

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° C (Brander 1994), it is clear that cod in some areas off Newfoundland are able to withstand temperatures as low as -1.5° C (Goddard *et al.* 1999). This temperature is below that (-0.5 to -0.8° 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; Bratley *et al.* 2001b, Bratley *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; Bratley *et al.* 2008a). For example, Bratley *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 (*Tautoglabrus 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 ≥ 5.0 yr for all stocks, except ≥ 4.0 yr for Western Scotian Shelf/Bay of Fundy cod and ≥ 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 $\ln(N_t) = \alpha + \beta \cdot t$. The percentage decline over y years can be calculated as $(1 - \exp(\beta \cdot y)) \cdot 100$.

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 DWA0, 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 DWA0 data will be primarily reported. This status report recommends the identification of six DUs of Atlantic Cod which are detailed below.

Arctic Lakes DU

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 <i>et al.</i> 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.

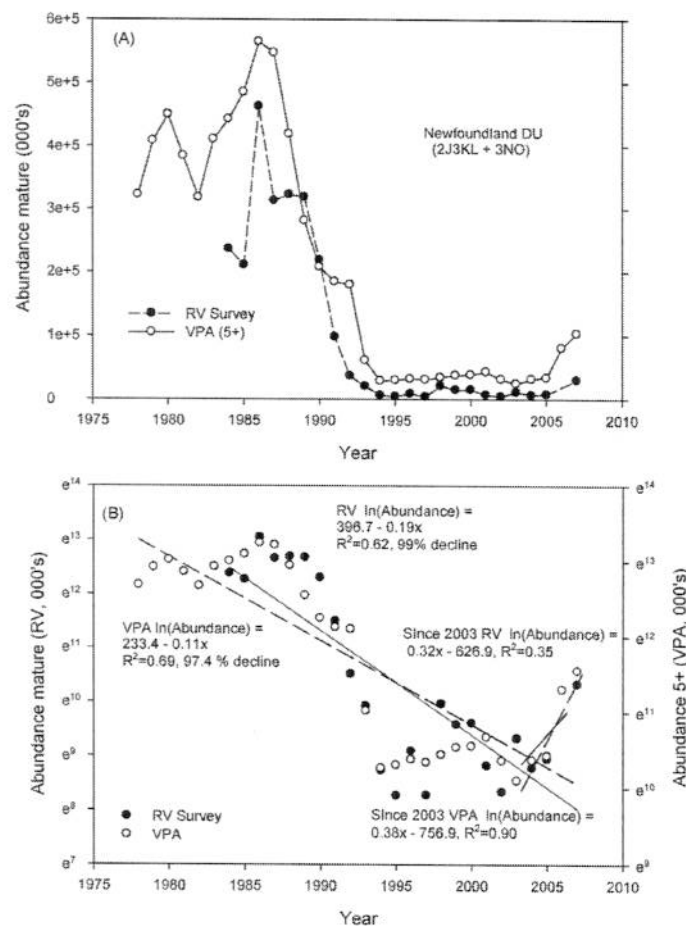


Figure 8. Temporal variation in the estimated number of mature individuals in the Newfoundland and Labrador DU (A). Data for northern cod (NAFO 2J3KL) and southern Grand Bank cod (NAFO 3NO) are shown in Appendix 1. (B) Plot of \log_e (abundance, N_t) versus time (t , in years) for the Newfoundland and 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 stock assessments of the 2K3KL and 3NO populations 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 km² (D95-169,000 km²).

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.

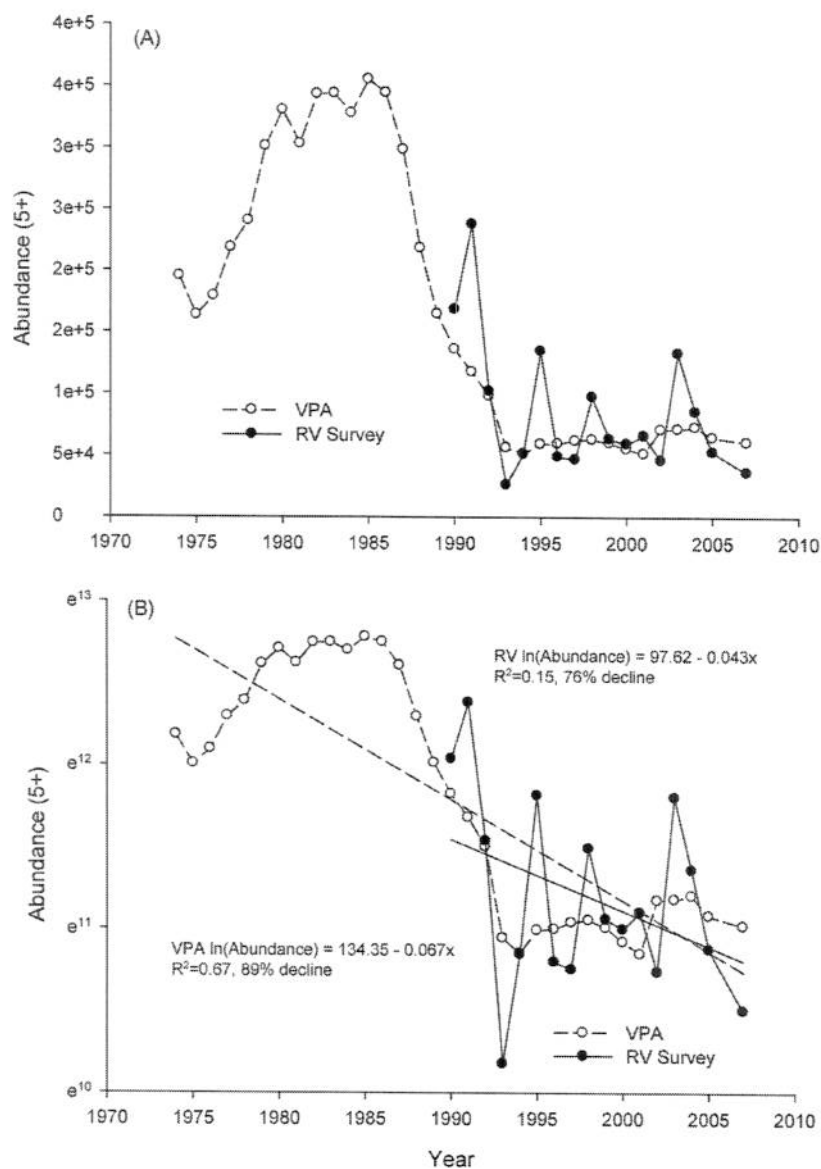


Figure 9. Temporal variation in the estimated number of mature individuals in the Laurentian North DU (A). Data from the 3Ps and 3Pn4RS stocks are shown in Appendix 1. (B) Plot of \log_e (abundance, N_t) versus time (t , in years) for the Laurentian North DU and the estimation of the 3-generation rate 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 km² (Worcester *et al.* 2009). Area of occupancy data for the years 1991 to 2001 declined marginally from approximately 96,000 km² to approximately 89,000 km², a decline of roughly 7% (Smedbol *et al.* 2002). Since 2002, the area of occupancy increased from approximately 76,000 km² to approximately 101,000 km², and the D95 increased from 35,000 km² to 62,000 km² (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.