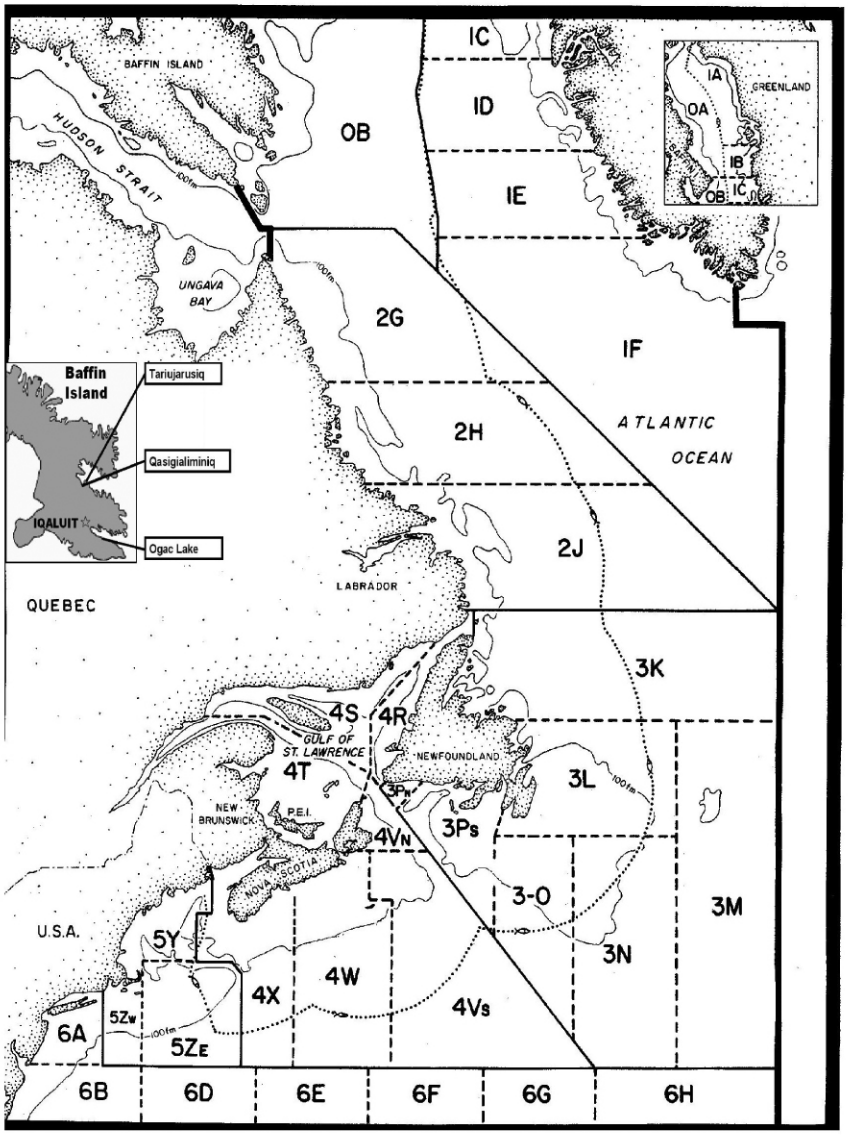

Figure 7. Map showing the NAFO (Northwest Atlantic Fisheries Organization) Divisions used to identify stocks of Atlantic Cod managed by NAFO and Fisheries and Oceans Canada. The insert on the left side of the map shows the location of the three Arctic lakes that constitute the Arctic Lakes DU. The Arctic Marine DU includes NAFO 0A and 0B. The Newfoundland and Labrador DU includes NAFO 2GHJ and 3KLNO. The Laurentian North DU includes NAFO 3P and 4RS. The Laurentian South DU includes NAFO 4TVW. The Southern DU includes NAFO 4X and the Canadian portions of Divisions NAFO 5Y and 5Z.

The extent of occurrence of Atlantic Cod in Canadian waters is probably on the order of 1.1 million square kilometres, an area larger than that of Ontario, and an area slightly smaller than to that of Quebec. The extent of occurrence has either remained stable over the past four decades (and earlier) or it has declined. Estimates of the extent of occurrence of the individual DUs are provided in the following sections.

HABITAT

Habitat requirements

Knowledge of the habitat requirements of Atlantic Cod is rather poor. Despite the paucity of data, it is reasonable to predict that habitat requirements change significantly with age in this species. With the exception of the few cod that have been observed in situ, the following information is based on the sampling of cod at various life stages from different depths and different areas of the ocean. Also the broad-scale habitat requirements may change with specific migratory life history which seems to correlate with abundance (Robichaud and Rose 2004). Small resident non-migratory populations may exist in inshore bays and likely complete their life cycle in a restricted geographic area (Bradbury *et al*. 2008) and hence have very different habitat requirements in comparison to migratory populations.

During the first few weeks of life, cod exist as eggs, and then as larvae, in the upper 10 to 50 metres of the ocean. The primary factors affecting habitat suitability for cod during these early stages of life are probably food availability and temperature (the lower the temperature, the longer the development time, and the longer the period of time during which cod are at sizes that make them highly vulnerable to predation and advection). As such, oceanographic features which retain and concentrate cod eggs and larvae as well as potential prey are likely important to early life history survival (e.g., Bradbury *et al*. 2000, 2002, 2008).

The most essential physical habitat characteristics for Atlantic Cod may be those required during the juvenile stage when cod have settled to the bottom for the first 1 to 4 years of their lives. Several studies suggest that a heterogeneous habitat, notably in the form of vertical structures, such as Eelgrass, *Zostera marina*, in nearshore waters, is favoured by juvenile cod (e.g., Gotceitas *et al*. 1995, 1997; Tupper and Boutilier 1995; Gregory and Anderson 1997; Laurel *et al*. 2003a,b, 2004). Based on observational studies (Tupper and Boutilier 1995) and on experimental manipulations (Gotceitas *et al*. 1995; Linehan *et al*. 2001; Laurel *et al*. 2003a, b), physically heterogeneous habitat appears advantageous to juvenile cod because it reduces the risk of predation and may allow for increased growth. As such, other habitats such as macroalgae (Keats 1990), obble (Gotceitas *et al*. 1995; Tupper and Boutilier 1995) and deep-water emergent structures (Lindholm *et al*. 2007) may also be important.

Offshore, it is logical to assume that physical structure would also reduce predator-induced mortality of juvenile cod. For example, video recorded on a submersible during an August 2001, survey of deep, continental-slope waters off southwestern Nova Scotia revealed juvenile cod amongst the extensive growths of deep-sea corals (Anna Metaxas, pers. comm., Department of Oceanography, Dalhousie University, Halifax, Nova Scotia).

As cod grow older, it appears as though their habitat requirements become increasingly diverse. Indeed, it is not clear that older cod have particular depth or bottom-substrate requirements. The primary factors affecting the distribution and habitat of older cod are probably temperature and food supply. In a general sense, it appears that cod tend to avoid cold temperatures. But what is cold for cod in one area is evidently not cold for cod in other areas. For example, it is widely believed that cod migrate out of the southern Gulf of St. Lawrence in autumn to avoid the cold water temperatures in the Gulf during winter (Campana *et al*. 1999). However, cod off eastern Newfoundland, notably those that overwinter in inshore waters, exist at temperatures below 0^{o}C (Goddard *et al*. 1999). Perhaps the most reasonable explanation for these apparent differences in water temperature tolerance is that cod in different areas are adapted to their local environments. This conclusion is supported by the finding that cod in different areas of coastal Newfoundland possess different levels of antifreeze protein (see Physiology section below), a physiological adaptation that would influence the tolerance of cod to low water temperatures.

From a spawning perspective, it is not known if cod have specific habitat requirements. Cod spawn in waters ranging from tens (Smedbol and Wroblewski 1997, Morris and Green 2002) to hundreds of metres in depth (Hutchings *et al*. 1993; Bradbury *et al*. 2000; 2008). Atlantic Cod in Canadian waters are known to spawn extensively throughout the inshore, nearshore, and offshore waters (McKenzie 1940; Scott and Scott 1988; Hutchings *et al*. 1993; Morgan and Trippel 1996), a conclusion also supported by fishermen (Neis *et al*. 1999). Although cod spawning appears to be associated with the bottom (Morgan and Trippel 1996; Hutchings *et al*. 1999), this may have more to do with the cod mating system (a lek mating system has been hypothesized; Hutchings *et al*. 1999; Nordeide and Folstad 2000; Windle and Rose 2007) rather than any physical requirements for the offspring, given that cod neither build egg nests nor provide parental care. Perhaps the factor most beneficial to the survival of their offspring is the presence of physical oceanographic features (e.g., water currents) that would serve to entrain the buoyant eggs and prevent them from being dispersed to waters poorly suited to larval cod, e.g., waters off the continental shelf. It is highly unlikely that spawning habitat is limiting for Atlantic Cod.

Thus, the habitat most likely to be potentially limiting for Atlantic Cod may well be the vertical, “three-dimensional” structures provided by plants, rocks, physical relief, and corals. In addition to providing protection from predators, such physical heterogeneity would almost certainly provide habitat for small fish and invertebrates, organisms upon which juvenile cod could feed.

Trends

If physical structure is critically important to the survival of juvenile cod, notably in the form of plants, bottom physical relief, and corals, there may be less habitat available today than decades ago in some parts of the range of this species. Repeated trawling in a given area tends to “smooth” and flatten the bottom, reducing vertical and physical heterogeneity (Collie *et al*. 1997, 2000; Kaiser and de Groot 2000). Any reduction in physical heterogeneity on the bottom since the 1960s if present may be attributed to the increased use of bottom-trawling gear to catch groundfish such as cod, Haddock, Pollock, and several species of flatfish. The destruction of deep-dwelling corals off Nova Scotia—first reported and well-documented by fishermen—is another product of bottom-trawling and, to a considerably lesser degree, long-lining (Mortensen *et al*. 2005). Although physically heterogeneous areas frequented by juvenile cod may not have been heavily trawled where gear damage or loss was likely, no studies have been undertaken to evaluate the effects of trawling on the quantity and quality of juvenile cod habitat. Trawling in many areas has been substantially reduced following the ground fish collapse of the early 1990s. In addition to trawling effects, the recent discovery of Green Crab (*Carcinus maenas*) in Placentia Bay, Newfoundland, and their well documented negative impact on eelgrass beds (e.g., Davis *et al*. 2002), may present a significant threat to juvenile cod habitat and survival. The magnitude of the threat of Green Crab to juvenile cod habitat remains unknown and requires further evaluation.

BIOLOGY

General

Despite having been fished for more than 500 years in Canadian waters, there remain large gaps in our knowledge of many of the most basic elements of the biology and ecology of this species. Nonetheless, it is known that after hatching, a period of time that takes approximately 60 degree-days, the larvae obtain nourishment from a yolk sac for a few days. During the larval stage, the young feed on phytoplankton and small zooplankton in the upper 10 to 50 metres of the water column. After a few weeks, the larvae swim, or “settle”, to the bottom, where they appear to remain for a period of 1 to 4 years throughout most of the species’ Canadian range. These settlement areas are known to range from very shallow (< 10 m to 30 m) coastal waters to moderately deep (50 to 150 m) waters on offshore banks and almost certainly provide larval and juvenile cod protection from predators as well as potential prey. After this settlement period, it is believed that the fish begin to undertake the often-seasonal movements (apparently undirected swimming in coastal waters) and migrations (directed movements to and from specific, highly predictable locations) characteristic of adults (e.g., Cote *et al*. 2001; 2004).

Reproduction: Life history variation

The life history of cod varies a great deal (Myers *et al*. 1996; McIntyre and Hutchings 2003, Olsen *et al*. 2005, 2008). Most life history traits, such as age and size at maturity, longevity, and size-specific fecundity differ greatly among populations, while some, such as egg size, appear to be similar throughout the species’ range. As with most indeterminately growing organisms (those that continue to increase in size after maturity), fecundity (the number of eggs per female per breeding season) increases with body size. In cod, as with most fish, the number of eggs per female generally increases with body mass as a power function. Body size at a given age is a function of growth rate, a parameter that varies greatly among cod populations, being relatively slow in the north and fast in the south. In turn, growth rate of cod is a function of temperature, food supply, density, and the proportional allocation of energy to reproduction.

In the relatively warm waters at the southern end of its Canadian range (Georges Bank, off the state of Maine) and in the Bay of Fundy, cod commonly attain maturity at 2 to 3 years of age (Trippel *et al*. 1997; McIntyre and Hutchings 2003). By contrast, cod inhabiting the Northeast Newfoundland Shelf, eastern Labrador, and the Barents Sea reproduce for the first time between ages 5 and 7 yr (Myers *et al*. 1997b; Smedbol *et al*. 2002). One consequence of these population differences in age at maturity is population variation in generation time. However, when providing an estimate of generation time, one needs to be cognizant of the fact that generation time has almost certainly changed over time for Atlantic Cod. This can be attributed to reductions in age at maturity in some populations (Trippel *et al*. 1997; Olsen *et al*. 2004, 2005) and to reductions in longevity. For example, in the early 1960s, it is estimated that more than 50% of the eggs produced by Newfoundland's northern cod stock were produced by females 10 years of age and older (Hutchings and Myers 1994). By the late 1980s, this age class is estimated to have contributed less than 10% of the eggs. In the late 1990s females older than age 10 were not sampled by DFO surveys of the northern cod stock (Lilly *et al*. 2001), and in 2007 these individuals are still very rare (<0.01% of sampled individuals; Worcester *et al*. 2009).

Size at maturity can also differ significantly among cod populations. On average, length at maturity typically ranges between 45 and 55 cm. Smaller sizes at maturity have been reported in recent years for Eastern Scotian Shelf cod (33-37 cm; Paul Fanning, DFO, Bedford, NS, pers. comm.) and for cod in the genetically isolated population inhabiting Gilbert Bay, Labrador (31-42 cm; Morris and Green 2002). The number of eggs produced by a single female in a single breeding season typically ranges from between 300,000 and 500,000 at maturity to several million for females greater than 75 cm in length. There is recent evidence that size-specific fecundity, that is, the number of eggs produced per unit of body mass, differs significantly among cod populations in the Northwest Atlantic and within populations over time (McIntyre and Hutchings 2003; Fudge and Rose 2008).

Reproduction: Spawning behaviour

Atlantic Cod typically spawn over a period of less than three months (Brander 1994; Chambers and Waiwood 1996; Kjesbu *et al*. 1996) and spawning events occur at water depths of tens (Smedbol and Wroblewski 1997) to hundreds of metres (Brander 1994; Morgan *et al*. 1997). Nonetheless, early stage cod eggs can be sampled in the waters off Newfoundland from April to October and back-calculated spawning dates from juvenile otoliths suggest protracted spawning may be common (Pinsent and Methven 1997, Bradbury *et al*. 2001). Although individuals are assumed to breed annually, there is strong evidence that a large portion of individuals may skip years (~18%) and this may vary by region and condition (1-33%, Rideout *et al*. 2006). Atlantic Cod are described as batch spawners because only 5 to 25% of a female's egg complement is released at any given time during her spawning period (Chambers and Waiwood 1996; Kjesbu *et al*. 1996). Spawning intervals of 2 to 6 days appear typical of individual females held in captivity (Kjesbu 1989; Chambers and Waiwood 1996; Kjesbu *et al*. 1996).

Successful reproduction in Atlantic Cod involves a complex repertoire of behaviours within and between sexes (Brawn 1961; Hutchings *et al*. 1999). The behaviour that immediately precedes the release of sperm and eggs was initially documented at nineteenth century Atlantic Cod hatcheries in Newfoundland (Templeman 1958) and Norway (Dannevig 1930). These observations, and those of Brawn (1961), describe a “ventral mount” in which the male, while grasping the female with his pelvic fins and matching her swimming speed, positions himself beneath the female with the urogenital openings of both fish opposite one another. Spawning male cod appear to establish a dominance hierarchy, with rank determined by aggressive interactions, particularly chases of one male by another, and possibly by body size, larger individuals often being dominant over smaller individuals. Agonistic interactions, continuing through the spawning season, may allow high-ranking males to defend territories. Genetic data suggest that male fertilisation success increases with male body size and/or behavioural dominance (Hutchings *et al*. 1999), that eggs from a single reproductive bout can be fertilized by more than one male (Hutchings *et al*. 1999; Rakitin *et al*. 2001), and that reproductive success increases with number of males contributing (Rowe *et al*. 2004). Hutchings *et al*. (1999) hypothesized that females may be choosing males on the basis of the sounds produced by male gadids during spawning (Brawn 1961; Hawkins and Amorim 2000; Nordeide and Folstad 2000). In cod, acoustic communication is facilitated by drumming muscles whose rapid vibrations against the air bladder are capable of producing low-frequency sounds audible to other cod. It now seems clear that greater reproductive success is associated with size-selective mating (Rowe and Hutchings 2006, Rowe *et al*. 2007, 2008), and the production of sound may be a cue for body size. As such, the mass of the drumming muscles has been shown to correlate with body size in males and develop during the spawning season (Rowe *et al*. 2004, 2008).

Survival

The high fecundity of Atlantic Cod (ranging from several hundred thousand to several million eggs per female per breeding season) represents a life history strategy allowing them to forgo parental care or the protection of a nest and release their eggs directly into the water column. This strategy of maximizing the production of eggs rather than the size of eggs has been interpreted as an adaptive response to environments in which egg size confers no consistent inter-generational advantage to survival in early life (Hutchings 1997). Based on estimates of fecundity, weight-at-age, and age-specific abundance of northern cod, Hutchings (1999) estimated that survival from birth until the age of 3 yr averaged 1.13×10^{-6}, or approximately one in one million, for the cohorts of cod born from 1962 to 1988. Between the ages at which cod first become vulnerable, or are recruited, to the commercial fishery (varying between 1 and 3 yr for Canadian stocks of cod, being younger in the south) and the age at death, the annual natural mortality probability of cod, independent of age and size, has been estimated to be 18% (Pinhorn 1975). Although recent evidence from catch-at-age analysis and tagging suggests higher values of Z in several Canadian cod stocks (Worcester *et al*. 2009), estimates based on recent catch-at-age analysis for Canadian stocks indicate total mortality (Z) has ranged from 0.35 to 1.42 representing annual losses of 30% to 76% depending on the area (see Table A2). In fact, in many areas where fishing pressure is negligible, Z remains high (>0.70) indicating that natural mortality is unusually high in these areas.

Prior to the closure of most fisheries to targeted or directed fishing in the early 1990s (July 1992, for northern cod; January 1994, for northern Gulf cod; September 1993, for all other stocks except Western Scotian Shelf/Bay of Fundy cod and Georges Bank cod, neither of which ever closed), fishing was the dominant source of mortality for Atlantic Cod. At one extreme, it is estimated that fishing removed annually more than 70% of Newfoundland's northern cod available to be caught in the late 1980s and early 1990s (Baird *et al*. 1992; Hutchings and Myers 1994). Fishing remains a primary source of mortality in parts of the Newfoundland & Labrador, Laurentian North, and Southern DUs (Worcester *et al*. 2009). In some areas (eastern Scotian Shelf and southern Gulf of St. Lawrence), the bulk of mortality experienced by Atlantic Cod, at all life stages, is attributed primarily to natural sources (e.g., predation by fish, marine mammals, invertebrates and birds (Bundy *et al*. 2000; DFO 2009e)). Nonetheless, fishing still remains a sizable source of mortality in many areas, a result of directed fishing quotas and bycatches (Shelton *et al*. 2006, Worcester *et al*. 2009). The impact of continued fishing pressure has undoubtedly been to delay and prevent recovery for some cod populations (Shelton *et al*. 2006; Worcester *et al*. 2009) providing clear evidence that small quotas can negatively affect the recovery of fish stocks when the stocks themselves are at historically small sizes (see LIMITING FACTORS AND THREATS).

Physiology

From a physiological perspective, the environmental variable of greatest import to Atlantic Cod is probably water temperature. It has been suggested that cod will actively avoid waters deemed to be low in temperature. For example, avoidance of cold water is the primary reason given for the autumnal migration of cod out of the Southern Gulf of St. Lawrence to the northeast waters off Cape Breton (Campana *et al*. 1999). And there is a sound empirical basis for believing that temperature selection by cod should be density-dependent, with the optimal temperature for growth declining as food ration declines (Swain and Kramer 1995).

Although cod are generally found in waters ranging in average annual temperature from 2 to 11^{o} C (Brander 1994), it is clear that cod in some areas off Newfoundland are able to withstand temperatures as low as -1.5^{o} C (Goddard *et al*. 1999). This temperature is below that (-0.5 to -0.8^{o} C) at which ice crystals form in the blood. Cod are able to withstand such cold waters, and to prevent the formation of ice crystals in the blood, by producing plasma antifreeze proteins or glycoproteins (AFGPs) that improve freeze resistance. Interestingly, there appears to be an effect of size and/or age on the ability of cod to withstand sub-zero-degree waters. For example, Goddard and Fletcher (1994) reported that juvenile cod (10-40 cm) produce approximately twice as much AFGP as adult cod.

Some of the best evidence that Atlantic Cod are adapted to local environments at scales considerably smaller than those corresponding to the NAFO Divisions is physiological in nature. In a common garden experiment in which all individuals were reared under the same environmental conditions, Goddard *et al*. (1999) reported that juvenile cod from the northernmost part of Division 3K (Northern Peninsula, Newfoundland) develop antifreeze protein levels approximately 50% higher than cod located further south in Notre Dame, Trinity, and Conception Bays. The authors attributed these physiological differences in antifreeze production to population differences in water temperatures experienced during winter. Further evidence for a physiological basis for cold adaptation in cod comes from a recent genome scan of expressed DNA polymorphisms. Bradbury *et al*. (submitted) scanned 1640 polymorphisms from expressed DNA sequences and found a number of genes which are highly correlated to ambient water temperature across the entire range of the species displaying parallel trends on either side of the Atlantic. Spatial variation in these genes suggests adaptive differences at scales of ~500 km consistent with previous common garden experiments. However, similar trends have been observed by Anderson *et al*. (2009) who document two hemoglobin polymorphisms in cod which affect temperature-dependent oxygen binding properties and show spatial variation associated with ambient temperature. Given the strong evidence for temperature based physiological adaptation in cod, the potential for contemporary rescue from neighbouring regions or differing thermal regimes (such as Newfoundland's south and north coast) and the detrimental influence climate change may have on some cod populations requires future examination.

Movements/dispersal

Dispersal potential in Atlantic Cod appears to be highest in the egg and larval phases of life, during which surface and near-surface water currents and turbulence are the primary determinants of horizontal and vertical displacement in the water column. For some cod populations, eggs and larvae are capable of dispersing very long distances. For example, based on the movement of satellite-tracked drifter buoys, Helbig *et al*. (1992) and Pepin and Helbig (1997) concluded that eggs spawned off south-eastern Labrador (NAFO 2J) disperse as far south as Grand Bank. By contrast, eggs spawned by cod in inshore coastal waters, especially at the heads of large bays, may experience dispersal distances of a few kilometres or less (Bradbury *et al*. 2000, 2002, 2008). Surveys for cod eggs, larvae and juveniles in Placentia Bay, Newfoundland document a clear signature of decay with distance from an inshore spawning ground across life stages suggesting dispersal distances of less than 100 km for pelagic eggs and larvae (Bradbury *et al*. 2008). For settled juvenile cod, dispersal rates from an eelgrass area of c. 13,000 m2 was calculated to be 17% d–1 (Laurel *et al*. 2004) and similar calculations by Tupper and Boutilier (1995) were even less for post-settled age 0 cod. Sonic telemetry studies by Cote *et al*. (2004) have shown that 2-3 yr old juvenile cod home ranges during summer months averaged 2-3 ha; up to 30% of fish tracked had maintained these ranges year round.

Seasonal movements by mature cod can often be attributed to geographical and seasonal differences in water temperature, food supply, and possibly spawning grounds. At one extreme, some inshore populations are suspected to have extremely short migrations, possibly limited to tens of kilometres, or less, in distance. In fact, resident populations account for 44% of all identified cod populations (Robichaud and Rose 2004). By contrast, cod in other populations are known to traverse hundreds of kilometres during their seasonal migrations. Examples of long-distance seasonal migrations are those undertaken by cod in the Southern Gulf of St. Lawrence and on the Northeast Newfoundland Shelf. The former overwinter off northeast Cape Breton, migrating into the southern Gulf in April, where they spend the summer months feeding and spawning, before returning to the deep, relatively warm waters off Cape Breton in November. Many Northeast Newfoundland Shelf cod migrate from the relatively warm offshore waters to inshore coastal waters in spring to feed primarily on Capelin (Mallotus villosus) before returning offshore in autumn.

Movements by Atlantic Cod can be inferred from multiple data sources such as mark-recapture experiments, genetic analyses, otolith micro-chemistry, and variation in vertebral counts. Between 1954 and 1993, a total of 205,422 cod were tagged in Newfoundland waters and released; 36,344 of these fish were recaptured by fishermen (Taggart *et al*. 1995). Although exceedingly rare (5 of 36,344 recaptures), some cod tagged in Newfoundland waters have been recaptured in the Northeast Atlantic, although no such recaptures have been reported since the 1960s (Taggart *et al*. 1995). Based on this exhaustive set of tagging studies, coupled with those conducted more recently (Hunt *et al*. 1999; Brattey *et al*. 2001b, Brattey *et al*. 2008a), one can conclude that, with one exception, cod tend to be recaptured in the NAFO Management Area (as defined by the Divisions given in Figure 7) in which they were initially tagged. The one area in which movement appears to be relatively extensive is that encompassing NAFO 3Ps, 3N, 3O, and 3L along the southeastern coast of Newfoundland and including Grand Bank. However, tagging work suggests straying from NAFO 3Ps into NAFO 3L is restricted to southern 3L and there appears limited overlap in spatial distribution of tag returns. Moreover, telemetry-based studies of homing in cod suggest strong multiyear site fidelity, suggesting straying associated with extensive migrations may be low (Green and Wroblewski 2000; Cote *et al*. 2001; Windle and Rose 2005; Brattey *et al*. 2008a). For example, Brattey *et al*. (2008a) document annual rates of homing to Smith Sound Trinity Bay ranging from 65-100%.

Irrespective of method used, estimates of dispersal are consistent with the hypothesis that these cod exist as separate populations in the Northwest Atlantic (Bentzen *et al*. 1996; Ruzzante *et al*. 1998; Campana *et al*. 1999; Beacham *et al*. 2002; Bradbury *et al*. in press). In fact, the emerging consensus from adult tagging data (Figure 4A), genetic differentiation and isolation by distance (Figure 4C), life history variation (Figure 3) and demographic correlation is that distinct cod populations exist on scales of <500 km suggesting a limit to effective dispersal in this species. Moreover, in the presence of physical barriers to movement or hydrographic transport, significantly smaller-scale structure and strong isolation may be present such as in Gilbert Bay or the Arctic lakes (e.g., Morris and Green 2002; Hardie *et al*. 2006).

Nutrition and interspecific interactions

As larvae, they feed primarily on zooplankton (copepods and amphipods). As cod grow, they tend to feed on larger and larger prey. Immediately after the larval stage, small crustaceans, mysid shrimp, and euphausiids feature prominently in the cod diet. Once their gape is large enough, cod begin feeding on fish, including other cod (Scott and Scott 1988; Bogstad *et al*. 1994). Fish that have been recorded in cod stomachs have included the following: Capelin, Sand Lance (*Ammodytes americanus*), Herring (*Clupea harengus*), Redfish (*Sebastes* sp.), Arctic Cod (*Boreogadus saidus*), Cunners (*Tautogolabrus adspersus*), Alewives (*Alosa pseudoharengus*), Haddock (*Melanogrammus aeglefinus*), Winter Flounder (*Pseudopleuronectes americanus*), Mackerel (*Scomber scombrus*), Shannies (*Lumpenus maculatus*, *Stichaeus punctatus* and *Ulvaria subbifurcata*), Silversides (*Menidia menidia*), and Sculpins (*Cottus* sp.). In addition to fish, adult cod will also consume Squid, Crabs, Shrimp, Mussels, Clams, Whelks, Tunicates, Comb Jellies, Brittle Stars, Sand Dollars, Sea Cucumbers, and polychaetes.

Although studies are few, it is clear, given the wide variety of prey consumed by cod, that to varying degrees cod compete with other species for their food. There is no firm evidence that food availability is a limiting factor affecting the recovery of this species in Canadian waters, particularly given the historically low levels of abundance at which the species exists throughout much of its range. However, it is difficult to assess the degree to which capelin may or may not be limiting the recovery of cod in the Newfoundland & Labrador DU. Nonetheless, it has been hypothesized that one of the primary sources of food for adult cod in the Newfoundland & Labrador DU, capelin, may be limiting in northern areas (Rose and O'Driscoll 2002), thus affecting recovery.

Behaviour/adaptability

Atlantic Cod are generalists. Given that cod almost certainly exist as more than one evolutionarily significant unit in Canada, reflected to some degree by the populations proposed here, it would be reasonable to predict that cod populations respond differently to anthropogenic influences, the most obvious (and best-studied) being fishing. Such differential population responses may be reflected by differential responses to population collapse and fishery closures. For example, despite their close proximity, and reasonably higher interchange of individuals (Worcester *et al*. 2009), the St. Pierre Bank population in the Laurentian North DU recovered relatively rapidly while the adjacent Newfoundland and Labrador DU has shown little sign of recovery until recent years (see POPULATION SIZES AND TRENDS below).

The fact that anthropogenic influences may result in large adaptive or evolutionary changes in cod seems unequivocal. Several examples now exist of declines in both age and size at maturity in several cod stocks associated with dramatic stock collapses (Olsen *et al*. 2004, Hutchings 2004). In addition to selection for size or growth rate, the potential exists for strong selection associated with global climate change. Bradbury *et al*. (submitted) have documented molecular evidence for local adaptation associated with temperature on scales of 500-1000 km throughout the North Atlantic. How local populations will respond to small changes in ocean temperature seems unclear but the potential for strong temperature-based selection in northern cold regions seems likely.

POPULATION SIZES AND TRENDS

Estimates of the size of the breeding portion of the population for Atlantic Cod are available from two sources. One source of estimates is derived from Virtual Population Analysis (VPA), an analysis reliant on commercial fishery catch data, an index of population abundance over time, and various assumptions concerning the magnitude of natural, or non-fishing, mortality. VPAs provide estimates of the proportional representation of mature fish by applying proportions mature at age to estimates of numbers alive at age. The second means of estimating the size of Atlantic Cod breeding populations is to use the catch rates of cod of reproductive age as determined from the annual research surveys conducted by the Fisheries and Oceans Canada (DFO). All survey data have been provided by Fisheries and Oceans Canada and were adjusted to consistent units when there were changes in fishing gear (e.g. when the Campelen trawl was introduced).

Population trends were estimated using both VPA and research vessel survey results. The primary utility of VPA estimates of abundance is that they smooth out year effects (error) in the survey indices and allow one to express breeding population size in the same units (numbers of individuals) for each stock or population. The main weaknesses associated with VPA estimates of abundance are that they rely upon accurate reporting of commercial catch data, they do not account for the illegal practices of discarding and catch misreporting, and they depend upon reliable estimates of mortality due to natural causes. At present, many stocks do not have accepted or working VPAs. Research survey estimates of the size of the breeding population are obtained from a stratified random sampling design that attempts to cover the geographical area of each stock. Thus, they do not depend upon the validity of assumptions concerning natural mortality and the accuracy of commercial fishery data. Nonetheless, considerable differences can occur among the surveys in terms of their catchability, i.e. the proportion of the true population size represented by the survey index. This is caused by differences in survey coverage, trawl gear effects, fishing vessel effects, and differences in fish behaviour. The approach implemented here acknowledges the limitations of each data source and that it is the long-term trends in abundance which are of interest.

For the trends described below, the ages of mature / breeding fish in each DU were $\geq$ 5.0 yr for all stocks, except $\geq$ 4.0 yr for Western Scotian Shelf/Bay of Fundy cod and $\geq$ 3 yr for Georges Bank cod. Generation time, as usually applied by COSEWIC (2009), is the average age of parents in the current cohort. However, COSEWIC notes that among species for which generation time varies under threat, generation time should be that estimated for the species during the pre-disturbance state. Generation time was calculated as the age at first reproduction + 1/*M*, where *M* is the instantaneous rate of mortality due to natural events, and age at first reproduction is approximated by the age at which 50% of the adults are mature. *M* is thought to be 0.2 for cod in an unfished state (Smedbol *et al*. 2002). The rate of decline was estimated from the slope of the linear regression of $\log_e$ abundance (N_t) versus time (t, in years) following COSEWIC (2003). The resulting regression equation is $\ln(N_t) = \alpha + \beta*t$. The percentage decline over y years can be calculated as $(1-\exp(\beta*y))*100$.

The DFO has estimated area of occupancy for each of the stocks it manages in two ways (Worcester *et al*. 2009). One, called the design-weighted area of occupancy, or DWAO, most closely approximates the definition of area of occupancy used by COSEWIC. The second is defined as the minimum area containing 95% of the cod, or D_{95}. Both indices are based on the fisheries-independent research survey data collected annually by the DFO. Because of its concordance with COSEWIC's definition of area of occupancy, only the analyses of the DWAO data will be primarily reported. This status report recommends the identification of six DUs of Atlantic Cod which are detailed below.

<u>Arctic Lakes DU</u>

Cod in this DU inhabit three meromictic lakes (Ogac, Qasigialiminiq and Tariujarusiq Lakes) on south Baffin Island (Hardie 2007, Hardie *et al*. 2008). These lakes are characterized by physical barriers which restrict connectivity with the coastal environment (Hardie 2007) and result in high levels of genetic isolation from marine stocks and from each other (Hardie *et al*. 2006). The best-studied of these lake populations is that inhabiting Ogac Lake, a salt, meromictic lake on Baffin Island that receives influxes of seawater only during the highest summer tides (McLaren 1967; Patriquin 1967). Although no regular assessment is conducted of these lakes, a mark-recapture study conducted in 1957-1962 and a recent estimate of population size (2003-2004) in Ogac Lake suggest little change with the estimated number of individuals at 500 >60 cm and 10,000 >25 cm (Hardie *et al*. 2006, 2008). Life history data are sparse. Hardie (2007) suggests the size of 50% maturity is 36 cm (males) and 42 cm (females) and that age at maturity is 5 years (Hardie 2007, Table 5.6). The maximum size of cod captured in Ogac Lake in 1965 was 144 cm, and in 2003 Hardie *et al*. (2008) report the maximum length as 133 cm. Increased angling pressure has been identified as a concern by local inhabitants. Indeed, studies since the 1960s have remarked on the extraordinary ease with which large numbers of cod can be captured from these lakes. Moreover, given that genetic differentiation among these lakes is quite large, and exchange with each other and the coastal environment is rare, these populations are likely very susceptible to disturbance and unlikely to be rescued from neighbouring locations.

Indices **(Data from Hardie *et al*. 2008)**	**Lake**		
	Ogac	**Qasigialiminiq**	**Tariujarusiq**
Cod Abundance (kg hook-1 h-1)	2.5-57.0	1.5-5.0	0.5-5.0
Mean TL (cm)	59	52	53
Max TL (cm)	133	82	111
Mean Fulton's	0.75	0.72	0.69
Number sampled	103	106	92

Arctic Marine DU

Cod are present in the Arctic marine waters (NAFO 0A, 0B), although little is known about cod in this area. Research surveys in these divisions are infrequent and those that have been undertaken have usually targeted Shrimp (*Pandalus sp*), or Greenland Halibut (*Reinhardtius hippoglossoides*). Depth-stratified random surveys have been conducted by DFO in Div. 0A (1999, 2001, 2004 and 2006) and Div. 0B (2000 and 2001). In 0A, across the four years, only 16 cod were caught in total; and similarly in 0B, the two surveys caught only 2 fish total. In addition, the Northern Shrimp Research Foundation has conducted an exploratory survey since 2005. Again, catches remain very low with average catches <0.5 cod per tow per survey. Finally, observer coverage of the shrimp fishery in this area again indicates slightly higher catches for the period 1984 to 2007 averaging 6.5 fish per tow. This number includes a period prior to 1997 before the Nordmore grate became mandatory which is characterized by significantly higher catches than in recent years. In total, less than 1000 kg of cod/yr have been caught in the shrimp fishery since 1998 (Worcester *et al*. 2009). In 2007, DFO conducted a multi-species survey in Hudson Strait, Canadian Shrimp Fishing Area 3 and in 2008 Div. 0A was surveyed; very few cod were caught in these surveys (DFO unpublished data).

The observation that cod in Arctic marine waters exist at very low densities is supported by other information. The Iqaluit Hunters and Trappers Organization reports that cod are absent from Frobisher Bay. Low densities of cod in Arctic marine waters is also suggested by McLaren's (1967) report that no cod were taken during surveys of Frobisher Bay by M/V *Calanus* in the 1950s. Given the limited spatial data, little is known regarding stock dynamics in the marine arctic cod. Cod in offshore areas of Division 0A have been caught very close to the boundary with Division 1 and may reflect an extension of stocks found within Greenland waters, and Atlantic Cod found in offshore areas of 0B may either reflect an extension of stocks found within subarea 1 (Greenland waters) or subarea 2GH (Canadian waters). Recent genetic data of 0A cod clearly clusters cod in this area with populations from the eastern Atlantic supporting affinities with subarea 1 and the stocks around Greenland and Iceland (Bradbury *et al*. submitted).

Survey	**Gear**	**Area Swept (km^2)**	**Average Depth (m)**	**Average catch (#/tow) (% stations with cod)**
2008 NSRF	Campelen	62.15	347.2	0.42 (17%)
2007 NSRF	Campelen	60.07	345.0	0.33 (16%)
2006 NSRF	Campelen	54.80	328.9	0.40 (12%)
2005 NSRF	Campelen	61.30	349.7	0.09 (5%)
2008 DFO 0A	Alfredo-03 / Cosmos 26	99.34	694.8	0.17 (5%)
2007 DFO SFA3	Cosmos 26	35.60	309.9	0.02 (2%)
2006 DFO 0A	Alfredo-03	49.95	841.37	0.32 (3%)
Shrimp Fishery 1984-2007	Shrimp Trawl	-	372	5.94

Newfoundland & Labrador DU

Cod in this DU combine the stocks identified for management purposes by DFO as: (1) Northern Labrador cod (NAFO 2GH; (2) "Northern" cod, i.e., those found off southeastern Labrador, the Northeast Newfoundland Shelf, and the northern half of Grand Bank (NAFO 2J3KL); and (3) Southern Grand Bank cod (NAFO 3NO). Temporal trends in abundance for each of these stocks are presented separately in Appendix 1. Generation time calculated from the means for each of its constituent stocks (Appendix 1), is estimated to be 11.0 yr for this DU, yielding a three-generation time period of 33 years. Abundance data represent the sum of the VPA estimates and the sum of RV estimated portion of mature population for each of the stocks included in this population (see Appendix 1 for calculation of stock-specific estimates). These data are included here for the purpose of estimating the three-generation rates of population decline only. Estimates of abundance for Northern Labrador cod are sparse and as such this stock is not included in estimates of the DU abundance decline rates, though the stock-specific decline rates are presented (Fig. A1). See Figure 8 for the three-generation decline trends and associated relationships.

Since the late 1990s, information on the status of much of the Newfoundland and Labrador DU (primarily NAFO 2J3KL) has been presented for the offshore and inshore separately as it became obvious these regions were displaying very different population dynamics (Worcester *et al*. 2009). Abundance trends and status in the offshore have been monitored by DFO research bottom-trawl surveys (Worcester *et al*. 2009) and hydro-acoustic surveys (Mello and Rose 2008), and abundance trends in the inshore have been monitored by hydro-acoustic surveys of cod in Smith Sound, Trinity Bay (Rose 2003), conducted by George Rose (Memorial University of Newfoundland) since 1995, and DFO-sponsored sentinel survey catch rate data obtained by fishermen. Acoustic estimates of Smith Sound biomass increased to a peak of about 26,000 t in 2001, declined to 18,000 t in 2004, were stable in 2006 at 16,500-18,500 t, and declined to 14,000 t in 2007 and to 7,200 t in 2008, the lowest in the time series. Low exploitation rates from tagging and high survival rates of telemetred cod suggest the decline is not solely due to the combined effects of fishing and natural mortality. The decline more likely reflects a redistribution of some over-wintering cod to other inshore areas or to the offshore (DFO 2009a). Assuming an average weight of 2 kg, the Smith Sound aggregation in winter 2007 (14,000 t) would equate to about 7 million cod, the majority of which appear to be mature. Sentinel surveys for cod were conducted by fishing enterprises operating from many communities in the nearshore of Div. 2J, 3K and 3L at various times during summer and autumn from 1995 onwards (Lilly *et al*. 2006; Maddock-Parsons and Stead 2008). Overall the sentinel survey data indicate that catch rate indices in the inshore have generally increased in recent years based on the 5½ inch mesh gillnet catch rate indices. Nonetheless, in comparison to historic levels of abundance in the offshore, the inshore represents a very small portion of the total DU with peak values from Smith Sound in 2001 representing approximately 1%.

Abundance in the offshore has remained extremely low in recent years (range 21.8 million to 75 million from 1994 to 2003); however, an increasing trend is present during 2003-2007, visible both through the RV survey and a hydro-acoustic survey (Figure 8). It is worth noting that this increasing trend since 2003 is driven by 2J3KL, and no increase has been observed in 3NO. Moreover, despite the fact that the value in 2007 is the highest since 1992, the RV abundance index during 2005-2007 is approximately 6-7% of the 1980s average. In addition to the DFO RV survey, a dedicated hydro-acoustic / bottom trawl survey was conducted in the Newfoundland offshore during winter 2007 (Mello and Rose 2008). Cod were highly aggregated at both Bonavista Corridor (NAFO 3KL) and Hawke Channel (NAFO 2J). Sampling on aggregations indicated these fish were predominantly immature. Biomass estimates (using acoustic data) over the surveyed areas were approximately 2,600 t (3L), 4,000 t (2J) and 17,000 t (3K), totalling 23,600 t. There is no corresponding increase in the inshore. In fact, as noted above, abundance in the inshore appears to be declining.

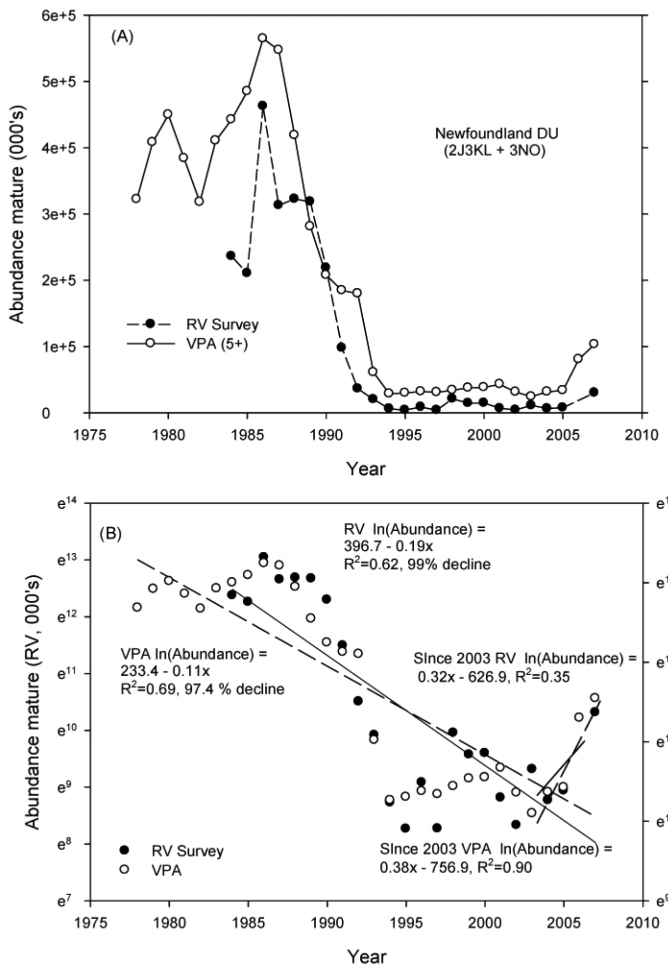

Figure 8. Temporal variation in the estimated number of mature individuals in the Newfoundland and Labrador DU (A). Data for northern cod (NAFO 2J3KL) and southern Grand Bank cod (NAFO 3NO) are shown in Appendix 1. (B) Plot of $\log_e$ (abundance, N_t) versus time (t, in years) for the Newfoundland and Labrador DU and the estimation of the 3-generation rate of decline. Trends in abundance since 2003 are included for comparison.

Based on the offshore component of the stock, the 3-generation decline experienced by the Newfoundland and Labrador DU was 97% and 99% for the VPA and RV survey data respectively (Figure 8). See Appendix 1 for the stock-specific details and data. It is also worth noting that, even in the presence of the recent increases observed in 2J3KL, the decline rates remain unchanged in comparison to 2003 estimates (see Table A1). Furthermore, recent stoch assessments of the 2K3KL and 3NO popuations indicate the stocks are well below any critical level of sustainability.

Age at maturity	Generation time (yr)	Data source	Data type	Time period	Rate of change
6.0	11.0	VPA	number of individuals	1978-1992(2007)	−97%
6.0	11.0	RV Survey	number of individuals	1983-2007	-99%

Area of occupancy for this DU declined rapidly as the stock collapsed in the early 1990s and reached a minimum in 1994 (Worcester *et al*. 2009). Subsequent changes in area of occupancy are less clear given a change in survey gear in 1995 which was accompanied by a large increase in this statistic. During the recent period where the same gear has been used, there has been a slight increase in the area occupied primarily due to fish in 3NO being less aggregated with the most recent estimate of 318,000 km^2 (D95-169,000 km^2).

Laurentian North DU

Cod in this DU combine the stocks identified for management purposes by DFO as (1) St. Pierre Bank (NAFO 3Ps) and (2) Northern Gulf of St. Lawrence (NAFO 3Pn4RS). Temporal trends in abundance for each of these stocks are presented separately in Appendix 1. Calculated from the means for each of its constituent stocks (Appendix 1), generation time is estimated to be 10 yr for this DU, yielding a three-generation time period of 30 years. Abundance data represent the sum of the stock-specific VPA estimates and RV survey estimates of mature population size for each included in this DU, yielding an abundance time series for both the VPA and RV. The time period for which data were available for both stocks was 1977 to 2000 for the VPA (extended using estimated VPA values, see Appendix 1) and 1990 to 2007 for the survey data. Note that the survey for 3Ps was absent in 2006 so this year is absent. These data are included here for the purpose of estimating the three-generation rate of population decline only. The 2009 assessment of 3Ps cod (DFO 2009b) suggests that spawner biomass has declined by a factor of three between 2004 and 2008 and that current estimates are the lowest in the time series. The 2009 assessment of 3Pn4RS cod suggests that the decline that occurred in the late 1980s and early 1990s has ceased and that spawner biomass has been relatively stable for the last 15 years at a low level (DFO 2009c). The Laurentian North DU has declined 90% (VPA) over the past three generations (Figure 9). This trend is driven primarily by the decline experienced by the Northern Gulf stock (3Pn4RS) as it accounts for 70% of historic biomass of the DU.

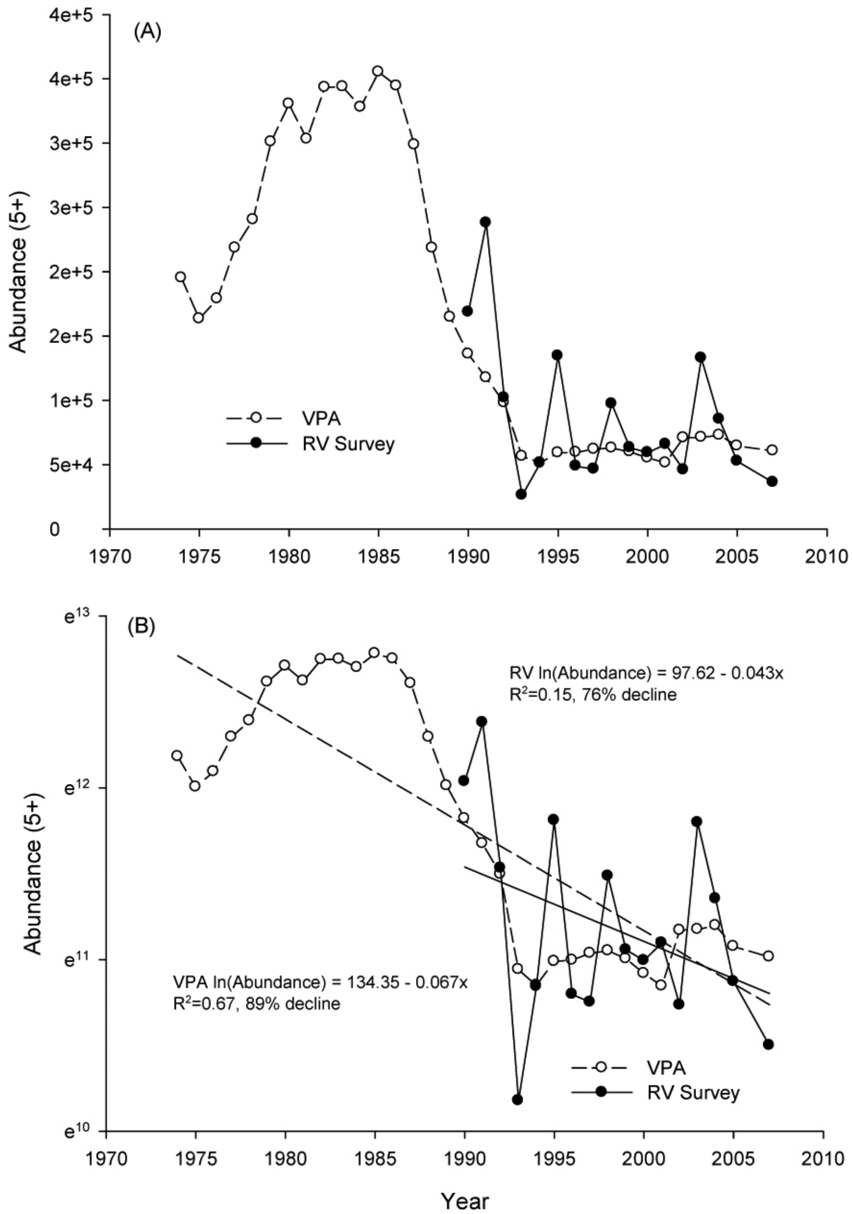

Figure 9. Temporal variation in the estimated number of mature individuals in the Laurentian North DU (A). Data from the 3Ps and 3Pn4RS stocks are shown in Appendix 1. (B) Plot of $\log_e$ (abundance, N_t) versus time (t, in years) for the Laurentian North DU and the estimation of the 3-generation rate of decline.

Age at maturity	Generation time (yr)	Data source	Data type	Time period	Rate of change
5.0	10.0	VPA	number of individuals	1974-2000(2007)	−90%
5.0	10.0	RV	number of individuals	1990-2007	−76%

Area of occupancy for this DU was relatively stable as the abundance declined in the early 1990s and it increased during the period 2002 - 2008 to a value of 90,000 km^2 (Worcester *et al*. 2009). Area of occupancy data for the years 1991 to 2001 declined marginally from approximately 96,000 km^2 to approximately 89,000 km^2, a decline of roughly 7% (Smedbol *et al*. 2002). Since 2002, the area of occupancy increased from approximately 76,000 km^2 to approximately 101,000 km^2, and the D95 increased from 35,000 km^2 to 62,000 km^2 (Worcester *et al*. 2009).

Laurentian South DU

Cod in this DU combine the stocks identified for management purposes by DFO as: (1) Southern Gulf of St. Lawrence (NAFO 4TVn Nov. to April); (2) Cabot Strait (NAFO 4Vn May – Oct.); (3) Eastern Scotian Shelf (NAFO 4VsW). Temporal trends in abundance for each of these stocks are presented separately in Appendix 1.

Calculated from the means for each of its constituent stocks (Appendix 1), generation time is estimated to be 9 yr for this DU, yielding a three-generation time period of 27 years. Abundance data represent the sum of the VPA estimates and RV survey estimates of mature population size for each of the stocks included in this DU. The time period for which data were available for all stocks was 1981 to 2002 for the VPA and 1971 to 2007 for the survey data. These data are included here for the purpose of estimating the three-generation rates of population decline only. The 2009 assessment for 4TVn cod indicates that following a brief recovery in the 1980s, spawner biomass has been declining consistently since 1998 (DFO 2009d).

The Laurentian South DU has declined 90-91% (VPA) over the past three generations (Figure 10). All of the stocks in this DU display ≥80% declines individually. Projections of future changes for the southern Gulf of St. Lawrence indicate that extirpation (spawning biomass < 1000t) is certain in 40 years with no fishing if the current demographic conditions persist (Swain and Chouinard 2008). Shelton *et al*. 2006 also concluded that the Eastern Scotian Shelf component of the DU would decline in the absence of fishing.

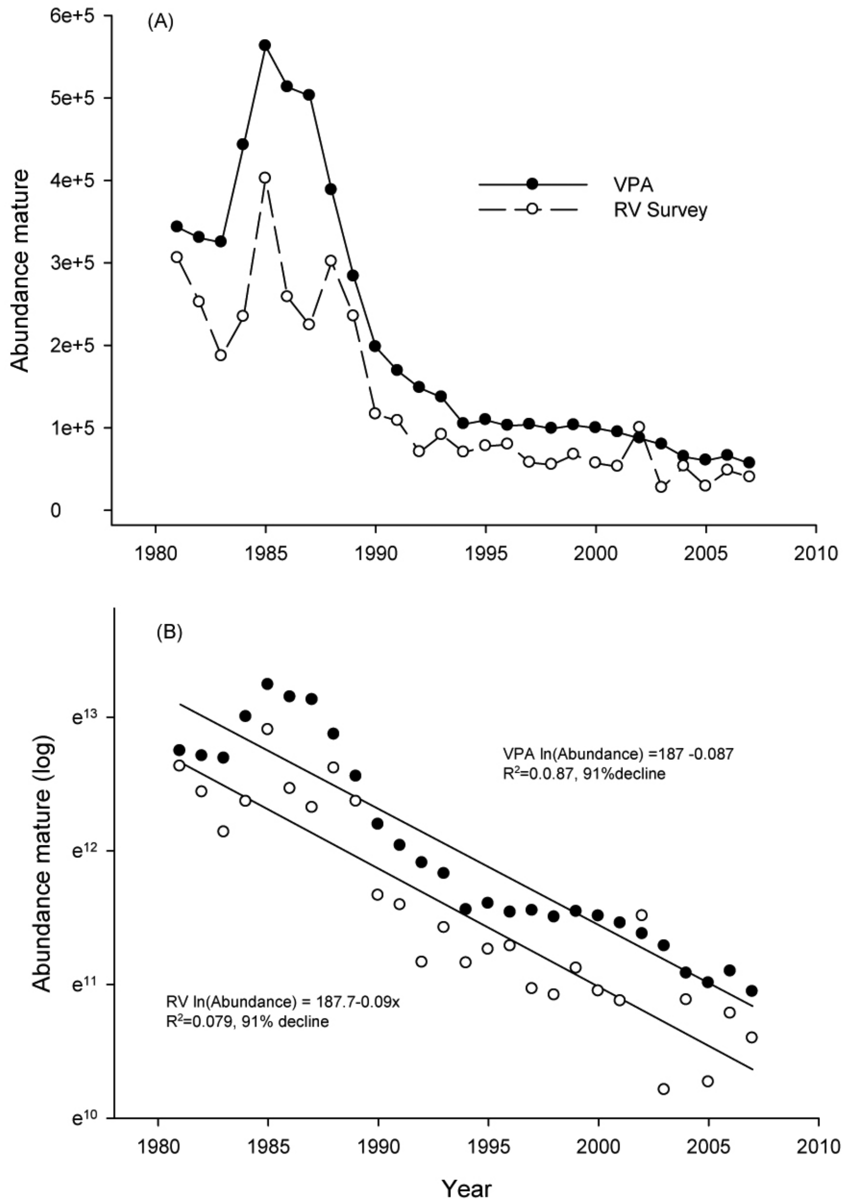

Figure 10. Temporal variation in the estimated number of mature individuals in the Laurentian South DU (A). Data from the 4TVn, 4Vn, and 4VsW stocks are shown in Appendix 1. (B) Plot of $\log_e$ (abundance, N_t) versus time (t, in years) for the Laurentian South DU and the estimation of the 3-generation rate of decline.

Age at maturity	Generation time (yr)	Data source	Data type	Time period	Rate of change
4.0	9.0	VPA	number of individuals	1981-2001(2007)	−90%
4.0	9.0	RV	number of individuals	1971-2007	−91%

Area of occupancy: Area of occupancy for the years 1991 to 2007 declined from approximately 140,000 km^2 to approximately 92,000 km^2.

Southern DU

Cod in this DU combine the stocks identified for management purposes by DFO as: (1) Bay of Fundy/Western Scotian Shelf (NAFO 4X and the Canadian portion of NAFO 5Y); and (2) Eastern Georges Bank ($5Z_{jm}$). Temporal trends in abundance for each of these stocks are presented separately in Appendix 1. Calculated from the means for each of its constituent stocks (Appendix 1), generation time is estimated to be 7.5 yr for this DU, yielding a three-generation time period of 22.5 years. Abundance data represent the sum of the VPA estimates and RV survey estimates of mature population size for each of the stocks included in this DU (see Appendix 1 for details). The time period for which data were available for all stocks was 1978 to 2008 for the VPA, 1978 to 2007 for the NMFS Autumn survey, 1986 to 2008 for the DFO survey. These data are from Worcester *et al*. (2009) and Clark *et al*. (2008) and are included here for the purpose of estimating rates of population decline only. The 2009 assessment of the 4X cod stock indicates that spawner biomass has been declining continuously since 1996 and at the beginning of 2008 was at its historic lowest level, 9,000t (DF0 2009f). Recently mortality other than reported landings has been high, estimated at 0.70 (46%).

The Southern DU has declined 59%-64% over the past three generations (Figure 11).

Age at maturity	**Generation time (yr)**	**Data source**	**Data type**	**Time period**	**Rate of change**
2.5	7.5	VPA	number of individuals	1985-2007	−64%
2.5	7.5	Various Surveys	number of individuals	1985-2007	–59% to –39%

Area of occupancy for this DU has been relatively stable across the time period of observation ranging from approximately 23,000 km^2 in the early 1970s to approximately 24,000 km^2 in recent years.

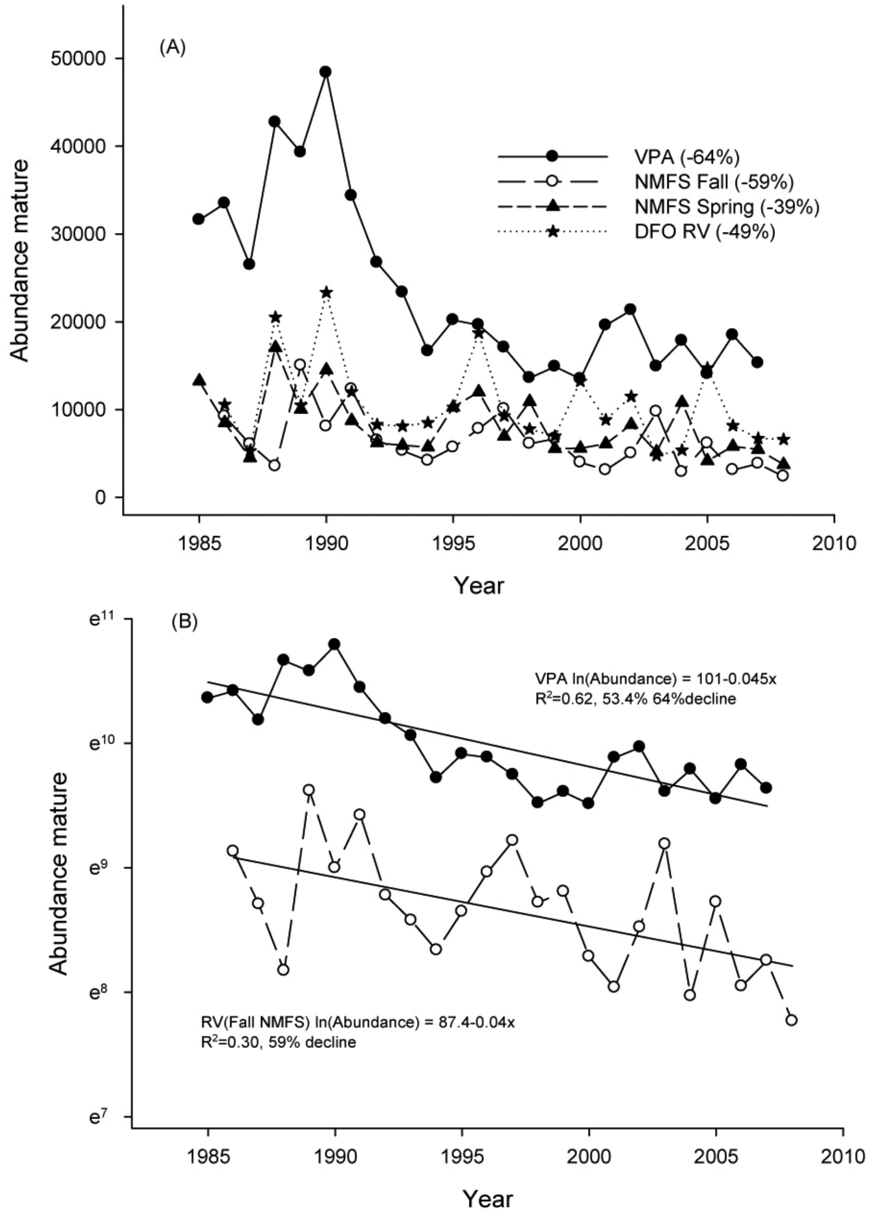

Figure 11. Temporal variation in the estimated number of mature individuals in the Southern DU (A). Data from the 4X and 5Zjm stocks are shown in Appendix 1. (B) Plot of $\log_e$ (abundance, N_t) versus time (t, in years) for the Southern DU and the estimation of the 3-generation rate of decline. Both panels show the data for the various 5Zjm surveys combined with the single 4X survey.

LIMITING FACTORS AND THREATS

The factor responsible for the decline of Atlantic Cod in the 1990s was primarily overfishing (Hutchings and Myers 1994; Hutchings 1996; Myers *et al*. 1997b; Shelton and Lilly 2000; Hutchings and Ferguson 2000a,b; Bundy 2001; Fu *et al*. 2001; Smedbol *et al*. 2002; Worcester *et al*. 2009), though several studies suggest a potential role for unfavourable climatic conditions (Rose *et al*. 2000; Rose 2004; Halliday and Pinhorn 2009). At present, fishing pressure continues to be the primary threat range-wide. However, natural mortality predominates in some areas (Scotian Shelf and southern Gulf of St. Lawrence) resulting in predictions of possible extinctions in the near future (e.g., Swain and Chouinard, 2008).

Fishing pressure

Directed harvest, substantial bycatch, discarding, and to a lesser extent illegal fishing continues in many regions despite record lows in abundance and high total mortality, and clearly threatens rebuilding and continued persistence of cod populations in Canadian waters.

Although a moratorium exists in the offshore of the Newfoundland and Labrador DU, along the northeast coast of Newfoundland fishing pressure was present for the period 2006-2008 in the form of a directed “stewardship” fishery and a recreational fishery for cod. Exploitation rates in many coastal Newfoundland areas are often high (>30%, Worcester *et al*. 2009) based on mark-recapture estimates (DFO 2002; Brattey and Healey 2007). A summary of these estimates is provided in the table below (these data were obtained from Table 6 in Brattey and Healey 2007, and Worcester *et al*. 2009). Exploitation rates for 2007 are available for some inshore Newfoundland areas and range from 6-7% (Worcester *et al*. 2009). It seems likely that these high rates of exploitation have directly contributed to recent declines in abundance observed in estimates from Smith Sound, Trinity Bay (see Appendix).

Tagging location coastal Newfoundland	**Exploitation rates in 1999**	**Exploitation rates in 2002**	**Exploitation rates in 2006**
Notre Dame Bay	30-63%	12-20%	10-35%
Bonavista Bay	6-18%	14-19%	5%
Trinity Bay	4-13%	10-27%	4-15%
Placentia Bay	8-15%	4-27%	25%

High exploitation rates have recently been identified as a direct threat to rebuilding in the offshore regions of the Newfoundland and Labrador DU (Shelton and Morgan 2005; Worcester *et al*. 2009). This threat to recovery comes both through a reduction in overall population growth rate in the inshore, as well as through fishing mortality on the offshore portion (3NO, Shelton and Morgan 2005), and the migratory/offshore stock during summer periods inshore (2J3KL, Worcester *et al*. 2009). Prior to the cod collapses in the early 1990s, it was estimated that cod populations could increase in abundance at exploitation rates less than 18%. As such, exploitation rates reported above exceeding this value permit little or no population growth. Moreover, maximum rates of population increase for northern cod have been estimated at between 10 to 30% per annum (Myers *et al*. 1997a; Hutchings 1999). Given that the range in exploitation rate estimates typically falls within this 10-30% range of maximum population growth, population recovery will not occur, irrespective of the number of individuals in the population.

Since 2003 a positive trend in abundance has been observed in the offshore component of the Newfoundland and Labrador DU (Appendix 1). Brattey *et al*. (2008a) report that cod currently offshore in 2J3KL may undergo spring/summer feeding migrations to the inshore. Tagging and telemetry studies have revealed cod tagged 170 Nm offshore on their traditional over-wintering grounds migrated inshore to the northeast Newfoundland coast in 2008 consistent with the hypothesis that the inshore fishery is a potential threat to offshore rebuilding. This link between offshore recruitment and inshore fishing mortality is supported by the observation that the closure of the fishery in 2003 and lower landings in 2004-2005 coincided with a decline in mortality, improved survival in the offshore and a rise in Sentinel catch rates during this period. Accordingly it is clear that the present moratorium in the offshore is not sufficient to protect this stock until rebuilding has occurred (DFO 2009a) and further restrictions in the inshore are required immediately to protect the present increasing trend in abundance.

High exploitation is impacting abundance and recovery elsewhere as well. Total mortality in the Laurentian North DU based on estimates of its constituent regions is >0.55 of which the main factor is fishing pressure (DFO 2009b,c). In the southern gulf (4TVn) fishing mortality has been estimated at 0.08, and though low is unsustainable given the dramatic increases in natural mortality (DFO 2009d).

Fishing pressure in the 4X component of the Southern DU remains well above recommended levels with fishing mortality estimated at 0.35 (DFO 2009f). In addition to the direct harvest, bycatch of cod in many regions continues to pose a significant threat to rebuilding (Shelton and Morgan 2005) and in some regions contributes to continued declines (Worcester *et al*. 2009). Bycatch is associated with many fisheries including Haddock, Winter Flounder, Shrimp, and Lobster (Worcester *et al*. 2009). And though there is substantial uncertainty regarding the magnitude of these harvests, it seems unequivocal that these are influencing present rates of declines (Shelton and Morgan 2005; Worcester *et al*. 2009).

In summary, it seems clear that across the range in Canadian waters, overfishing, both direct harvest and bycatch, remains a significant threat to the stability and persistence of cod populations.

Natural mortality

Despite the clear influence of fishing pressure on cod survival, the most important factor contributing to the current low productivity of some stocks (e.g., 4TVn) is elevated natural mortality (Swain and Chouinard 2008). Historical estimates of natural mortality (M) suggest a range of values between 0.07 to 0.40, and value of 0.2 has been commonly used in stock assessments (Sinclair 2001). Despite regional restrictions in fishing pressure, total mortality remains high (>0.2) in many areas (Table A2) consistent with elevations of M and estimates of M which do exist indicate some areas are experiencing natural mortality rates of 0.60-0.70. Natural mortality appears most severe in stocks south of the Laurentian Channel (i.e. the southern Gulf of St. Lawrence (4T), eastern Scotian Shelf (4VsW) and western Scotian Shelf/Bay of Fundy (4X) stocks). To the north, M is estimated to be slightly elevated in some regions, but overall values are lower than to the south of the Channel. Until recently, offshore northern cod (2J3KL) were also experiencing high M; however, M has declined in recent years (DFO 2009e).

Population projections for the southern Gulf of St. Lawrence indicate that even without harvest, the spawner stock biomass of 4TVn will decline by at least 10%, with a 53% probability of a 15% decline or greater (Chouinard *et al*. 2008) over 2009. Long-term stochastic projections (Swain and Chouinard 2008) for current conditions suggest the stock will be extinct (i.e., less than 1000 t) within 40 years in the absence of fishing, and within 20 years with fishery removals at the 2007-2008 level. If natural mortality continues to increase, Swain and Chouinard (2008) warn these projections may be overly optimistic. The dominant source of natural mortality remains up for debate; however, several hypotheses have been proposed and evaluated (DFO 2009e). These include disease, the impact of contaminants, starvation, effects of life history change, impact of increased seal abundance, other sources of predation (DFO 2009e). The applicability of these projections to neighbouring stocks remains unclear but available evidence indicates similar sources of M may be influencing other areas as well (4VsW and 4X; DFO 2009e).

That Grey Seal predation may be the source of an elevated M appears probable. Trzcinski *et al*. (2006) modelled the impact of Grey Seal predation on eastern Scotian Shelf cod populations and concluded that since the fishery closure, Grey Seals have been responsible for a significant component of the natural mortality (~30%) experienced and were playing a role in the lack of recovery. Similarly, previous cod assessments (Smedbol *et al*. 2002; DFO 2009e) have concluded, based on seal feeding behaviour and trends in the abundance of both seals and cod, that predation by seals is a factor contributing to the high total mortality of cod in the offshore and the high natural mortality of adult cod in the inshore. The DFO has recently suggested that Grey and Harp Seal predation may be a direct influence on cod recovery and declines, and seals are thought to be a significant source of mortality in at least seven of the managed stock areas (4X, 4TVn, 4VsW, 3Pn, 4RS, 2J3KL, Worcester *et al*. 2009). The observation that in several cases, the trends in high natural mortality of cod are mirrored in other marine fish such as White Hake, American Plaice, and several Skate species, supports a hypothesis of an ecosystem level change in dynamics and not a species-specific hypothesis.

Total mortality (Z) is comprised of both natural mortality and fishing related mortality and was estimated for all Fisheries and Oceans management units (Table A2). In several regions fishing pressure is much reduced in comparison to historic levels; accordingly, much of Z may be attributed to natural mortality. The estimated population ranges are below and range from 30-75% annual total mortality. Estimates of the size of natural mortality are available for 4TVn (M=0.60), and 3Pn4RS (M=0.28). Overall the uniformity and magnitude of these estimates suggests that total mortality has reached an unsustainable level, and it seems that in many regions the primary factor driving these values is mortality due to natural causes.

Designatable Unit	**Range of Z estimates for DFO managed stocks**	**Range of annual mortality among stocks (%)**
Newfoundland and Labrador	0.346-0.519	29-40%
Laurentian North	0.792-0.899	55-59%
Laurentian South	0.722-0.791	51-57%
Southern	0.437-1.420	35-76%

In addition to ecological sources of mortality (i.e predation, starvation, etc.) the direct and indirect influences of climatic variation on cod population productivity remain poorly understood. Halliday and Pinhorn (2009) document a strong relationship between cod biomass and the North Atlantic Oscillation (NAO) and suggest cod population fluctuations over the last century can be largely attributed to environmental causes. The proposed mechanism is that positive NAO anomalies are associated with lower temperatures, which influence population parameters and migration / distribution parameters resulting in poor condition and sharp increases in natural mortality (e.g., Dutil and Lambert 2000). Some supporting evidence exists. Mann and Drinkwater (1994) observed an association between the NAO index and the productivity of Northern cod in the early 1990s, and Drinkwater (2002) indicates that the NAO often explains as much if not more of the variance in biological time series than local oceanographic factors. Finally, further correlative evidence is present during the late 1980s and early 1990s when high values of M were observed in many stocks, which has been identified as a seven-year period of high NAO anomalies. Though intriguing, and appealing in its ability to explain past population fluctuations, at present there is little direct mechanistic evidence that this has played a dominant role and future exploration of the link between cod population productivity and climatic variation is needed.

The alteration of essential habitat may also play a large role in influencing recovery and decline rates. If physical structure is critically important to the survival of juvenile cod as many studies suggest (Laurel *et al*. 2003a, 2003b, 2004), notably in the form of plants, bottom heterogeneity, and corals, then reductions in suitable habitat may also be affecting recruitment and recovery. Eelgrass in the nearshore has been shown to provide important habitat to juvenile cod, providing a refuge from predators (Laurel *et al*. 2003). The recent discovery of Green Crab (*Carcinus maenas*) in Placentia Bay

Newfoundland, and their well documented negative impact on Eelgrass beds (e.g., Davis *et al*. 2002), may present a significant threat to juvenile cod habitat and survival. In addition to the nearshore where the link to habitat has been clearly established, the reduction of physical heterogeneity in deeper waters, and the loss of potentially important deep-sea corals, can be attributed to the bottom-trawling for groundfish (Collie *et al*. 1997, 2000; Kaiser and de Groot 2000) and may also represent a loss of habitat though mechanistic link remains to made.

In summary, the primary cause of the reduction of Atlantic Cod throughout its range and primary threat at present remains over-exploitation. However, in some areas, the rate of decline appears independent of harvest and is primarily associated with elevations in natural mortality which are becoming increasingly important. Identifiable threats to the stability and recovery of present Atlantic Cod populations include directed fishing (a consequence of the setting of quotas and the allowance of recreational or food fisheries), unreported fishing (a consequence of illegal fishing, catch misreporting, discarding), and bycatch from other fisheries for bottom-dwelling species (Haddock, Lobster, Winter Flounder, etc.). There is increasing evidence that natural unaccounted for mortality represents a significant unidentified threat in many stocks and requires immediate attention as the projected rates of decline are unprecedented even for cod (Swain and Chouinard 2008). At present, natural mortality threatens to drive cod in the southern Gulf of St. Lawrence (Laurentian South DU) to extinction within decades. Additional threats to recovery include altered biological ecosystems, and concomitant changes to the magnitude and types of species interactions (such as an increase in cod mortality attributable to seal predation). These ecosystem-level changes appear to have resulted in increased mortality among older cod. Selection against late maturity and rapid growth rate, induced by previously high rates of exploitation, may also be contributing to the higher mortality (effected by earlier maturity; Beverton *et al*. 1994) and slower growth observed in some areas today. Whatever the cause, it seems clear the natural mortality in addition to exploitation pressure now pose significant threats to many cod populations throughout Canadian waters.

SPECIAL SIGNIFICANCE OF THE SPECIES

Given its historical and contemporary importance to society, few species have been of greater significance in Canada. After the short-lived Viking-based settlements on Newfoundland’s Northern Peninsula in the late tenth century, it was cod that brought the first Europeans to Newfoundland waters in the late fifteenth century, an economic venture that spawned one of the first permanent settlements in British North America (1612; Cupids, Newfoundland). Until the early 1990s, Atlantic Cod was the economic mainstay for Newfoundland and Labrador, as it was for a large part of the population in the Maritimes and along Quebec’s north shore and Gaspé Peninsula. From a biological perspective, the Atlantic Cod, which numbered approximately 2.5 billion spawning individuals as recently as the early 1960s, was one of the dominant species of the marine food web in the Northwest Atlantic.

EXISTING PROTECTION OR OTHER STATUS DESIGNATIONS

In Canada, Atlantic Cod is protected federally by the *Fisheries Act* and by the *Oceans Act*. Conservation Harvesting Plans are in place for the Southern Gulf of St. Lawrence, and as of 2003, three Federal/Provincial Cod Action Teams have been established (Newfoundland and Labrador, Maritimes, Quebec) with a mandate to promote recovery. Several of the cod populations in Canadian waters are managed jointly with other countries. For example, the Eastern Georges Bank cod stock is jointly managed by Canada's DFO and the National Marine Fisheries Service in the United States, and cod inhabiting 3Ps are fished jointly with France. The cod stocks inhabiting the offshore waters south of the Arctic DU inside 200 miles are managed by Canada and outside by the Northwest Atlantic Fisheries Organization (NAFO). In most regions quotas as well as seasonal and gear restrictions have been incorporated into the management framework (Worcester *et al*. 2009). Although biologically relevant reference points for stock abundance have been identified in several areas, these are currently not used in the management of these stocks.

Other Status Designations: IUCN: Vulnerable; Global Heritage Status Rank: G5

ASSESSMENT OF RISK

The report suggests that Atlantic Cod in Canada be recognized as six DUs, in accordance with known genetic, ecological, and demographic data, and in accordance with COSEWIC's guidelines (COSEWIC, March 25, 2008).

Regarding the assignment of risk, only the primary cause of the reduction in Atlantic Cod (fishing) can be deemed reversible and understood. However, fishing continues in many of the populations (although it has been restricted spatially and temporally in some parts of some populations, such as Eastern Scotian Shelf). Fishing in the Laurentian South DU for instance ceased from 1994-1997, in 2003, and again in 2009. In the Laurentian North population, excessive fishing mortality has reduced the breeding part of the population, particularly in the Northern Gulf area. For the Newfoundland & Labrador DU, it is evident, based on harvest rates estimated by the DFO, that fishing is delaying recovery in parts of this population's range. Moreover, both the Southern and Laurentian South DU have experienced increases in the rate of decline since 2003 independent of fishing mortality, likely associated with increases in natural mortality (not unaccounted fishing mortality), and the Laurentian South DU seems at imminent risk of an extinction in 20-40 years.

There are several additional factors that may influence one's perception of risk. The first concerns the downgrading of risk when there is a possibility of "rescue", that is, immigration to a portion of the DU within Canada from outside of Canadian waters. It is not clear that such a downgrading is warranted when the neighbouring population(s) is also at risk. In the present case, there are no data that would allow one to evaluate the levels of immigration or emigration into or out of the Canadian and foreign portions of the Arctic Marine DU. And though rescue is possible from American populations of cod in the extreme southern part of the Southern DU, the American populations are also at low levels, and such contributions are likely minimal. A second factor that might influence perception of risk pertains to changes in the life history of cod in some parts of its Canadian range, notably for the Newfoundland & Labrador DU. The high exploitation rates experienced by cod in the late 1980s and early 1990s were sufficiently high to affect genetic selection responses to life history traits, favouring earlier maturity and slower growth (Sinclair *et al*. 2002, Olsen *et al*. 2004) as a consequence. These life history changes represent a significant reduction in population growth rate of up to 30% (Hutchings 2005). This reduction results from a truncation of the age structure, the reduced success of young spawners, and an associated reduction in the expected number of lifetime reproductive events. Given the absence of cod aged 10 yr and older on the Northeast Newfoundland Shelf in recent years, the expected number of lifetime reproductive events for cod in this area is clearly less than 5 and may well be as few as 2 or 3. Although fecundity has been shown to be compensating to some degree (Fudge and Rose 2008) with current estimates at 75% of historic levels, the considerable reduction in lifetime breeding events and changing demography (i.e., increase in proportion of first time spawners, and resulting lower reproductive success) can be expected to have rather serious consequences to the persistence of this and other similarly affected populations, irrespective of the absolute numbers of individuals in each population.

For the Newfoundland and Labrador DU, it is important to note that this population represents over 75% of the historic biomass in Canadian waters and has undergone the largest declines with minimal sign of recovery. Moreover, the slight increases of abundance in recent years represent less than 8% of 1980s levels and 2% of the historic biomass, and any substantial recovery will likely require a rebuilding of the offshore. At present, the inshore fishery though small, represents a significant threat to rebuilding of the stock as a whole, the magnitude of which remains unclear as long as total catch rates are unknown. When assessing risk for the Laurentian North DU, it is important to note that the two stocks in this population have previously shown positive signs of recovery following severe reductions in fishing pressure. This is in contrast to cod in other areas, such as the Newfoundland & Labrador DU and the Eastern Scotian Shelf component of the Laurentian South DU, where reductions in fishing pressure have not been associated with a significant recovery. Also, 3Ps seems dominated by a few year classes, and Brattey and Healey (2006) cautioned that as the dominant 1997 and 1998 year classes leave the fishery, the result could be an increase in fishing mortality for younger year classes which should be accounted for. The 2009 assessment indicates that spawner biomass in this stock has in fact declined by a factor of 3 since 2004. For the Laurentian South DU, it is the rate of change here which is noteworthy. Cod in the southern Gulf have undergone a 100-200% increase in the decline rate in just a few years and this rate of change is largely of unknown causes, though predation may be implicated.

TECHNICAL SUMMARY – ARCTIC LAKES

Gadus morhua

Atlantic Cod — morue franche

Arctic Lakes population — population des lacs de l'Arctique

Range of Occurrence in Canada: Southwest Baffin Island, Nunavut

Demographic Information

Generation time (average age of parents in the population)	10.0 yrs
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 or 5 years, or 3 or 2 generations].	Unknown
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 or 5 years, or 3 or 2 generations].	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 or 5 years, or 3 or 2 generations] period, over a time period including both the past and the future.	Unknown
Are the causes of the decline clearly reversible?	Unknown
Are the causes of the decline understood?	Unknown
Have the causes of the decline ceased?	Unknown
[Observed, inferred, or projected] trend in number of populations	Unknown
Are there extreme fluctuations in number of mature individuals?	Unknown
Are there extreme fluctuations in number of populations?	Unknown

Extent and Area Information

Estimated extent of occurrence	<20 km²
[Observed, inferred, or projected] trend in extent of occurrence	Unknown
Are there extreme fluctuations in extent of occurrence?	Unknown
Index of area of occupancy (IAO)	<20 km²
[Observed, inferred, or projected] trend in area of occupancy	Unknown
Are there extreme fluctuations in area of occupancy?	Unknown
Is the total population severely fragmented?	Yes, probability of migration among lakes is likely very low.
Number of current locations	3
Trend in number of locations	none
Are there extreme fluctuations in number of locations?	no
Trend in [area and/or quality] of habitat	Unknown

Number of mature individuals in each population

Population	**N Mature Individuals**
Total	Unknown
Number of populations (locations)	three

Quantitative Analysis

	None

Threats (actual or imminent, to populations or habitats)

Increased angling pressure in Ogac Lake has been identified as a concern by local inhabitants.

Rescue Effect (immigration from an outside source)

Status of outside population(s)? Newfoundland and Labrador population is at a historic low, as is cod in Greendland.	
Is immigration known?	High genetic differentiation would be consistent with no migration
Would immigrants be adapted to survive in Canada?	Unknown, lakes are distinct habitats
Is there sufficient habitat for immigrants in Canada?	Unknown
Is rescue from outside populations likely?	Unlikely

Current Status

COSEWIC: Special Concern (April 2010)

Status and Reasons for Designation

Status: Special Concern	**Alpha-numeric code:** N/A
Reasons for designation: This designatable unit (DU) exists in 3 isolated lakes on Baffin Island, Nunavut. The combined surface area of the 3 lakes is less than 20 km^2. Rescue from other DUs is not possible. One of the lakes, Ogac Lake, is accessible for fishing and large numbers of the species may be removed from the lake if fishing increases.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Does not meet criterion A as two population estimates spanning > 40 years indicate no change in abundance in one lake.
Criterion B (Small Distribution Range and Decline or Fluctuation): Not applicable.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable.
Criterion D (Very Small Population or Restricted Distribution): Not applicable.
Criterion E (Quantitative Analysis): None undertaken.

TECHNICAL SUMMARY – ARCTIC MARINE

Gadus morhua
Atlantic Cod — morue franche
Arctic Marine population — population marine de l'Arctique
Range of Occurrence in Canada: Nunavut, Northwest Atlantic Ocean
This population includes the Northwest Atlantic Fisheries Organization (NAFO) Divisions 0A and 0B.

Demographic Information

Generation time (average age of parents in the population)	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 or 5 years, or 3 or 2 generations].	Unknown
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 or 5 years, or 3 or 2 generations].	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 or 5 years, or 3 or 2 generations] period, over a time period including both the past and the future.	Unknown
Are the causes of the decline clearly reversible?	Unknown
Are the causes of the decline understood?	Unknown
Have the causes of the decline ceased?	Unknown
[Observed, inferred, or projected] trend in number of populations	Unknown
Are there extreme fluctuations in number of mature individuals?	Unknown
Are there extreme fluctuations in number of populations?	Unknown

Extent and Area Information

Estimated extent of occurrence	50,000 km²
[Observed, inferred, or projected] trend in extent of occurrence	Unknown
Are there extreme fluctuations in extent of occurrence?	Unknown
Index of area of occupancy (IAO)	Unknown
[Observed, inferred, or projected] trend in area of occupancy	Unknown
Are there extreme fluctuations in area of occupancy?	Unknown
Is the total population severely fragmented?	Unknown
Number of current locations	N/A
Trend in number of locations	N/A
Are there extreme fluctuations in number of locations?	N/A
Trend in [area and/or quality] of habitat	Unknown

Number of mature individuals in each population

Population: Arctic Marine	**N Mature Individuals**
Total	Unknown
Number of populations (locations)	Unknown

Quantitative Analysis

	None

Threats (actual or imminent, to populations or habitats)

Unknown

Rescue Effect (immigration from an outside source)

Status of outside population(s)? Newfoundland and Labrador and Greenland populations are at low levels.	
Is immigration known?	No
Would immigrants be adapted to survive in Canada?	Likely
Is there sufficient habitat for immigrants in Canada?	Likely
Is rescue from outside populations likely?	Unknown

Current Status

COSEWIC: Data Deficient (April 2010)

Status and Reasons for Designation

Status: Data Deficient	**Alpha-numeric code:** N/A
Reasons for designation: Information to establish any COSEWIC status category with assurance is not available. Data on distribution, abundance, habitat, and changes over time are insufficient.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable.
Criterion B (Small Distribution Range and Decline or Fluctuation): Not applicable.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable.
Criterion D (Very Small Population or Restricted Distribution): Not applicable.
Criterion E (Quantitative Analysis): Not applicable.

TECHNICAL SUMMARY – NEWFOUNDLAND AND LABRADOR

Gadus morhua
Atlantic Cod — morue franche
Newfoundland and Labrador population — population de Terre-Neuve-et-Labrador
Range of Occurrence in Canada: Newfoundland and Labrador, Northwest Atlantic Ocean
This population includes the Northwest Atlantic Fisheries Organization (NAFO) Divisions 2GHJ and 3KLNO

Demographic Information

Generation time (average age of parents in the population)	11.0 yrs
Observed percent reduction in total number of mature individuals over the last 3 generations	97-99%
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 or 5 years, or 3 or 2 generations].	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 or 5 years, or 3 or 2 generations] period, over a time period including both the past and the future.	Unknown
Are the causes of the decline clearly reversible?	No
Are the causes of the decline understood?	Yes
Have the causes of the decline ceased?	No
[Observed, inferred, or projected] trend in number of populations	Unknown
Are there extreme fluctuations in number of mature individuals?	No
Are there extreme fluctuations in number of populations?	No

Extent and Area Information

Estimated extent of occurrence	620,000 km²
[Observed, inferred, or projected] trend in extent of occurrence	Unknown
Are there extreme fluctuations in extent of occurrence?	Unhnown
Index of area of occupancy (IAO)	318,000 km²
[Observed, inferred, or projected] trend in area of occupancy	Rapid decline as the population declined in the early 1990s
Are there extreme fluctuations in area of occupancy?	No
Is the total population severely fragmented?	No
Number of current locations	N/A
Trend in number of locations	N/A
Are there extreme fluctuations in number of locations?	N/A
Trend in [area and/or quality] of habitat	Unknown

Number of mature individuals in each population

Population	**N Mature Individuals**
Total	Approx. 40,000,000
Number of populations (locations)	Unknown

Quantitative Analysis

	none

Threats (actual or imminent, to populations or habitats)

- directed commercial and recreational fishing
- fishing during spatial overlap between inshore residents and offshore migrants in northern cod stock
- fisheries bycatch
- illegal fishing and other sources of unreported bycatch
- fishing-induced natural changes to the ecosystem
- predation by Harp Seals and other predators on the northern cod stock
- habitat alteration is possible but un-evaluated threat

Rescue Effect (immigration from an outside source)

Status of outside population(s)? Laurentian North is at low level	
Is immigration known? Yes	
Would immigrants be adapted to survive in Canada?	Probably
Is there sufficient habitat for immigrants in Canada?	Probably
Is rescue from outside populations likely?	Low

Current Status

COSEWIC: Endangered (April 2010)

Status and Reasons for Designation

Status: Endangered	**Alpha-numeric code:** A2b
Reasons for designation: This designatable unit (DU) includes the cod management units 2GH, 2J3KL and 3NO, located in the inshore and offshore waters of Labrador and eastern Newfoundland, and the Grand Banks. Cod in this area have declined 97-99% in the past 3 generations and more than 99% since the 1960s. The area of occupancy declined considerably as the stock collapsed in the early 1990s. The main cause of the decline in abundance was overfishing, and there has been a large reduction in the fishing rate since 1992. However, the population has remained at a very low level with little sign of substantive recovery. The most recent surveys indicate an increase in abundance over the past 3 years; however, this change in abundance is very small compared to the measured decline over the past 3 generations. The extremely low level of abundance and contracted spatial distribution makes the population vulnerable to catastrophic events, such as abnormal oceanographic conditions. Threats from fishing, predation, and ecosystem changes persist. There is no limit reference point (LRP) for the 2J3KL management unit but the population in this area is considered to be well below any reasonable LRP value. The offshore 2J3KL fishery is under moratorium and there is an inshore stewardship fishery with no formal total allowable catch (TAC). The fishery in the 3NO management unit is also under moratorium. There is an LRP for this management unit and the population is well below this value.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Meets Endangered A2b as there has been a measured decline of 97-99 % over the past 3 generations. While the causes of the decline are understood, threats persist, they are not fully understood, and they are not clearly reversible.
Criterion B (Small Distribution Range and Decline or Fluctuation): Does not meet the criterion.
Criterion C (Small and Declining Number of Mature Individuals): Does not meet the criterion.
Criterion D (Very Small Population or Restricted Distribution): Does not meet the criterion.
Criterion E (Quantitative Analysis): Not undertaken.

TECHNICAL SUMMARY – LAURENTIAN NORTH

Gadus morhua
Atlantic Cod — morue franche
Laurentian North population — population nord-laurentienne
Range of Occurrence in Canada : Newfoundland and Labrador, Quebec, Atlantic Ocean
This population includes the Northwest Atlantic Fisheries Organization (NAFO) Divisions 3P and 4RS.

Demographic Information

Generation time (average age of parents in the population)	10.0 yrs
Observed, percent reduction in total number of mature individuals over the last 3 generations.	76 - 89%
Percent reduction in total number of mature individuals over the next 3 generations.	Unknown
Percent reduction in total number of mature individuals over a 3 generation period, over a time period including both the past and the future.	Unknown
Are the causes of the decline clearly reversible?	No
Are the causes of the decline understood?	Yes
Have the causes of the decline ceased?	No
[Observed, inferred, or projected] trend in number of populations	Unknown
Are there extreme fluctuations in number of mature individuals?	No
Are there extreme fluctuations in number of populations?	No

Extent and Area Information

Estimated extent of occurrence	155,000 km²
trend in extent of occurrence	Unknown
Are there extreme fluctuations in extent of occurrence?	Unknown
Index of area of occupancy (IAO)	90,000 km²
trend in area of occupancy	increase
Are there extreme fluctuations in area of occupancy?	No
Is the total population severely fragmented?	No
Number of current locations	Unknown
Trend in number of locations	Unknown
Are there extreme fluctuations in number of locations?	Unknown
Trend in [area and/or quality] of habitat	Unknown

Number of mature individuals in each population

Population	**N Mature Individuals**
Total	Approx. 60,000,000
Number of populations (locations)	Unknown

Quantitative Analysis

	None

Threats (actual or imminent, to populations or habitats)

- directed commercial and recreational fishing
- fisheries bycatch
- illegal fishing and other sources of unreported bycatch
- fishing-induced natural changes to the ecosystem
- predation by Harp Seals and other predators on the Northern Gulf stock
- habitat alteration is possible but an un-evaluated threat.

Rescue Effect (immigration from an outside source)

Status of outside population(s)? Newfoundland and Labrador population is at historic low, Laurentian South population is at historic low and declining.	
Is immigration known?	Yes
Would immigrants be adapted to survive in Canada?	Unknown
Is there sufficient habitat for immigrants in Canada?	Likely
Is rescue from outside populations likely?	Low

Current Status

COSEWIC: Endangered (April 2010)

Status and Reasons for Designation

Status:	**Alpha-numeric code:**
Endangered	A2b

Reasons for designation:
Populations in this designatable unit (DU) have declined 76-89% in the past 3 generations. The main cause of the decline in abundance was overfishing and there is no indication of recovery. This DU includes the cod management units 3Ps and 3Pn4RS. A limit reference point (LRP) has been estimated for the 3Pn4RS management unit. The abundance for this management unit has been relatively stable over the past decade, but it is well below the LRP, and directed fisheries continue. Abundance in southern Newfoundland (3Ps) is declining. The assessment indicates that this management unit is at the LRP, and directed fisheries continue.

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Meets Endangered A2b as there has been a measured decline of 76-89 % over the past 3 generations. While the causes of the decline are understood, threats persist, and they are not clearly reversible.

Criterion B (Small Distribution Range and Decline or Fluctuation): Does not meet the criterion

Criterion C (Small and Declining Number of Mature Individuals): Does not meet the criterion.

Criterion D (Very Small Population or Restricted Distribution): Does not meet the criterion.

Criterion E (Quantitative Analysis): Not undertaken.

TECHNICAL SUMMARY – LAURENTIAN SOUTH

Gadus morhua
Atlantic Cod — morue franche
Laurentian South population — population sud-laurentienne
Range of Occurrence in Canada: Quebec, Prince Edward Island, Nova Scotia, New Brunswick, Atlantic Ocean
This population includes the Northwest Atlantic Fisheries Organization (NAFO) Divisions 4TVW

Demographic Information

Generation time (average age of parents in the population)	9.0 yrs
Observed percent reduction in total number of mature individuals over the last 3 generations.	90%
Projected percent reduction in total number of mature individuals over the next 3 generations.	87-98% (based on projections for 4T)
Percent reduction [or increase] in total number of mature individuals over any period, including both the past and the future.	Unknown
Are the causes of the decline clearly reversible?	No
Are the causes of the decline understood?	No
Have the causes of the decline ceased?	No
[Observed, inferred, or projected] trend in number of populations	Unknown
Are there extreme fluctuations in number of mature individuals?	no
Are there extreme fluctuations in number of populations?	no

Extent and Area Information

Estimated extent of occurrence	Approx-120,000 km²
Trend in extent of occurrence	Unknown
Are there extreme fluctuations in extent of occurrence?	Unknown
Index of area of occupancy (IAO)	95,000 km²
Trend in area of occupancy	Declining
Are there extreme fluctuations in area of occupancy?	No
Is the total population severely fragmented?	No
Number of current locations	N/A
Trend in number of locations	N/A
Are there extreme fluctuations in number of locations?	N/A
Trend in [area and/or quality] of habitat	Unknown

Number of mature individuals in each population

Population	**N Mature Individuals**
Total	Approx 48,000,000
Number of populations (locations)	Unknown

Quantitative Analysis

The population will continue to decline in the absence of fishing	Yes

Threats (actual or imminent, to populations or habitats)

• natural mortality (i.e., predation by Grey Seals and other predators) • directed commercial and recreational fishing • fisheries bycatch • illegal fishing and other sources of unreported bycatch • fishing-induced natural changes to the ecosystem • habitat alteration is possible but an un-evaluated threat.

Rescue Effect (immigration from an outside source)

Status of outside population(s)? Both Laurentian North and Southern stocks continue to be at historic low abundances.	
Is immigration known?	Yes
Would immigrants be adapted to survive in Canada?	Yes
Is there sufficient habitat for immigrants in Canada?	Likely
Is rescue from outside populations likely?	Low

Current Status

COSEWIC: Endangered (April 2010)

Status and Reasons for Designation

Status:	**Alpha-numeric code:**
Endangered	A2b+3b+4b; E
Reasons for designation: Populations in this designatable unit (DU) have declined by 90% in the past 3 generations. The main cause of the rapid decline in abundance during the early 1990s was overfishing. Commercial fisheries were curtailed in 1993 and the abundance stabilized for a number of years. However, increased natural mortality and continued small catches have caused the abundance to decline again. Quantitative analysis of population demographic parameters indicate the population will continue to decline in the absence of fishing if the current elevated level of natural mortality persists. This DU includes the cod management units 4TVn (November – April), 4Vn (May – October) and 4VsW. A limit reference point (LRP) has been estimated for the 4TVn management unit and the current status is assessed to be well below the LRP. An LRP has not been estimated for the 4VsW management unit; however, it is considered to be at a critically low level.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Meets Endangered A2b+3b+4b as the population has declined by 90% over the past 3 generations and it is forecast that the remaining 10% will decline by a further 90% in the next 3 generations under current conditions and in the absence of fishing.
Criterion B (Small Distribution Range and Decline or Fluctuation): Does not meet criterion.
Criterion C (Small and Declining Number of Mature Individuals): Does not meet criterion.
Criterion D (Very Small Population or Restricted Distribution): Does not meet criterion.
Criterion E (Quantitative Analysis): Meets criterion E for Endangered. The Southern Gulf of St. Lawrence portion of the DU is projected to become extirpated (< 1000 t) in 40 years (4.4 generations). The Eastern Scotian Shelf portion of the DU is forecast to decline in the absence of fishing.

TECHNICAL SUMMARY – SOUTHERN

Gadus morhua
Atlantic Cod — morue franche
Southern population — population du Sud
Range of Occurrence in Canada: New Brunswick, Nova Scotia, Atlantic Ocean
This population includes the Northwest Atlantic Fisheries Organization (NAFO) Division 4X and the Canadian portions of NAFO 5Y and 5Z.

Demographic Information

Generation time (average age of parents in the population)	7.5 yrs
Observed percent reduction in total number of mature individuals over the last 3 generations.	Approx. 64%
Percent reduction in total number of mature individuals over the next 3 generations.	Unknown
Percent reduction or increase in total number of mature, over a time period including both the past and the future.	Unknown
Are the causes of the decline clearly reversible?	No
Are the causes of the decline understood?	No
Have the causes of the decline ceased?	No
trend in number of populations	Unknown
Are there extreme fluctuations in number of mature individuals?	Unknown
Are there extreme fluctuations in number of populations?	Unknown

Extent and Area Information

Estimated extent of occurrence	120,000 km²
[Observed, inferred, or projected] trend in extent of occurrence	Unknown
Are there extreme fluctuations in extent of occurrence?	Unknown
Index of area of occupancy (IAO)	23,000 km²
Observed trend in area of occupancy	Stable
Are there extreme fluctuations in area of occupancy?	No
Is the total population severely fragmented?	No
Number of current locations	N/A
Trend in number of locations	N/A
Are there extreme fluctuations in number of locations?	N/A
Trend in [area and/or quality] of habitat	Unknown

Number of mature individuals in each population

Population	**N Mature Individuals**
Total	5,000,000-15,000,000
Number of populations (locations)	Unknown

Quantitative Analysis

	None

Threats (actual or imminent, to populations or habitats)

• directed commercial and recreational fishing • fisheries bycatch • natural mortality (i.e., predation by Grey Seals and other predators) • illegal fishing and other sources of unreported bycatch • fishing-induced natural changes to the ecosystem • habitat alteration is possible but an un-evaluated threat.

Rescue Effect (immigration from an outside source)

Status of outside population(s)? USA: Georges Bank US population is at historic low, as is Laurentian South population	
Is immigration known?	Yes
Would immigrants be adapted to survive in Canada?	Likely
Is there sufficient habitat for immigrants in Canada?	Likely
Is rescue from outside populations likely?	Low

Current Status

COSEWIC: Endangered (April 2010)

Status and Reasons for Designation

Status: Endangered	**Alpha-numeric code:** A2b
Reasons for designation: Populations in this designatable unit (DU) have declined by 64% in the past 3 generations and the decline is continuous. Commercial fishing is ongoing and is an important contributor to the decline. As well, there is evidence of an unexplained increase in natural mortality in the 4X portion of the DU. Rescue from the US population is unlikely given the low abundance of the species in that area. This DU includes the cod management units 4X5Y and 5Zjm. There is a directed fishery for the species in the 4X5Y area, and although there is no limit reference point (LRP), recent fishery management advice indicates that this management unit is at a critically low level. There is also a directed fishery in the 5Zjm management unit and this fishery is co-managed with the United States.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Meets Endangered A2b as there has been a 64% decline in abundance over 3 generations. The causes of decline have not ceased, they are not fully understood, and they may not be reversible.
Criterion B (Small Distribution Range and Decline or Fluctuation): Does not meet the criterion.
Criterion C (Small and Declining Number of Mature Individuals): Does not meet the criterion.
Criterion D (Very Small Population or Restricted Distribution): Does not meet the criterion.
Criterion E (Quantitative Analysis): Not undertaken.

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BIOGRAPHICAL SUMMARY OF CONTRACTOR

Ian Bradbury is a postdoctoral fellow with the University of Windsor, Ontario. He has been working on questions of egg and larval dynamics, dispersal, and the evolution of cod for over a decade. Dr. Bradbury has published extensively on many aspects of cod life history from reproduction and fecundity to spatial genetic structure.

APPENDIX 1. Population trend data for each of the Atlantic Cod management units recognized by Fisheries and Oceans Canada

1. Cod in the Arctic Marine (0AB)

Stock Structure

There are very few population abundance data for cod in this region. Surveys of the offshore component date from 1999 to present and have produced low catches, but in general very little is known. Data on catches in the marine environment was provided by Tim Siferd (Fisheries and Oceans Canada) based on DFO and Northern Shrimp Research Foundation surveys. In addition to limited numbers of cod in the offshore, cod inhabit three meromictic lakes (Ogac, Qasigialiminiq and Tariujarusiq Lakes) on south Baffin Island. These lakes are characterized by physical barriers which restrict connectivity with the coastal environment (Hardie 2007) and result in high levels of genetic isolation from marine stocks and from each other (Hardie *et al*. 2006).

Life History

Very little life history information is available, Hardie (2007) suggests that for the lake populations, the size at 50% maturity is 36 cm (males) and 42 cm (females) and the age at 50% maturity varies between 3.9-5.0 yrs. Nothing is known regarding the life history of cod in the marine environment.

Abundance Trends

Although no regular assessment is conducted of these lakes, a mark-recapture study conducted in 1957-1962 and a recent estimate of population size (2003-2004) in Ogac Lake suggest little change with the estimated number of individuals at 500 >60 cm and 10,000 >25 cm (Hardie *et al*. 2006 and 2008). Little abundance data is available for marine cod in this region.

Threats

At present, the main threat to these lake populations is recreational fishing.

2. Northern Labrador (2GH)

Stock Structure

Templeman (1962) included cod off Newfoundland and Labrador in a single stock though acknowledging that future data may separate stocks in this region. The presence of a cline in growth rates from Labrador to Newfoundland (Fleming 1960) is consistent with isolation from Newfoundland populations.

Abundance Trends

There are very few population abundance data available for cod in this area. The available data are complicated by the fact that surveys prior to 1986 were line transect surveys (i.e., involving non-random sampling) whereas those conducted thereafter were stratified-random surveys and that the gear was changed in 1995 from the Engel trawl to a Campelen trawl. The data reported here are from Smedbol *et al*. (2002) and Worcester *et al*. (2009) and provided by D. Power, Fisheries and Oceans Canada (Figure A1). Based on an estimated age at maturity of 5.25 yr for the period 1947 to 1950 (Smedbol *et al*. 2002), northern Labrador cod have declined 85% over the past three generations, based on the available data (Table A1).

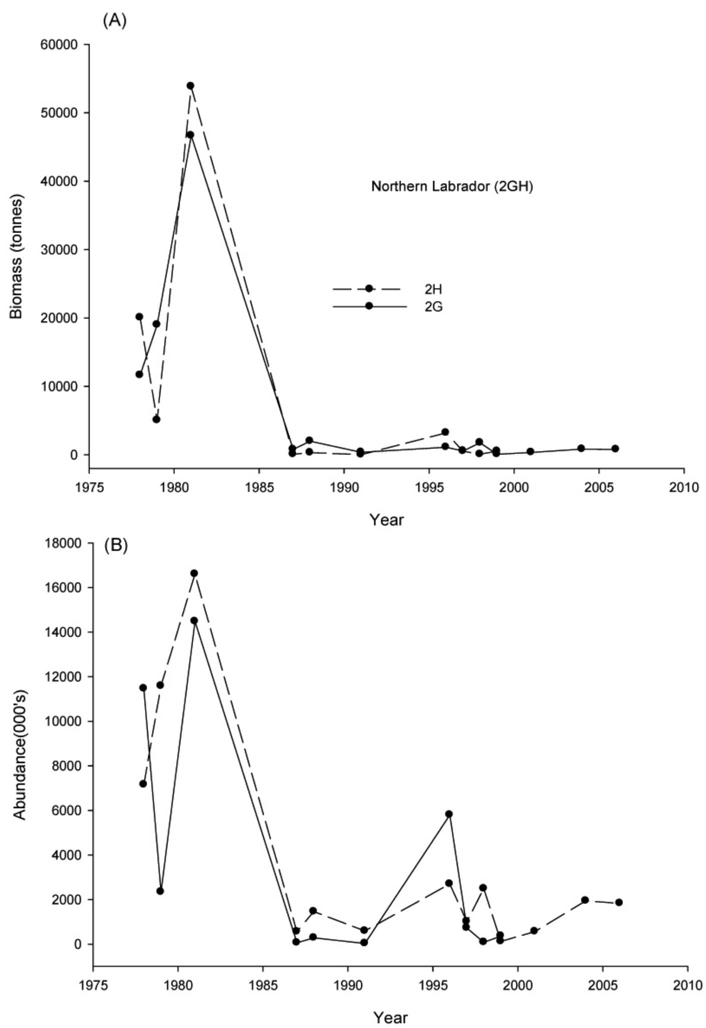

Figure A1. Temporal variation in biomass (A) and number of individuals (B) in the Labrador Stock (2GH). Data from DFO RV survey. See Worcester *et al*. 2009 for details.

Area of Occupancy

The survey coverage of 2GH is limited and as such that the calculation of area of occupancy is not considered to be valid.

Threats to Recovery

Commercial landings are minimal. Bycatch of cod in shrimp fisheries in 2G from 2004-2007 ranged between 241kg to 500kg annually (Orr 2008).

3. Northeast Newfoundland Shelf, or "Northern" Cod (2J3KL)

Stock Structure

Templeman (1962) designated cod from northern Labrador to the northern region of the Grand Banks as comprising a single stock. Increasing evidence is suggesting that a separation between offshore migratory and inshore resident stock components exists. In contrast to a historical focus on offshore/migratory cod in this region, a large body of work since the last report has documented the presence of an inshore component of Atlantic Cod in 2J3KL which currently represents a significant portion of the overall stock (Bradbury *et al*. 2008). Tagging and telemetry data (Brattey and Healey 2003, 2005, 2007, Brattey *et al*. 2008a) and hydro-acoustics (DFO, 2008) provide strong support for the conclusion that there is a resident inshore component of northern cod that over-winters in Smith Sound and disperses around the inshore area during summer months. Recent work has demonstrated the presence of a genetically isolated inshore population in Gilbert Bay, Labrador, which is distinct from Newfoundland inshore cod and suggests the potential for fine-scale genetic and adaptive divergence within the coastal stock component (Ruzzante *et al*. 1998; Beacham *et al*. 2002). Moreover, there is recent evidence of a renewed presence of cod in the offshore and of offshore cod making the traditional migration to the Northeast Newfoundland coast in the summer months (Worcester *et al*. 2009, Brattey, J. pers. comm.).

Life History

Age at maturity has changed significantly since the 1950s. The estimated age at 50% mature was 6-7 during the 1950s, declined to 6.0 during the 1960s, and is currently 4.9-5.7 for cohorts since 1990 with no apparent trend. Thus, in an unfished state, generation time is estimated to be 6+(1/0.2) = 11yr, yielding a three-generation time period of 33 yr. These declines in age at maturity have been attributed to fishery - induced evolutionary changes in life history of the stock (Olsen *et al*. 2004, 2005). Though the impact of life history changes on the productivity of the stock is unknown, fecundity in 2J cod was examined by Fudge and Rose (2008). They demonstrate that fecundity is currently >75% of pre-industrial levels suggesting a compensatory effect; however, the exact mechanism remains unclear.

Abundance Trends

Long-term abundance estimates are primarily available for the mature portion of the offshore stock component and are available in two types. At present there is no accepted VPA formulation for 2J3KL (See Brattey *et al*. 2008b for the 2008 assessment). VPA estimates are available from Baird *et al*. (1992) for the years 1962 to 1977 and from Bishop *et al*. (1993) for the years 1978 to 1992. In the absence of contemporary VPA-based estimates, temporal trends in abundance were examined using two approaches. First areal expansions of survey abundance were calculated using the number of trawlable units in the survey area and the average catch at age per tow (See Worcester *et al*. 2009). This was based on the autumn RV survey which has been conducted since 1981. This period encompasses a transition from the Engel trawl to the Campelen trawl (1994) and as such all data presented are converted to Campelen equivalents (Figure A2a). Survey data presented here are based on “offshore index” strata and represent strata that have been fished most consistently since the start of the survey and were provided by J. Brattey, Fisheries and Oceans Canada. Second, the existing VPA estimates for 2J3KL were extended forward in time, as in the previous report (COSEWIC 2003), using a regression of VPA and RV-data for the period of overlap. To undertake this estimation, a regression of the (log) survey catch rate data (numbers per tow for individuals age 5 years and older) against the (log) VPA abundance estimates ($r=0.74$, $p<0.01$) was used incorporating the survey catch rate data from 1993 to 2007, to estimate numbers of individuals (Figure A2.). Irrespective of the data source, the 3-generation rate of decline experienced by northern cod exceeded 97% (Figure A2b, Table A1). Since 2003, both metrics show some increase in abundance (Figure A2b). A hydro-acoustic survey in the offshore from Hawke channel to the nose of the Grand Bank estimated biomass in 2007 at 2,600 t (3L), 4,000 t (2J) and 17,000 t (3K) (Mello and Rose 2008). Nonetheless, the current estimates for the 2J3KL offshore area are still historically low (<8% of 1980 levels).

Area of occupancy

Between 1983 and 1995 the area of occupancy for the offshore declined from approximately 260,000 km^2 to 80,000 km^2 and the D95 from 170,000 km^2 to approximately 50,000 km^2. Following an initial increase to 225,000 km^2 and 140,000 km^2 for the area of occupancy and D95 respectively, there has been little recent change.

Threats to recovery

Directed harvest in 2J3KL is substantial though not entirely known. In 2003, most of the harvest was associated with an unusual inshore mortality event due to extremely cold water in Smith Sound (Colbourne *et al*. 2003). In 2006, 2007 and 2008, a directed “stewardship” fishery and a recreational fishery for cod were re-opened in the inshore with landings in 2006 of 2,679 t, including 380 t in the recreational fishery, 159 t in the sentinel surveys, and 45 t of bycatch of which 20 t came from the offshore. Similar landings were reported in 2007 with a total of 2,364 t including 2,192 t directed catch, 172 t as bycatch, and 182 t in the sentinel surveys. Total landings in 2008 increased to

4,162 t, including an estimate for recreational fisheries based on a telephone survey. Recreational fisheries landings prior to 2008 are unavailable and as such total harvest levels remain unknown. The impact of natural mortality in 2J3KL is poorly understood. It seems likely that high natural mortality contributed to the high total mortality experienced in the offshore in the late 1990s and up till 2002. The source of this high natural mortality remains under speculation and possible causes include increased marine mammal predation, or other ecosystem changes. Since 2002, it seems natural mortality has decreased significantly; however, the cause is unknown at present, nor is it known how long this period of low natural mortality will continue.

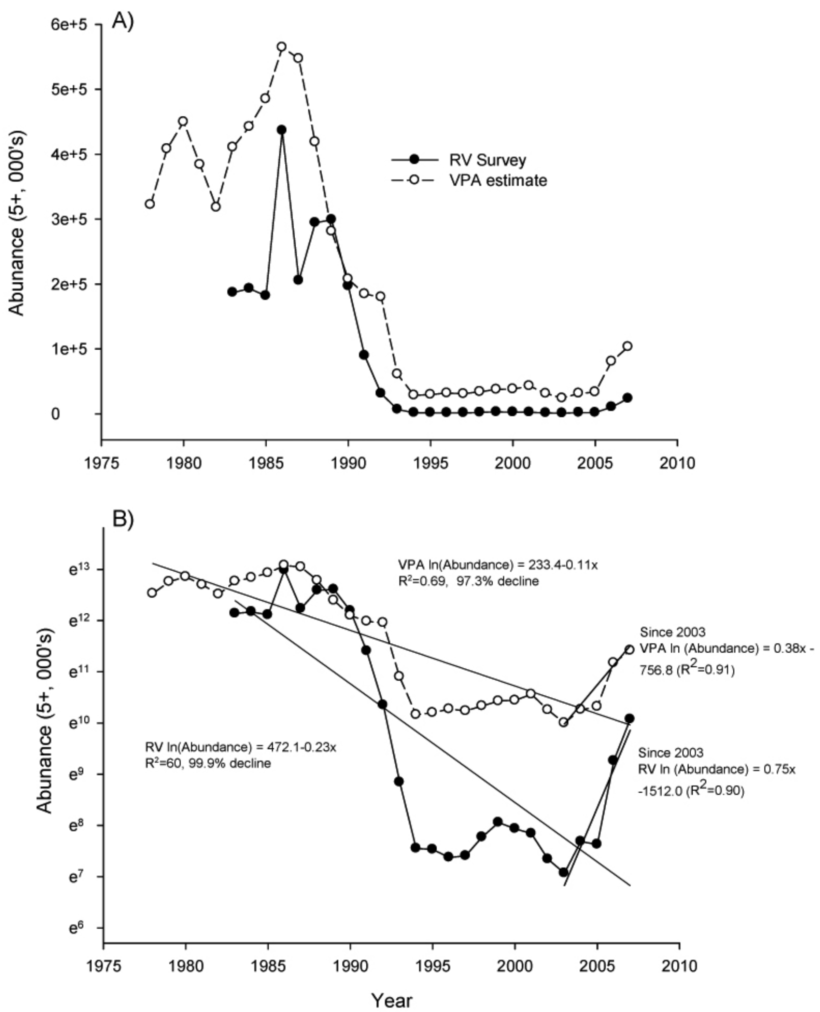

Figure A2. (A) Temporal variation in abundance of mature individuals in the northern cod stock (2J3KL). (B) Estimation of three-generation rate of decline. RV survey data from Worcester *et al*. 2009. VPA estimates have not been available since 1992 (Bishop *et al*. (1993); following COSEWIC (2003), presented data are an extrapolation based the relationship (r=0.74) between VPA abundance and RV survey abundance for the time period 1983 to 1992. This extrapolation is done for the purposes of rate of decline calculation only. Relationships associated with recent (since 2003) positive trends are also noted.

Table A1. Summary of decline rate estimates for each of the NAFO subdivisions. Estimates in bold represent an increase from 2003.

Stock	Age at Maturity	Generation time	Data type	Time period	Rate of change	2003 Estimate
1. 2GH	5.25	11	RV Survey	1978-2006	-85%	Na
					Na	Na
2. 2J3KL	6	11	RV Survey	1983-2007	-99%	-99.9
			VPA	1978-2007*	-97%	-97
3. 3NO	6	11	RV Survey	1959-2007	**-99%**	-95
			VPA	1984-2007	-97%	-98
4. 3Ps	6	11	RV Survey	1983-2007	**-65%**	-47
			VPA	1959-2007*	-41%	-46
5. 3Pn4RS	4	9	RV Survey	1990-2007	-58%	-64
			VPA	1974-2008	**-97%**	-93
6. 4T	4.5	9.5	RV Survey	1950-2008	**-86%**	+27
			VPA	1971-2007	**-83%**	-23
7. 4Vn	4.5	9.5	RV Survey	1970-2007	**-91%**	-4
			VPA	1981-2007*	-94%	-95
8. 4VSw	4	9	RV Survey	1970-2007	**-93%**	-92
			VPA	1970-2007	**-80%**	-75
9. 4X	2.5	7.5	RV Survey	1970-2007	**-73%**	-53
			VPA	1948-2008*	-72%	-78
10. $5Z_{jm}$	2.5	7.5	DFO RV Survey	1986-2008	+3.7%	+6
			VPA	1978-2007	-49%	-70

*VPA data extended using linear approximation of relationship with RV survey data for overlapping time interval.

Annual estimates of exploitation rate (Brattey and Healey 2005, 2007) indicate that during 1998-2002, exploitation rates in the inshore ranged from 10-17% peaking in 1999, in area 3Ki at 37%. Exploitation rates dropped with the fishery closure (2-9%) during 2003-2005, but increased in 2006 and 2007 to 6-20% depending on region. As noted above, offshore 2J3KL cod may continue to make traditional feeding migrations to the inshore during the summer. At present levels of offshore population abundance, the levels of exploitation in the inshore represent a significant risk to stock growth offshore (Brattey *et al*. 2008b; Shelton *et al*. 2006). It is worth noting that the closure of the fishery in 2003 and lower landings in 2004-2005 coincided with a decline in mortality and improved survival in the offshore. Sentinel catch rates in the inshore also began to increase in this period.

Bycatch represents another significant threat to cod in 2J3KL. Bycatches are common in gillnet fisheries for lumpfish, turbot and winter flounder (blackback). During 2004 and 2005, substantial bycatches (>600 t) of cod were taken in the inshore, mostly in 3KL, in the winter flounder (blackback, *Pseudopleuronectes americanus*) fishery, although it is well-known that blackback has limited commercial value and that this was in fact a cod-directed fishery. Bycatch of cod also occurs in the herring gillnet fishery, the capelin trap fishery, the bait-net fishery and the shrimp fishery, though this was dramatically reduced with the introduction of the Nordmore grate in 1993 (Kulka 1998). Total discards from the large vessel shrimp fishery in 2J3K were 5 t in 1995 and 13 t in 1996 (Kulka 1998).

Predation by marine mammals remains a concern. For this stock there is no new information regarding the influence of marine mammal predation on the rebuilding. Previous assessments (DFO 2008) have concluded that predation by seals is likely a major factor contributing to high levels of mortality in both the offshore and inshore.

During the period from 2003-2007, total mortality estimated following Sinclair (2001) was 0.346 (±0.174SE) or 29% annually (Table A2). This value represents a significant decline in comparison to the previous time period. As fishing pressure has not declined over this period, the drop in total mortality seems likely the result of declines in natural mortality, though this remains speculative.

4. Southern Grand Bank (3NO)

Stock structure

Cod in 3NO are commonly distributed over the shallower parts of the Grand Bank in summer such as the southeast shoal, and on the slopes of the bank in winter.

Life History

As noted elsewhere, there have been shifts in the age of maturity during the last 40-50 years in 3NO. Age at maturity declined from around 6-6.5 to under 5 and despite some recovery, the recent cohort still seems to be maturing at <6yrs of age (Trippel *et al*. 1997; Stansbury *et al*. 2001). Thus, in an unfished state, generation time is estimated to be 11yr, yielding a three-generation time period of 33 years.

Table A2. Estimates of total mortality (Z) for cod stocks in Canadian waters. Estimates based on the descending limb of the catch curve estimated using Analysis of Co-variance (ANCOVA) following Sinclair (2001).

Stock/NAFO Division	Data Source	Age groups considered	Survey years	Z (std. error)	Percent annual mortality
2J3KL	Brattey *et al*. 2008	4-6	2003-2007	0.346 (0.174)	29%
3NO	Morgan *et al*. 2007	4-6	2006-2006	0.519 (0.214)	40%
3Ps	Brattey *et al*. 2008	5-8	2002-2007	0.899 (0.124)	59%
3Pn4RS	Alain Frechet pers. comm.	5-10	2004-2008	0.792 (0.052)	55%
4T	Swain *et al*. 2008	7-11	2004-2008	0.722 (0.114)	51%
4Vn	M. Fowler pers. comm.	5-10	2003-2007	0.791 (0.117)	55%
4VsW	R. Mohn pers. comm.	3-8	2004-2008	0.845 (0.151)	57%
4X	J. Emberley pers. comm.	4-7	2004-2008	1.420 (0.273)	76%
$5Z_{jm}$	Clarke *et al*. (2008)	4-7	2003-2007	0.437 (0.193)	35%

<u>Abundance trends</u>

Survey catch data from the Spring RV survey and VPA estimates of abundance are from Morgan *et al*. (2007) and provided by J. Morgan, Fisheries and Oceans Canada. As per above, the areal expansions of survey abundance were calculated using the number of trawlable units in the survey area and the average catch at age per tow. Again this was based on the autumn RV survey and all data are presented as Campelen equivalents (Figure A3a). Contemporary total abundance represents about 2% of the average abundance of the 1960’s, and 25% of 2002. The abundance of mature individuals represents about 40% of the 2002 estimate (Figure A3a). Estimates of the 3-generation rate of decline indicate a 98% and 97% decline using the RV data or VPA respectively (Figure A3b, Table A1).

<u>Area of occupancy</u>

Between 2002 and 2007(since the last report), the area of occupancy has increased from 61,000 km^2 to 93,000 km^2 and the D95 from 29,000 km^2 to 48,000 km^2. This increase is similar to the increase from 1996 to 2001 and within the range of variation observed. Taken with the abundance data it seems that cod in 3NO are less aggregated in recent years despite lower abundances.

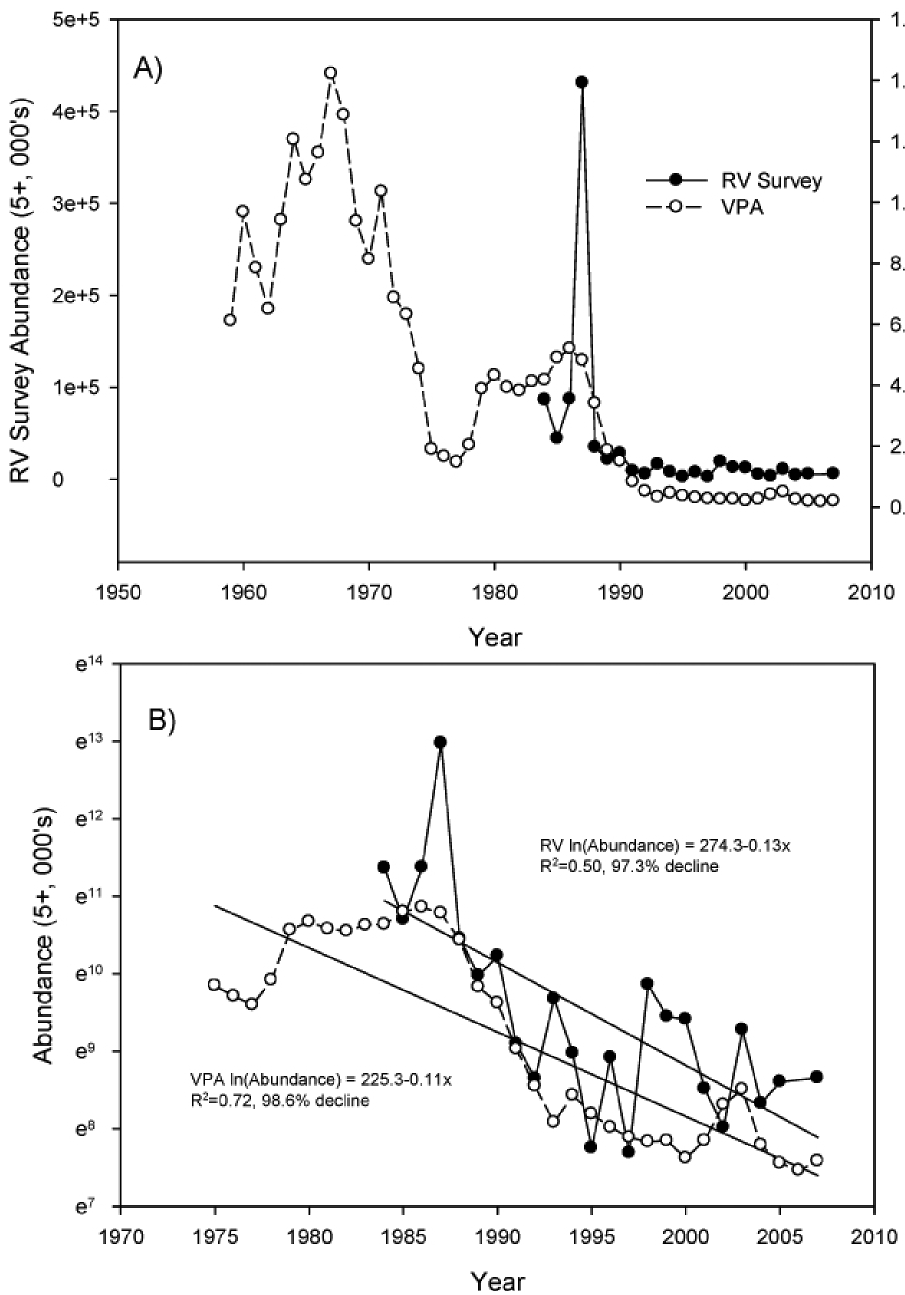

Figure A3. (A)Temporal variation in abundance of mature individuals in the southern Grand Bank cod stock (3NO). (B) Estimation of three-generation rate of decline. Data from Morgan *et al*. 2007.

Threats to recovery

DFO has identified fishing mortality as the main threat to cod in 3NO. Catches in 3NO peaked in 1967 at 227,000 t declining thereafter. Catches following the moratorium have increased from 170 t in 1995 to 4,800 t in 2003. Since 2003 catches have been below 1000 t. At the current level of fishing, spawner biomass is predicted to decline by

6% by 2012 (Shelton and Morgan 2005). During the period from 2002-2006, total mortality, estimated following Sinclair (2001), was 0.519 (±0.214SE) or 40% annually (Table A2).

5. St. Pierre Bank (3Ps)

Stock Structure

Tagging results from different regions within 3Ps (Brattey and Healey 2004, 2005, 2006) suggest that the stock comprises several offshore components and several inshore components in Placentia and Fortune Bay with limited mixing between. Regular shoreward migrations appear to occur in the offshore fish resulting in mixing with inshore fish during the summer and fall. Examinations of early life history stages within Placentia Bay suggest large amounts of eggs and larvae are exported from the Bay early in the season but local recruitment may occur later in the summer when temperatures warm (Bradbury *et al*. 2001, 2003, 2008). Egg production within the head of Placentia Bay did not correlate with local recruitment but rather stockwide recruitment suggesting either correlation or some connection (Rose *et al*. 2008). Comparison of the rate of multiyear spawning fidelity to spawning locations in Placentia Bay (~50%) and egg export from the bay (~100% Spring), suggests that mixing if it occurs may be primarily during the early life history.

Life History

Based on data from the 1960s and 1970s, age at 50% maturity is about 6-7 yrs for St. Pierre Bank cod (Brattey *et al*. 2001a, Worcester *et al*. 2009). Thus, in an unfished state, generation time is estimated to be 11yr, yielding a three-generation time period of 33 years.

Abundance Trends

The RV survey data are those reported by Worcester *et al*. (2009) and provided by B. Healey, Fisheries and Oceans Canada. Abundance data for the mature part of the population, as estimated by VPA, are also available from Brattey *et al*. (2001). The earliest year for which survey data are available is 1983. It is worth noting that the RV survey was conducted in the winter from 1972-1993, but moved to spring due to concerns of winter mixing between from 3Pn4RS (Worcester *et al*. 2009). Also since 1997, the survey has been modified to include inshore strata increasing the surveyed area by 12%. As with previous Newfoundland stocks, all data are presented in Campelen equivalents to account for the change from the Engel trawl. VPA estimates of abundance from the last accepted VPA (John Brattey, personal communication) extend from 1959 to 2000 (Figure A4a). The 3-generation rate of decline experienced by St. Pierre Bank cod was 65% and 41% for the RV survey and VPA respectively (Figure A4b, Table A1). Estimates of total abundance and abundance of mature individuals have been highly variable over time; however, since 2002 the number of mature individuals has dropped by 75%. The 2009 assessment, based on the DFO Spring RV survey, indicates that the stock has declined by a factor of 3 since 2004. Other sources of data include DFO sentinel surveys which show clear declines during the late 1990s and have remained low and stable since (Maddock Parsons and Stead 2007). In addition, an industry survey (1997-2005, McClintock 2007, Worcester *et al*. 2009) indicates that the total abundance index is highly variable and the 2004 and 2005 values were record lows.

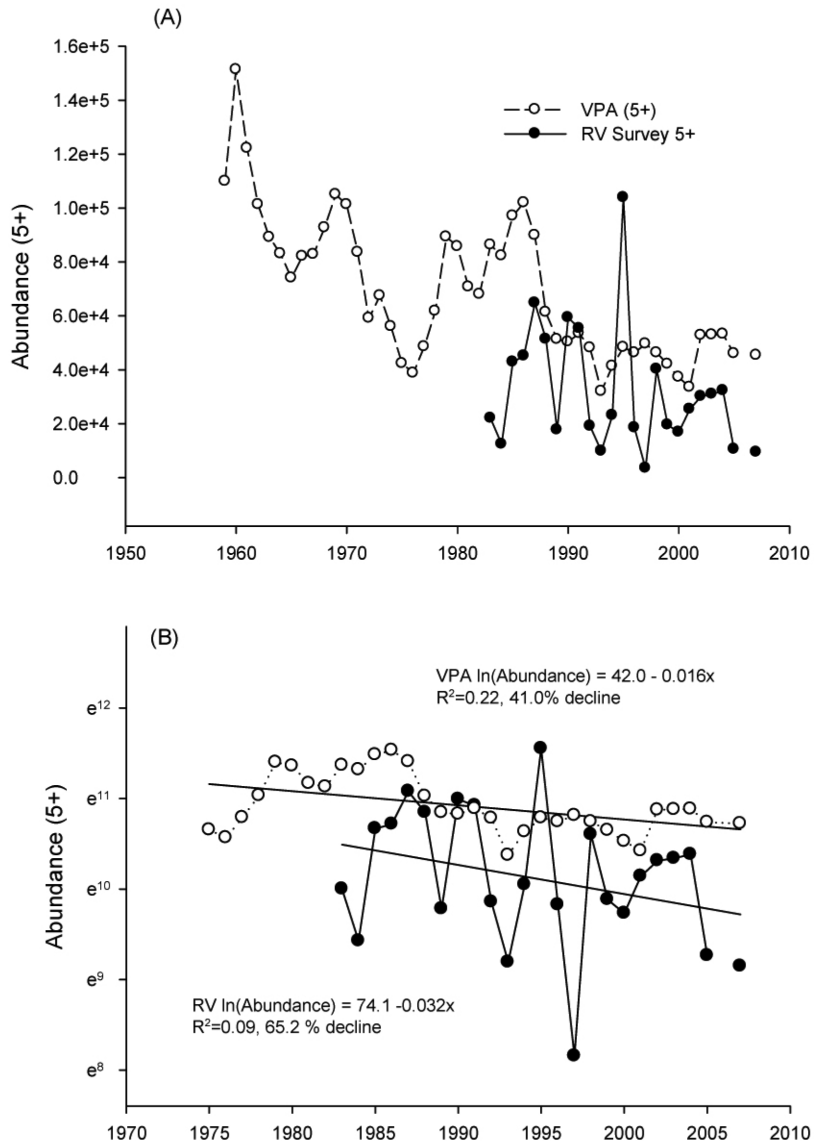

Figure A4. (A)Temporal variation in abundance of mature individuals in the St. Pierre Bank cod stock (3Ps). (B) Estimation of three-generation rate of decline. VPA estimates have not been available since 2000 (Worcester *et al*. 2000). Following COSEWIC (2003), presented data for 2001-2007 are an extrapolation based the relationship between VPA abundance and RV survey abundance for the time period 1983 to 2000. This extrapolation is done for the purposes of rate of decline calculation only.

Area of occupancy

Between 1983 and 2007 (the range of the reported data), area of occupancy, has been variable ranging from 30,000 km^2 to approximately 50,000 km^2 and the D95 index ranged between 10,000 km^2 to 25,000 km^2.

Threats to recovery

Worcester *et al*. (2009) estimated total mortality and concluded that the annual mortality rate was on average 30% during 1997-2007 and concluded that fishing mortality during this period has not been excessive. In the period 2001-2005, exploitation rates estimated based on tagging studies suggests exploitation was highest in Placentia Bay reaching 22-31%, and declined to the offshore. These high rates may pose a strong risk to the persistence of resident groups which do not migrate offshore (Mello and Rose 2005). During the period from 2002-2007, total mortality, estimated following Sinclair (2001), was 0.899 (±0.124SE) or 59% annually (Table A2).

6. Northern Gulf of St. Lawrence (3Pn4RS)

Stock Structure

Cod in 3Pn4RS are characterized by extensive migrations throughout Newfoundland's southern coast and Quebec's middle and lower north shore (Worcester *et al*. 2009). Tagging data suggests mixing occurring in the northwest Gulf of St. Lawrence, the Strait of Belle Isle, and the Burgeo Bank area. Tagging data predicts up to 75% of cod in the Burgeo Bank area of 3Ps in winter may be 3Pn4RS cod (Worcester *et al*. 2009). Within this region Templeman (1962) identified stocks associated with Burgeo Bank, western Newfoundland, and possibly the North Shore of the Gulf of St. Lawrence but noted significant spatial overlap particularly during winter months. Several studies (Templeman 1962, Campana *et al*. 1999) also identified the Laurentian Channel as a significant barrier (<5% straying across) though the nature of this barrier is unclear.

Life History

Life history characteristics of cod in 3Pn4RS have been variable over the last few decades. Growth, condition, size and age at maturity all declined in the 1980s but have rebounded since the mid-1990s and since 2000 have returned to 1980s levels. Based on maturity-at-age data for the 1970s and 1980s, age at 50% maturity is about 4yr for northern Gulf cod. Thus, in an unfished state, generation time is estimated to be 9yr, yielding a three-generation time period of 27 years.

Abundance Trends

Both the DFO RV survey data and the VPA-based abundance data for the mature part of the population were provided by A. Fréchet, Fisheries and Oceans Canada (Figure A5a). The earliest year for which survey data are available is 1990. VPA estimates of abundance extend back to 1974, and although there were two accepted VPA formulations in 2008, the rates of decline are similar so only one is shown (Fixed M). Only the VPA estimates encompassed the 3-generation time frame, and these data suggest a decline rate of 97% (Figure A5b, Table A1). In addition to the RV and VPA estimates, fixed gear sentinel fisheries provide two abundance indices. The abundance index of gillnet sentinel fisheries more than doubled from 2001 to 2003 peaking in 2006. The abundance index from the longline sentinel fisheries also increased from 2004 to 2006. Both the sentinel indices dropped from 2006 to 2007 (Worcester *et al*. 2009).

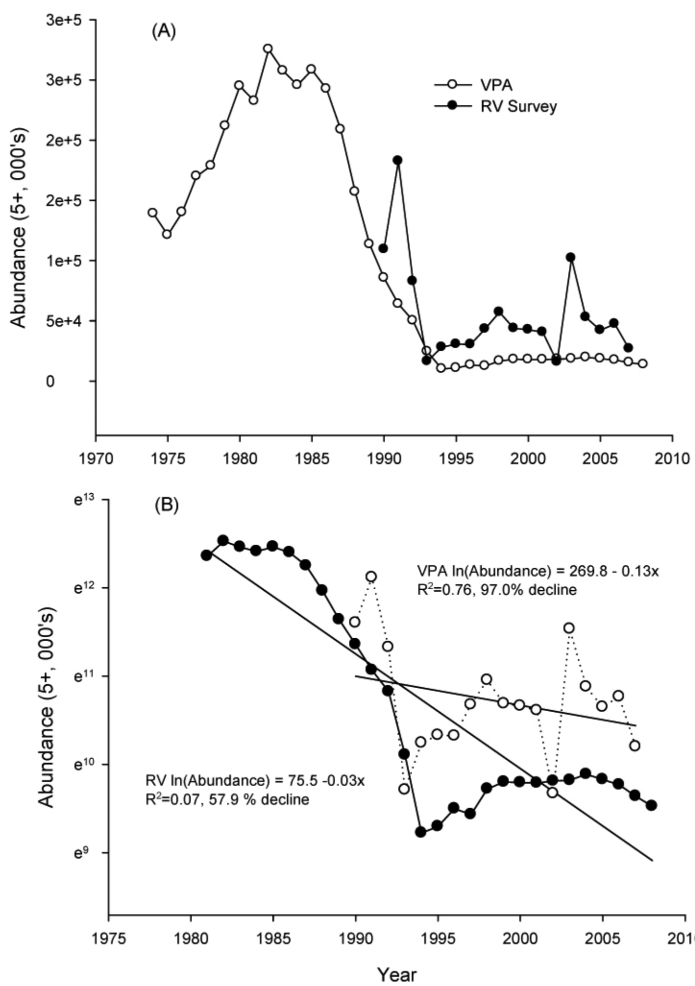

Figure A5. (A)Temporal variation in abundance of mature individuals in the Northern Gulf of St. Lawrence cod stock (3Pn4RS). (B) Estimation of three generation rate of decline. Data from Worcester *et al*. (2009) and Fréchet *et al*. (2007).

Area of occupancy

There was a decline in area of occupancy and geographic range from 1990 to 2002 (24%, Smedbol *et al*. 2002). Since that time the area of occupancy has risen from 40,000 km^2 to 60,000 km^2 and the D95 has risen from 25,000 km^2 to 40,000 km^2 for the period 2002 to 2008. Most of this increase appears due to spreading into 4S (Worcester *et al*. 2009).

Threats to recovery

Prior to 2002, exploitation rates had been steadily increasing to an estimated 30% in 2001 (Smedbol *et al*. 2002). Since 2002, fishing mortality continues to be the main threat to the stock. Spawning stock biomass is estimated to be well below the conservation limit (Worcester *et al*. 2009). Landings exceeding 5,500 tons recorded between 1999 and 2002 and in 2007 resulted in a 16% drop of mature biomass with exploitation rates reaching 29%. Such exploitation levels are inconsistent with a rebuilding strategy (Worcester *et al*. 2009). In addition to fishing, marine mammal predation appears to pose a threat to recovery for northern Gulf cod, as revealed by McLaren *et al*.'s (2001) statement: "The conclusion that seals are important predators on cod in this area appears to be inescapable". During the period from 2004-2008, total mortality, estimated following Sinclair (2001), was 0.792 (±0.0.52SE) or 55% annually (Table A2).

7. Southern Gulf of St. Lawrence (4TVn)

Stock Structure

Cod in the southern Gulf of St. Lawrence generally occupy summer spawning and feeding grounds throughout the Magdalen Shallows before overwintering outside the Gulf along the southern slope of the Laurentian Channel (4Vn) at depths near 200m (Campana *et al*. 1999; Ruzzante *et al*. 2000). As such the stock is usually identified as 4TVn(Nov.-Apr.). Within the Gulf, Templeman (1962) identified five distinct stocks in this region based on vertebral numbers, tag returns, and summer distributions but noted significant mixing likely occurs during winter. Between the Southern Gulf and neighbouring stocks, Campana *et al*. (1999) suggests that despite the apparent mixing during the winter months in the Cabot Strait, the various overwintering stocks maintain small-scale discrete spatial structure on scales <20km and as such actual mixing may be minimal.

Life History

Age at maturity in this stock declined in the 1960s and early 1970s but has remained roughly constant since then (Beacham 1983; D.P. Swain, unpublished analyses). The continued slow growth rate of 4T cod has been attributed to strong selection against fast growth which occurred in the late 1980s resulting in evolutionary changes within the stock (Swain *et al*. 2007). Data from the RV surveys (1990 to 1995) indicated that 12% of southern Gulf cod were mature at age 3, 37% at age 4, 72% at age 5, 91% at age 6, 97% at age 7 and 100% at older ages and age at 50% maturity is about 4.5yr (Trippel *et al*. 1997; Doug Swain, DFO, Moncton, personal communication). Thus, generation time is estimated to be 9.5yr, yielding a three-generation time period of 28.5 years.

Abundance Trends

The RV survey and VPA data are reported by Chouinard *et al*. (2008) and provided by D. Swain, Fisheries and Oceans Canada. A bottom-trawl survey of the southern Gulf has been conducted each September since 1971 (Figure A6a). The survey follows a stratified-random design based on the 24 strata. It is worth noting that a change from 12-hr to 24-hr sampling occurred in 1985, the gear changed from the Yankee-36 to the Western IIA trawl in 1985; and the survey has utilized four vessels over its time course. Comparative fishing experiments were conducted to estimate the effect of each of these changes on fishing efficiency and estimate conversion factors (Nielsen 1989, 1994; Swain *et al*. 1995; Benoît 2006). VPA-based estimates of abundance extend back to 1950 (Figure A6a). Estimated rates of decline for Southern Gulf cod ranged from 86% to 85% over the past three generations for the RV survey and VPA data respectively (Figure A6b, Table A1). Chouinard *et al*. (2008) estimated the 2008 SSB at 36,000 t which is the lowest value in the 59-yr record and well below the limit reference point for this stock (80,000 t). The 2009 assessment estimated SSB at the beginning of 2009 to be only 28,000 t (DFO 2009d) and the population no longer appears to be viable even in the absence of fishing (Swain and Chouinard 2008).

Area of Occupancy

The geographic distribution of cod in 4T during the summer months appears density-dependent, expanding into offshore colder water at high abundance and contracting to shallower inshore waters at low abundance (Swain and Sinclair 1994, Swain 1999) and as such largely tracks total abundance. Both area of occupancy and D95 increased from intermediate values in the early 1970s to peak values in the mid-1980s and then steadily declined throughout the 1990s to the lowest levels observed in the 38-yr time series. In the 2000s, average area of occupancy ranged from 51000 km^2 for ages 5+ to 57000 km^2.

Threats to Recovery

Since 1999, exploitation rates have been <10% (Worcester *et al*. 2009). Despite low exploitation rates, the most important factor contributing to the current low productivity of the southern Gulf cod stock remains elevated M (Swain and Chouinard 2008). Estimates of M from the recent VPA (Chouinard *et al*. 2008) suggest that M began increasing in the 1980s reaching a current value near 0.6. Causes of this high M are unknown, though grey seal predation remains a likely candidate (DFO 2009e). It is unlikely that unreported catch could account for the high estimates of M in the period after 1993, when there has been minimal fishing effort (Chouinard *et al*. 2005). Proposed hypotheses for elevated M of cod in this or other Northwest Atlantic Cod stocks include poor fish condition due poor environmental conditions (Dutil and Lambert 2000), increased survival costs to reproduction due to fishery-induced declines in age and size at maturity (Hutchings 2005), and increased predation by the expanding grey seal herd (Chouinard *et al*. 2005, DFO 2009e). Population projections indicate that even without harvest in 2008, SSB is will decline by at least 10%, with a 53% probability of a 15% decline or greater (Chouinard *et al*. 2008). Long-term stochastic projections (Swain and Chouinard 2008) at the current productivity suggest the spawning stock biomass is certain to be less than 1000 t within 40 years in the absence of fishing, and within 20 years with fishery removals at the level of the TAC in 2007 and 2008 (2000 t) (Figure A6c). Swain and Chouinard (2008) warn that as M appears to be increasing, these projections may be overly optimistic. During the period from 2004-2008, total mortality, estimated following Sinclair (2001), was 0.722 (±0.0.114SE) or 51% annually (Table A2).

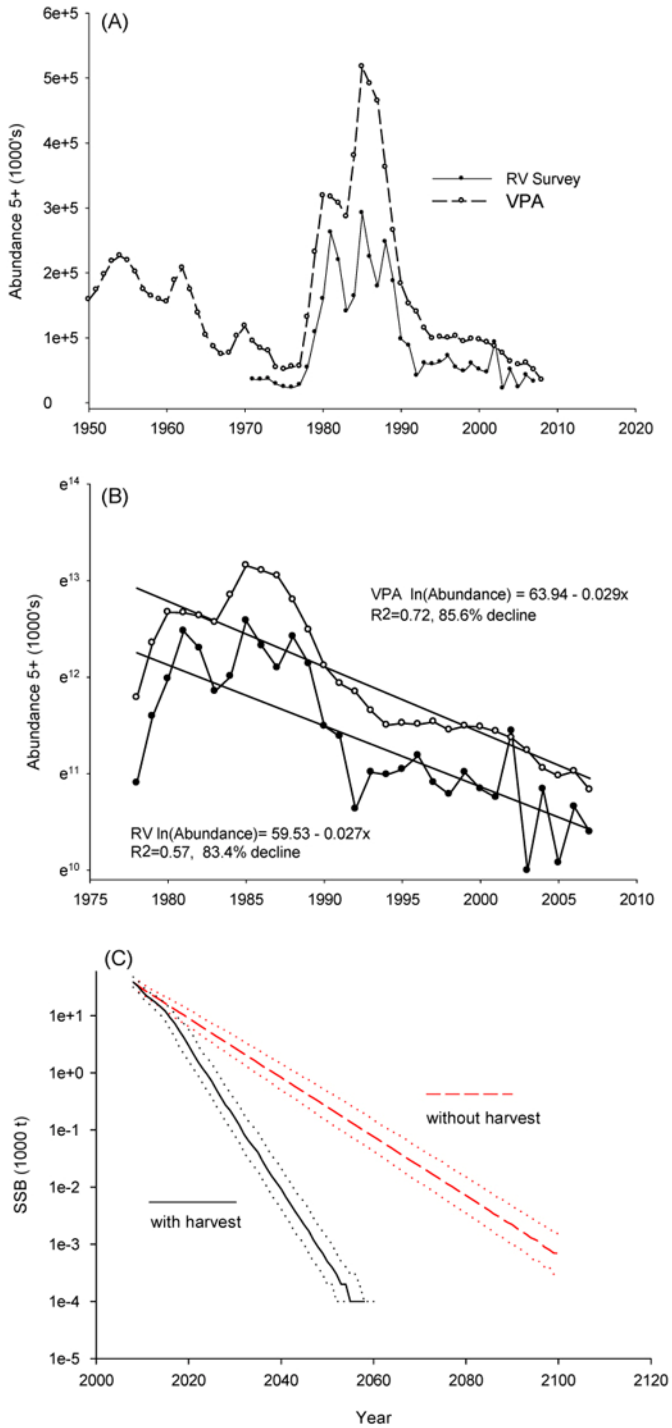

Figure A6. (A)Temporal variation in abundance of mature individuals in the Southern Gulf of St. Lawrence cod stock (4TVn). (B) Estimation of three-generation rate of decline. (C) Projections of population trends. See Chouinard *et al*. 2008 and Worcester *et al*. 2009 for details regarding data.

8. Cabot Strait (NAFO 4Vn)

Stock Structure

Cod in 4Vn are resident fish found in Sydney Bight, Cape Breton from St. Paul Island to Fourchu. As Gulf cod migrate into the area to overwinter, the stock is assessed and defined using the May-October period (i.e. 4Vn (May to Oct)).

Life History

Based on data from the 1970s and 1980s for 4T cod, age at 50% maturity is about 4.5yr for southern Cabot Strait cod (Trippel *et al*. 1997). Thus, in an unfished state, generation time is estimated to be 9.5yr, yielding a three-generation time period of 28.5 years.

Abundance Trends

Available data include the RV survey data which are available from 1970 to 2007 (Worcester *et al*. 2009, provided by M. Fowler, Fisheries and Oceans Canada) and VPA-based estimates of abundance are those reported by Mohn *et al*. (2001) which extend from 1981 to 2001. The survey data indicate the presence of a strong decline since the 1980s, with 2004 being the lowest year on record (Worcester *et al*. 2009) (Figure A7a). VPA-based abundances since 2001 were estimated to allow decline rate calculation following COSEWIC (2003) using the relationship between RV data and VPA data for the period 1981-2001 (R=0.73). The rate of decline experienced by Cabot Strait cod over the last 3 generations was estimated as 91% or 94% for the RV survey and VPA respectively (Figure A7b, Table A1).

Area of Occupancy

During the period 1990-2003 the area of occupancy displayed a gradual decline from 10,113 km^2 to 5073 km^2. Since 2003 the values have risen again slightly with 2007 at 7026 km^2.

Treats to Recovery

Since 1994, exploitation rates have remained very low at approximately 2% (Smedbol *et al*. 2002). Nonetheless, total mortality continues to be very high suggesting that natural mortality is the single most important factor threatening this stock (Worcester *et al*. 2009). At present the cause of this high natural mortality remains unknown (D. Swain, pers. comm.). DFO (2009e) recently concluded that this high mortality rate was likely associated with grey seal predation; however, the magnitude of the effect remains uncertain. During the period from 2003-2007, total mortality, estimated following Sinclair (2001), was 0.791 (±0.117SE) or 55% annually (Table A2).

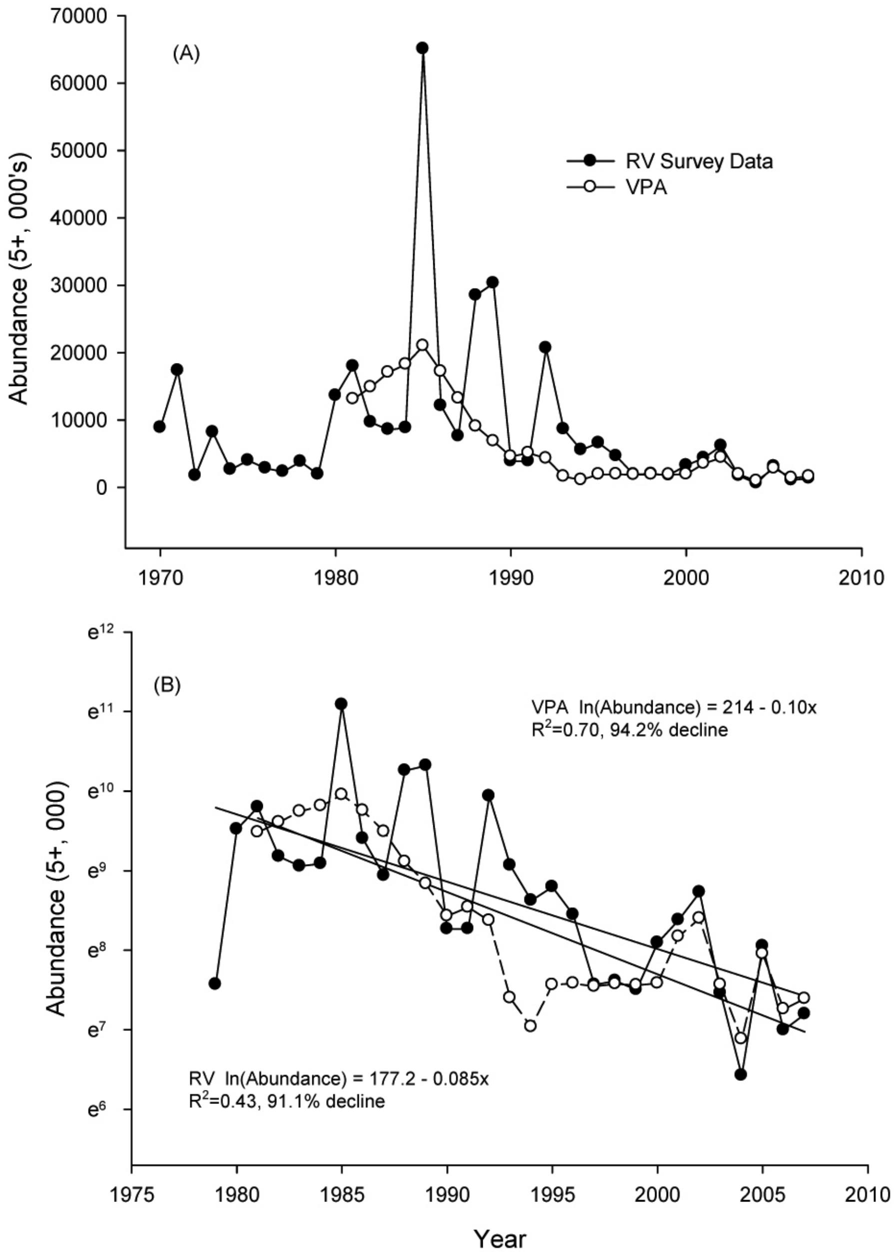

Figure A7. (A)Temporal variation in abundance of mature individuals in the Cabot Strait cod stock (4Vn). (B) Estimation of three-generation rate of decline. VPA estimates have not been available since 2001 (Mohn *et al*. 2001). Following COSEWIC (2003), presented data for 2001-2007 are an extrapolation based the relationship between VPA abundance and RV survey abundance for the time period 1981 to 2000. This extrapolation is done for the purposes of rate of decline calculation only. See Worcester *et al*. (2009) for data.

9. Eastern Scotian Shelf (NAFO 4VsW)

Stock Structure

Cod in 4VsW comprise a network of several offshore spawning locations as well as multiple inshore spawning sites (Frank *et al*. 1994). Templeman (1962) identified Western/Sable, Banquereau, and Canso Banks as possessing local stocks though there was evidence for overwintering fish from coastal Nova Scotia and the southern Gulf.

Life History

Based on data from the 1980s and 1990s, age at 50% maturity is about 4yr for eastern Scotian Shelf cod (Trippel *et al*. 1997). Thus, in an unfished state, generation time is estimated to be 9yr, yielding a three-generation time period of 27 years.

Abundance Trends

The survey data and VPA data were provided by R. Mohn, Fisheries and Oceans Canada. Abundance data for the mature part of the population, as estimated by VPA, and the RV survey extends from 1970 to 2007 (Figure A8a). The 3-generation rate of decline experienced by Eastern Scotian Shelf cod ranges between 93% and 80% for the survey data and VPA respectively (Figure A8b, Table A1).

Area of Occupancy

Between 1970 and 2007 (the range of the reported data), area of occupancy declined from approximately 78,000 km^2 to approximately 50,000 km^2.

Threats to Recovery

Since 1994, exploitation rates have remained very low at less than 2% (Smedbol *et al*. 2002). During the period from 2004-2008, total mortality, estimated following Sinclair (2001), was 0.845 (±0.151SE) or 57% annually (Table A2). DFO (2009e) recently concluded that this high mortality rate was likely associated with grey seal predation to some degree; however the magnitude of the effect remains uncertain.

10. Western Scotian Shelf/Bay of Fundy (4X/5Y)

Stock Structure

Cod in 4X are widely distributed geographically displaying both fall and spring spawning behaviour and Templeman (1962) listed 7 discrete populations within 4X. Fall spawning has been observed in the areas of Halifax Harbour, Sambro Head to St. Margarets Bay (McKenzie 1940, Templeman 1962) with spring spawning occurring on mainly on Browns Bank. In addition, tagging studies (Halliday 1971, Hunt *et al*. 1999) and phenotypic (Clarke and Perley 2006) differences support a division between cod from the Bay of Fundy and those inhabiting the western Scotian Shelf. There does appear to be some mixing of cod through the Gulf of Maine, Georges Bank and Scotian Shelf areas.

Life History

Based on data from the 1970s and 1980s for 4X cod, age at 50% maturity is about 2.5yr (Trippel *et al*. 1997). Thus, in an unfished state, generation time is estimated to be 7.5yr, yielding a three-generation time period of 22.5 years.

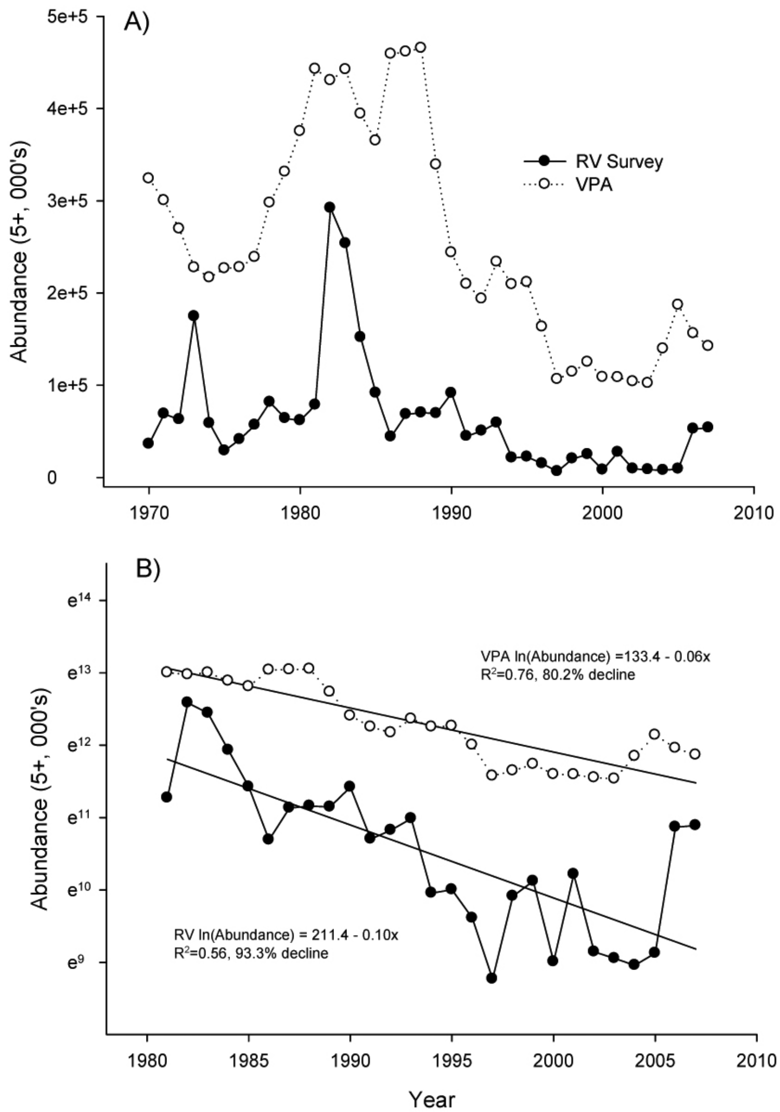

Figure A8. (A)Temporal variation in abundance of mature individuals in the Eastern Scotian Shelf cod stock (4Vsw). (B) Estimation of three-generation rate of decline. Data from R. Mohn (pers comm), and Worcester *et al*. (2009).

Abundance Trends

The survey data and VPA-based (Clarke *et al*. 2002) estimates of abundance were provided by D. Clark and J. Emberley, Fisheries and Oceans Canada. The earliest year for which survey data are available is 1970. VPA estimates of abundance at the time of the calculations for this status report extended from 1948 to 2002 and have been projected forward using the relationship for the overlapping period with the RV Survey ($R=0.7$, $p<0.001$). Abundance estimates from the RV surveys have been variable but show a decline in recent years to the lowest level on record in 2008 (Figure A9a, Clark and Emberley 2008). The 3-generation rate of decline experienced by cod on the Western Scotian Shelf and Bay of Fundy is estimated at 72% irrespective of data used (Figure A9b, Table A1). The 2009 assessment of this stock extends the VPA and provides estimates of SSB at the beginning of 2008 of 9,000 t, the lowest level in the time series for this stock (DFO 2009f).

Area of Occupancy

Between 1970 and 2002 the area of occupancy, declined slightly from approximately 45,000 km^2 to approximately 31,000 km^2 and since then has stabilized and slightly increased to 36,000 km^2.

Threats to Recovery

The primary threat to cod in 4X continues to be fishing. Although there is no directed cod fishery, cod is caught as part of multispecies groundfish fishery. Fishing mortality remains well above the 0.20 target and the TAC decline from 6000 t in 2000 to 5000 t in 2005 (Worcester *et al*. 2009). In recent years the TAC has not been caught and in 2007, DFO estimates 3790 t were taken in 4X. Possible sources of unknown mortality include the influence of a growing grey seal population and other sources of bycatch such as associated with the commercial Lobster fishery. Estimates of natural mortality have been unusually high since the mid- 1990s. During the period from 2004-2008, total mortality, estimated following Sinclair (2001), was 1.42 (±0.273SE) or 76% annually and was the highest in Canadian waters (Table A2). Mortality due to sources other than reported landings has also been high (DFO 2009f), estimated at 0.70 (46%).

11. Georges Bank ($5Z_{jm}$)

Stock Structure

There is no evidence of substructure within this region (Smedbol *et al*. 2002). However, there is evidence from tagging data of mixing between $5Z_{jm}$ and 4X. Hunt *et al*. (1999) and Wise (1963) documented mixing rates of up to 15% between Georges Bank and Browns Bank and the Bay of Fundy (4X). Recent tagging experiments suggest these rates are currently between 5-6%.

Life History

Based on data from the 1970s and 1980s, age at 50% maturity is about 2.5yr for Georges Bank cod (Hunt and Hatt 2002). Thus, in an unfished state, generation time is estimated to be 7.5yr, yielding a three-generation time period of 22.5 years.

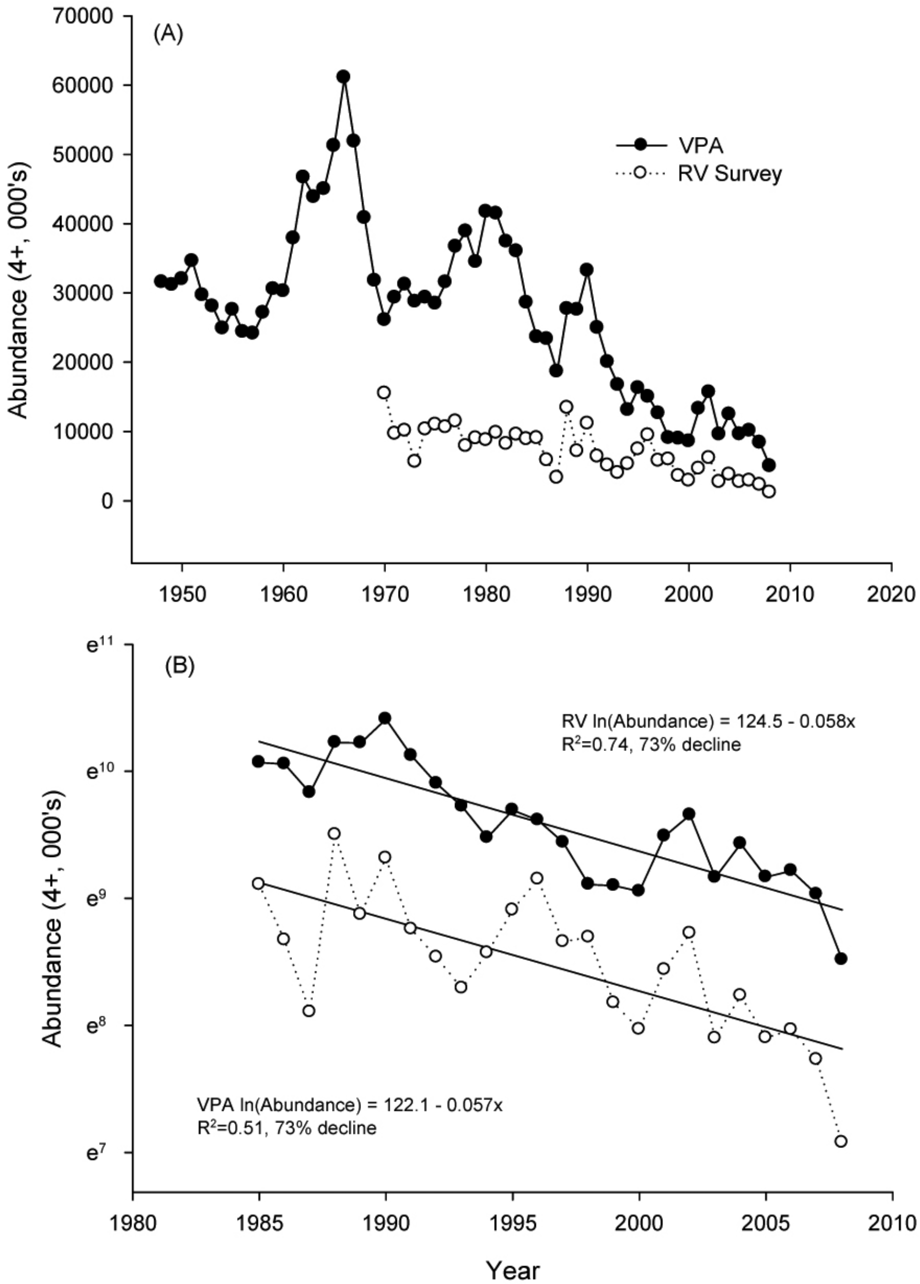

Figure A9. (A)Temporal variation in abundance of mature individuals in the Western Scotian Shelf/Bay of Fundy cod stock (4X). (B) Estimation of three-generation rate of decline. VPA estimates have not been available since 2002 (Clarke *et al*. 2002). Following COSEWIC (2003), presented data for 2002-2008 are an extrapolation based the relationship between VPA abundance and RV survey abundance for the time period 1985 to 2002. This extrapolation is done for the purposes of rate of decline calculation only.

Abundance Trends

The survey and VPA abundance data are those reported by Clark *et al*. (2008), and provided by K.J. Clark, Fisheries and Oceans Canada. Three research vessel surveys are used as indices in the eastern Georges Bank cod assessment: the NMFS spring and fall surveys and the DFO winter survey. The NMFS spring survey is partitioned into two indices to account for a change in the survey trawl in 1982. The earliest year for which survey data are available is 1978 for the U.S. NMFS (National Marine fisheries Service) fall survey and 1986 for DFO's spring survey (Figure A10a). VPA estimates of abundance extend back to 1978 (Figure A10a). Although only the eastern portion of Georges Bank lies within Canadian waters, the abundance trends represent both Canadian and US portions of Georges Bank. The estimated rate of decline for Georges Bank cod differed considerably among the sources of abundance data. Estimated rates of change over three generations ranged between 49% for the VPA data to 4% increase for the survey data (Figure A10b, Table A1). In general, the VPA abundance data reveal a steady decline since the late 1970s, and the survey catch rate data available since the mid-1980s are highly variable (Figure A10a).

Area of Occupancy

Between 1987 and 2007 (the range of the reported data), area of occupancy, remained unchanged at approximately 14,000 km^2 (Worcester *et al*. 2009).

Treats to Recovery

Between 1995 and 2004 fishing mortality varied for this stock from 0.19-0.50 and since 2005 fishing mortality has been below 0.18 with 2007 at 0.13. The source of this mortality is bycatch associated with the haddock fishery. It remains unclear to what degree marine mammal predation is influencing this stock. During the period from 2003-2007, total mortality, estimated following Sinclair (2001), was 0.437 (±0.193SE) or 35% annually (Table A2).

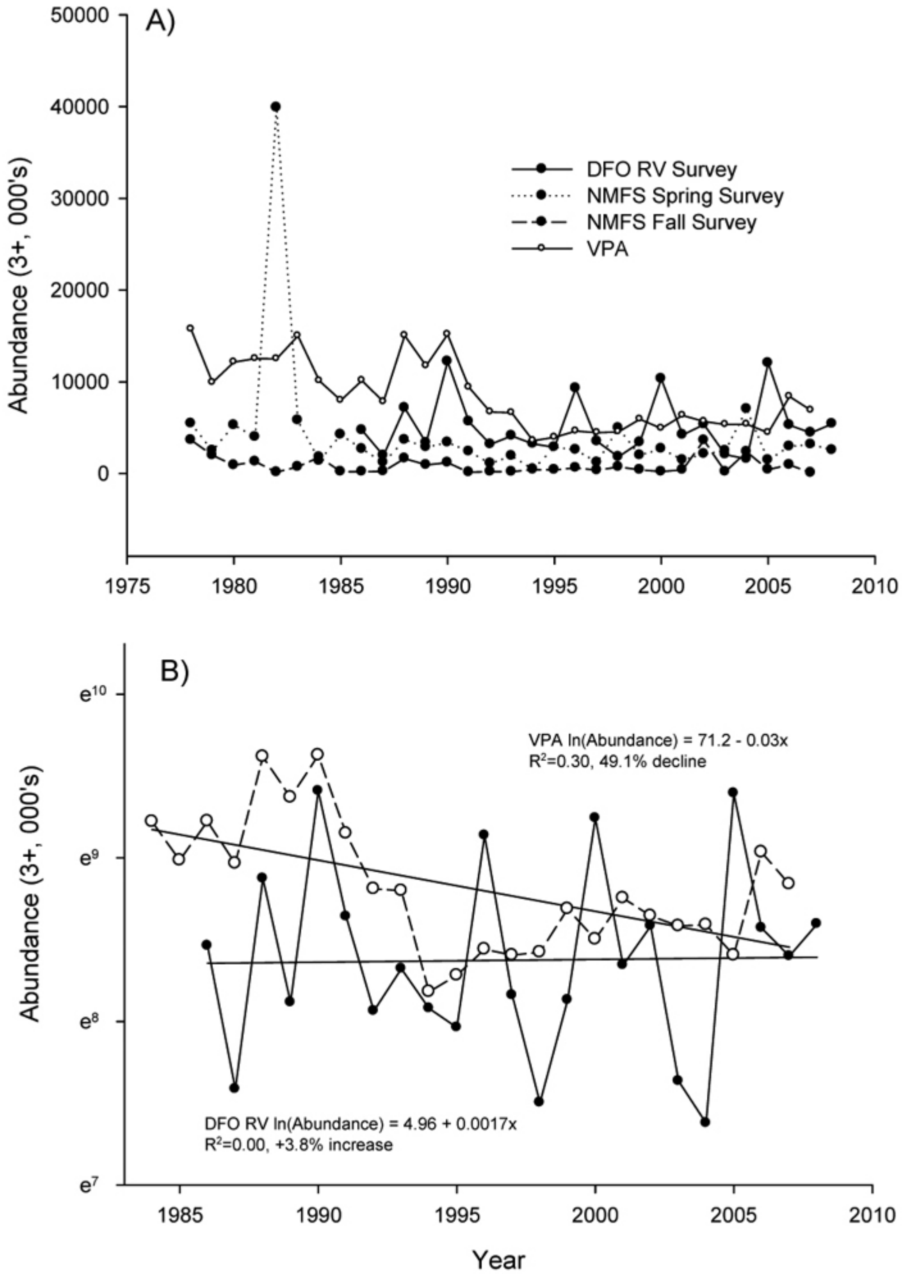

Figure A10. (A)Temporal variation in abundance of mature individuals in the Eastern Georges Bank cod stock ($5Z_{jm}$). (B) Estimation of three-generation rate of decline. Data from Clarke *et al*. 2008 and Worcester *et al*. 2009.