The Biological Collapse of Newfoundland’s Northern Cod

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The sustainability of communities from southeastern Labrador to southeastern Newfoundland is tied inextricably to the sustainability of the fish stock known as northern cod, *Gadus morhua*. This has been so since the early seventeenth century, when the English and French first established year-round settlements in Newfoundland (Cell 1982). When the moratorium on commercial fishing for northern cod was announced in 1992, an estimated 16 per cent of the total workforce – as much as 90 per cent in many communities – was directly employed by the fishery (Cashin 1993). However, since Canada’s extension of its fisheries jurisdiction limit to 200 miles (322 kilometres) in 1977, these communities have not simply depended on the sustainability of northern cod. They have also been dependent on the management strategies established by the Canadian Department of Fisheries and Oceans (DFO), whose mandate includes the establishment of harvesting regulations designed to conserve commercial fish species and to ensure their long-term viability. Against these socio-economic and institutional backgrounds, this chapter assesses the strengths and weaknesses of the main scientific hypotheses that have been proposed to explain the collapse of northern cod.

The influence of social interactions within DFO on the interpretation of fish stock assessments has been recently examined by Finlayson (1994). Within this context, and based on personal experience with recent reviews of stock assessments, I comment on the process by which a consensual view is reached at DFO stock assessment meetings. While providing personal comment is unavoidably encumbered with personal bias, the difference between this approach and that of a formal research study lies in the nature of the bias, since the latter has its own methodological and researcher-induced biases.

For simplicity, and to be consistent with previous treatments of this topic (for
example, Finlayson 1994), I refer to the assessment of stock status as ‘science,’
though some would argue it is not. Involving the formulation and testing of
hypotheses, fisheries science embodies that body of work intended to provide
information on the biology and population dynamics of harvested fishes. Such
information can include data on age structure, movement and migration, verti-
cal and horizontal patterns of abundance (i.e., distribution), relationships with
other species, morphological, behavioural, and genetic distinctiveness, life his-
tory strategies (i.e., age-specific rates of survival and fecundity), and associa-
tions between physical environmental factors (such as temperature and salinity)
and biological variables (such as growth rate and survival) (see Villagarcia et
al., this volume). Stock assessment, in contrast, is the estimation of past,
present, and future abundance (or biomass) of, and the past fishing mortality
imposed on, a given fish stock. These estimates are based on commercial catch
statistics and research surveys.

The Collapse

The Newfoundland fishery for Atlantic cod was once the largest (McGrath
1911) and the most productive (Thompson 1943) cod fishery in the world. Its
‘northern’ cod component has constituted upward of 70 per cent of all New-
foundland catches since 1954 and probably did so for most of the five hundred-
year history of the fishery (Hutchings and Myers 1995). The geographical range
of northern cod extends from southern Labrador southeast along the northeast
Newfoundland shelf to include the northern half of the once biologically rich
Grand Banks. For management purposes, northern cod are defined as those cod
found in Northwest Atlantic Fishery Organization (NAFO) divisions 2J (sou-
thern Labrador), 3K (northeast Newfoundland shelf), and 3L (northern Grand
Bank). Despite this geographical designation of the northern cod ‘stock,’ it is
highly probable that several inshore and offshore populations of cod exist
within these NAFO divisions (Hutchings, Myers, and Lilly 1993; Lear 1984;
Ruzzante et al. 1996; Templeman 1966; Thompson 1943).

Historical data suggest that northern cod catches of 200,000 to 300,000 met-
ric tonnes (1 t = 1,000 kg) were sustainable throughout the nineteenth and early
twentieth centuries (Hutchings and Myers 1995). However, the enormous
catches made possible by the introduction of the ‘factory freezer’ stern trawler,
which facilitates the freezing and packaging of fish on board, in the late 1950s
and early 1960s (the maximum reported catch for northern cod was 810,000
tonnes in 1968; Murphy et al. [1997]) may have changed for ever the ability of
northern cod to sustain catches of the size that were apparently sustainable in
the nineteenth century. By the time Canada extended its fisheries jurisdiction limit to 200 miles in 1977, it was clear that northern cod were in very serious trouble. Since 1962, the biomass of cod available for harvest had declined by 82 per cent from an estimated three million tonnes to 526,000 tonnes (data available in Bishop et al. 1994). The reproductive portion of the stock (cod seven years and older) had declined by 94 per cent from 1.6 million tonnes to 93,000 tonnes. Concomitant with this decline, recruitment (number of three-year-olds) decreased from an estimated one billion to 168 million individuals.

Imposition of the 200-mile limit resulted in an immediate and dramatic decrease in fishing mortality; most foreign trawler fleets were restricted from fishing, and Canada had yet to develop its own trawler fleet. This lull in trawler activity permitted a modest stock ‘recovery’ between 1977 and 1985, during which time harvestable biomass approximately doubled (Bishop et al. 1994). The stock declined thereafter until a moratorium on commercial exploitation of northern cod was announced on 2 July 1992. Similar moratoria were imposed on five other Atlantic Canadian cod stocks in September 1993. Comparing spawner biomass at the time the moratoria were announced with historical maxima for each of the six stocks, we find that northern cod experienced a decline considerably more severe than other cod stocks; spawner biomass in 1992 was only approximately 1 per cent of its historical maximum. By contrast, the size of the spawner biomass of other cod stocks when their fishing moratoria were announced averaged 13 per cent of their historical maxima (Myers, Hutchings, and Barrowman 1996).

Failure to Control Fishing Mortality

The primary cause of the collapse of northern cod was failure to maintain fishing mortality at a level that would allow the stock to sustain itself through time. The management strategy of DFO from 1977 to 1992 was based on, in technical terms, the $F_{0.1}$ strategy. The fishing mortality corresponding to $F_{0.1}$ can be estimated from the dome-shaped relationship presumed to exist between yield per recruit (plotted on the y-axis) and fishing mortality (plotted on the x-axis). The positive slope of such a curve is greatest near the origin (i.e., the point corresponding to $x = 0$ and $y = 0$). As fishing mortality increases, the rate at which yield per recruit rises per unit increase in fishing mortality (i.e., the slope of the curve) declines. The fishing mortality at $F_{0.1}$ corresponds to that point on the curve at which the slope is 10 per cent of the slope at the origin.

By comparison, the maximum sustainable yield (MSY) strategy would correspond approximately to an $F_0$ strategy – i.e., the point on the curve where the slope is equal to zero. The instantaneous fishing mortality ($F$) that corresponded
to $F_{0.1}$ for northern cod was $F = 0.2$. This level of fishing mortality would allow approximately 18 per cent of the harvestable biomass to be caught by commercial fishing gear every year. To maintain harvest rates at this 18 per cent target, the stock was regulated on the basis of catch quotas, or total allowable catches (TACs). In contrast, changes in harvesting capacity were not monitored.

*Estimating Stock Size*

The success of a catch-quota management system depends on the reliability of the estimate of stock size and on the accuracy of the reported statistics on catches. Errors in these cornerstones of the catch-quota strategy will become manifest as errors in the setting of TACs at the $F_{0.1}$ level. There is considerable evidence of errors in stock-size estimation and catch statistics for the northern cod stock (Walters and Maguire 1996).

There are two primary means of estimating the size of a commercially fished stock: virtual (or sequential) population analysis (VPA) and research surveys. VPA provides abundance-at-age estimates for cohorts (i.e., fish born in the same year) that have passed through the fishery and for those still present. These estimates, used to predict stock size in the future and to estimate past and present levels of fishing mortality, are based on the following general model:

\[
\text{abundance}_{\text{last year}} = \text{abundance}_{\text{this year}} + \text{last year's catch} + \text{those fish that died from natural causes last year}
\]

The accuracy of VPA estimates of stock size and $F$ depend on the validity of two primary assumptions – that commercial catch data are reported without error and that natural mortality is constant from one year to the next and does not vary with age. Research surveys have been conducted throughout the entire management unit of the northern cod stock since 1981. Annually, these surveys have consisted of 300 to 500 thirty-minute tows by a stern-hauled bottom trawl at randomly selected locations within each of seventy-five to eighty sampling areas, called ‘strata.’ The data from these random-stratified surveys provide the only available independent estimates of stock abundance and are typically reported as mean biomass or number per tow (see Villagarcia et al., this volume).

Between 1978 and 1988, catch rates from Canadian trawlers and the research surveys were used to describe trends in northern cod abundance. Catch rate was assumed to be directly proportional to abundance – i.e., a given increase in catch rate reflected a given increase in stock size, an assumption that now
appears unjustified (Hutchings and Myers 1994; Walters and Pearse 1996). Between 1978 and 1985, the data on the commercial catch rate suggested that the northern cod stock had more than trebled in size, while the survey data indicated a 50 per cent increase at best. An arbitrary decision was made to use the mid-point of the two catch rate trends in the stock assessments (Baird, Bishop, and Murphy 1991), despite the very real possibility that the increase in commercial catch rate could be attributed to increased harvesting efficiency resulting from the continual introduction of new technology as well as from learning by the novice Canadian trawler fleet. The use of data on the commercial catch rate to describe trends in fish abundance contributed to the overestimation of stock size in the 1980s.

The main consequence of this overestimation was that realized fishing mortalities exceeded the targeted \( F_{0.1} \) level more than two-fold between 1978 and 1983 and more than three-fold between 1984 and 1989 (Hutchings and Myers 1994; Murphy et al. 1997). By the late 1980s and early 1990s, VPA estimates of fishing mortality indicated that fishing was removing 60 to 80 per cent of the harvestable stock biomass every year (recall that the target, and presumed sustainable, harvest rate was 18 per cent).

However, since one assumption of VPA is that natural mortality is constant from one year to the next, the VPA-based fishing mortalities estimated for the late 1980s and early 1990s may have reflected a dramatic, short-term increase in natural mortality rather than an increase in fishing mortality. One recent analysis suggests that a biologically significant increase in natural mortality of northern cod did not occur prior to the stock’s collapse (Myers and Cadigan 1995), while additional analyses report that estimates of fishing mortality determined from mark-recapture experiments (the recaptures are tag returns from fishers) are consistent with those estimated by VPA, indicating that the rapid increase in fishing mortality in the late 1980s and early 1990s was real (Myers, Hutchings, and Barrowman 1996; Myers et al. 1996; Myers, Barrowman, and Hutchings 1997).

**Why Did Northern Cod Collapse?**

Hypotheses for the collapse of northern cod characterize the increase in mortality of cod in the 1980s and early 1990s as being largely a function of increasing natural mortality, increasing fishing mortality, or some combination thereof.

**Decline of Non-targeted Fish Species**

The concomitant decline of some fish species not directly targeted by the cod
fishery has been cited as evidence that ecosystem change helped produce the collapse of northern cod (Atkinson 1993; Atkinson and Bennett 1994; DFO 1995; FRCC 1995). Some researchers have identified bycatch fishing mortality as a dominant cause of changes of abundance in non-commercial species on the northeast Newfoundland shelf (Gomes, Haedrich, and Villagarcía 1995; Haedrich 1995; Villagarcía et al., this volume). Others disagree, particularly with regard to the decline of American plaice (Hippoglossoides platessoides) in division 2J. Brodie, Morgan, and Bowering (1995), for example, argue in effect that changes in the environment caused the natural mortality of plaice to rise dramatically in the 1980s.

Data from research surveys and commercial catches from 1981 to 1992 suggest that the mortality of American plaice caught as by-catch in the northern cod and other fisheries may have been considerable (Hutchings 1996). First, by-catch of plaice with cod in division 2J appears to be unavoidable: on average, 95 per cent of all research-survey trawls that caught cod between 1981 and 1992 also took American plaice. Second, there is a statistically significant positive relationship between plaice and cod survey biomass in most years prior to 1991; that is, the amount of plaice in a given survey tow increased with the amount of cod in that tow. Linear regressions between plaice and cod biomass, used to predict annual by-catches of plaice in the northern cod fishery in 2J, have resulted in predicted catches of plaice generally more than ten times greater than the reported catches (Hutchings 1996). Notwithstanding the considerable estimation errors associated with these predicted catches, this analysis does suggest that the attribution of the decline of 2J plaice primarily to non-fishing causes may be unwarranted.

Environmental and Ecosystem Change

Northern cod, and other Northwest Atlantic cod stocks, were closed because of a scarcity of individuals of reproductive age – i.e., low spawner biomass. It has been suggested that an increase in the natural mortality of cod aged one to three years in the mid-1980s helped produce this relative absence of spawners (Atkinson and Bennett 1994; Mann and Drinkwater 1994). This ‘poor recruitment’ hypothesis has recently been examined for the six Canadian cod stocks for which fishing moratoria currently exist. Using research survey data, Myers, Hutchings, and Barrowman (1996, 1997) tested the null hypothesis that recruitment of those year classes that would have dominated the spawner biomass at the time of the moratoria did not differ significantly from the average annual recruitment preceding those year classes. This hypothesis could not be rejected for northern cod. Of related interest, analyses that previously linked poor
recruitment of Atlantic cod to environmental factors such as cold water temperature (deYoung and Rose 1993) and low salinity (Myers et al. 1993) have not been supported on re-examination of the data (Hutchings and Myers 1994; Ouellet 1997).

Hypotheses linking the collapse of northern cod to environmental or ecosystem change bear the implicit assumption that environmental conditions in the late 1980s and early 1990s were temporally anomalous, given that collapses of the magnitude documented in 1992 have never been previously recorded. However, a comparison of various environmental indices on a decadal and on a century time scale indicates that the environmental conditions for northern cod since the late 1980s have clearly been experienced by the stock in the past.

Contrary to public perception (for example, FRCC 1995), water temperatures on the northeast Newfoundland shelf in the early 1990s were not temporally anomalous. Though low, the depth-averaged water temperatures recorded at a hydrographic station east of St John’s (station 27) in 1991 did not differ statistically from those in 1972–4 and 1984–5; bottom and near-bottom temperatures there were in fact lower in these two previous periods than in 1991 (Hutchings and Myers 1994). In addition, the volume of water at less than 0°C (the cold intermediate layer, or CIL) off southern Labrador in 1990 and 1991 was actually less than that of the CIL in 1972 and in 1985; the volume of the 1990–1 CIL farther south off Cape Bonavista was also less than the CIL volume in 1985 and equal to that recorded in 1972 (Colbourne 1995; see also Villagarcia et al., this volume).

Data available over a considerably longer time scale, such as water temperatures on Grand Banks since 1910, data on ice clearance from Labrador since 1800, and air temperature data from St John’s since 1874 (the latter two significantly associated with water temperature at station 27) all suggest that northern cod catches of the magnitude that proved unsustainable in the 1980s were sustainable in the nineteenth and early twentieth centuries in an environment that was on average considerably colder (Hutchings and Myers 1994). Therefore the description of oceanographic conditions off northeast Newfoundland in the early 1990s as temporally anomalous is simply not supported by empirical data.

There is to date no direct evidence linking the mortality of northern cod to changes in the environment or ecosystem: any apparent direct effect of temperature or salinity on recruitment can be rejected on statistical grounds (Hutchings and Myers 1994). The hypothesis that cod shifted their distribution southward in 1989 or 1990 – one possible response to environmental and/or ecosystem change (deYoung and Rose 1993; Rose et al. 1994) – is not supported by consideration of research survey data, age-specific growth data, and the results of tagging experiments (Hutchings 1996). The hypothesis that a severe decline in
prey abundance spurred the cod collapse (Atkinson and Bennett 1994) has been rejected by Lilly (1995), who reported that there is no evidence that average stomach fullness of cod decreased before, or in parallel with, the decline in northern cod.

**Interaction between Environmental Change and Fishing**

Some have argued that fishing pressure was indeed too high on northern cod – i.e., actual F exceeded the $F_{0.1}$ target – but not high enough to effect a stock collapse. For example, Shelton (1995) has argued that unusually poor recruitment (i.e., low production of offspring and/or survival of cod to age three) and declining weight-at-age may also have furthered the stock’s decline. However, his estimates of recruitment are based on VPA. These data indicate that recruitment declined in the mid-1980s to levels that would have resulted in very low spawner biomass at the time when the fishery was closed in 1992 (northern cod typically attain maturity at age five to seven years). However, as indicated above, the reliability of VPA abundance estimates declines with increased unreliability in the reporting of catch statistics. Research survey data, in contrast, indicate no such decline in recruitment during the same period (neither for northern cod nor for the other cod stocks closed in 1993; Myers, Hutchings, and Barrowman 1997).

The conclusion that unusually poor recruitment contributed heavily to the collapse of east coast cod is problematic. One reason for this is that underreporting, misreporting, and discarding of catches (see Palmer and Sinclair 1996 for one example) negatively bias VPA estimates of past abundance (refer to the equation above). Thus an increased tendency to underreport actual catches will cause a VPA to indicate a declining trend in past abundance when none had actually occurred. Thus the VPA downward trend in recruitment in the mid-1980s can be attributed to increased discarding of undersized cod of recruitment age. The observation that research survey estimates of recruitment do not show the decline in abundance of three-year-olds suggested by VPA also suggests that the collapse cannot be attributed to poor recruitment (Myers, Hutchings, and Barrowman 1996, 1997). Finally, the idea that the VPA decline in recruitment really reflects increased rates of discarding rather than poor recruitment is consistent with research survey–based estimates of mortality of three-year-old cod in the late 1980s and early 1990s (Myers, Hutchings, and Barrowman 1997) and with statements by fishermen (as in Palmer and Sinclair 1996; J.A. Hutchings and M. Ferguson, unpublished data).

The argument that the collapse can be attributed to an interaction between fishing mortality and a deteriorating environment, reflected by declining age-
specific body sizes, suffers somewhat from Pauly's (1995) 'shifting baseline syndrome of fisheries.' The time series over which the declining trend in cod weights-at-age is described begins in the late 1970s or early 1980s (for example, Bishop et al. 1994; Taggart et al. 1994). If this time series is extended to include age-specific body sizes over all years for which such data are available, it is apparent that it is the large age-specific body sizes of the late 1970s and early 1980s that are anomalous (Fleming 1952; Hutchings 1996).

The decline in age-specific body sizes observed through the 1980s is undoubtedly a consequence partly of water temperature but also of the increased rate of harvesting of the fastest growers within each cohort (Hutchings 1996). Consistent with this hypothesis is the observation that the high age-specific body sizes measured in the late 1970s and early 1980s coincided with the period during which cod experienced the lowest offshore fishing mortality since the early 1960s (Bishop et al. 1994; Myers et al. 1996). In addition, the physical oceanographic environment of the late 1970s and early 1980s (for example, water temperature; Hutchings and Myers 1994), was not notably favourable for fast growth. The decline in weights-at-age may also be a consequence of the observed trend towards earlier age at maturity (Trippel et al. 1997), which reduces body size at later ages (Hutchings 1993).

Was the Decline of Northern Cod Gradual or Sudden?

It has been suggested that the collapse of northern cod occurred suddenly over a single year, the spring of 1991 being the favoured time (Atkinson and Bennett 1994; Lear and Parsons 1993). This perception may be partly the result of use of trends in arithmetic mean biomass as a primary indicator of stock abundance. Estimators of temporal trends in stock biomass that are less sensitive to infrequent high-biomass tows (for example, geometric mean biomass, a rank-based biomass trend) indicate that the decline of northern cod was gradual rather than abrupt (Hutchings 1996). Changes in the density composition of the stock, as reflected by research survey data, coupled with spatial-temporal variation in stock biomass, also indicate that northern cod were declining throughout the 1980s (Hutchings 1996). The inshore fishery provides further evidence of a gradual stock decrease. Declining fixed-gear catch rates, evident from the mid-1980s on, suggest that the stock had been decreasing since at least 1985 (Hutchings and Myers 1994). The dramatic spatial shift in the gillnet fishery in the mid-1980s from inshore to offshore waters in response to declining catch rates is further evidence of a decline prior to the 1990s (Hutchings and Myers 1994, 1995; Neis et al. 1996).

There is thus considerable evidence that overfishing was the primary signifi-
cant cause of the collapse of northern cod and of other Northwest Atlantic groundfish stocks (Sinclair and Murawski, in press). The decline in northern cod through the mid-1980s occurred at the same time that offshore (Hutchings and Myers 1994) and inshore (J.A. Hutchings and M. Ferguson, unpublished data; Neis et al. 1996) fishing effort was increasing (a description of temporal changes in gear technology in the northern cod fishery is provided by Hutchings and Myers 1995).

Northern cod were apparently not sustainable at the age-specific rates of survival and fecundity experienced between 1985 and 1992 (Hutchings and Myers 1994). Statistical analyses of catch-at-age data for the species provide no evidence of a rise in natural mortality in 1991 (Myers and Cadigan 1995). One of the strongest sources of evidence of excessive fishing mortality are the estimates of fishing mortality derived from tagging studies, which indicate that fishing mortality on northern cod had exceeded $F = 1.0$ by the late 1980s (Myers, Barrowman, and Hutchings 1996, 1997). The primary role of overfishing has been accepted as an explanation for the collapse of southern Gulf of St Lawrence cod, for which trends in environmental factors and seal abundance were inconsistent with trends in cod mortality (Sinclair et al. 1995). More recently, Canadian government officials have also acknowledged that overfishing and poor fishing practices were the primary cause of the collapse of Atlantic cod throughout eastern Canada (Doubleday, Atkinson, and Baird 1997).

**A Comment on Stock Assessment Review**

Management consists of establishing and implementing harvesting regulations as means of controlling fishing mortality. These regulations can take the form of catch quotas, such as total allowable catches (TACs), and individual transferable quotas (ITQs); effort restrictions, such as minimum mesh sizes and maximum vessel sizes; and seasonal closures.

Prior to the collapse of northern cod, science was often poorly represented in DFO’s fishery management decisions. Uncertainties in data quality and abundance estimates, and the existence of alternative hypotheses for observed changes in fish stocks, were rarely evident in the stock-assessment documents on which management, in consultation with industry, based its decisions. For example, rather than including confidence intervals on abundance metrics or demonstrating how perception of stock status depends on the validity of different sets of assumptions, stock assessments usually offered a single perception of the health of a stock and little or no indication of the variability associated with the parameters used in abundance models or of the robustness of such models to such variability. In addition, documents on stock assessment did not reflect the
different opinions that often existed among scientists regarding the health of fish stocks. Because documents did not formally acknowledge the existence of differing opinions on the health of a fish stock, and did not report and quantify sources of variability and their effects on the robustness of abundance models, they provided fishery managers with input that was significantly inferior to that transferred among scientists (Hutchings, Walters, and Haedrich 1997).

Explicit identification of the sources of variability in stock assessment, and to a lesser extent differences in opinion among scientists, are now becoming increasingly common features of stock assessment documents prepared by DFO. There is, however, considerable room for strengthening the communication of fisheries science within DFO. Though this subject is dealt with more extensively elsewhere (Hutchings, Walters, and Haedrich 1997), I wish to comment briefly on what I perceive to be limitations in the means by which stock assessments are conducted and reviewed.

There tends to be a high degree of conceptual ‘compartamentalization’ in the stock assessments. Reviews evaluate the stock status of one species at a time, without consideration of the population dynamics of co-existing species, and rely overly on information enclosed in what I would identify as three ‘boxes.’ The first contains VPA estimates of fishing mortality and age-specific abundance – this is the ‘fishing box.’ The second contains survey-based trends in stock biomass, weight-at-age, and stock distribution – the ‘biology box.’ The third contains temporal trends in environmental variables such as temperature, ice coverage, and salinity – the ‘environment box.’ If trends in the biology box cannot be accounted for by the fishing box, they must, it is often argued, be the result of changes in the environment box.

Despite its considerable deficiencies (Myers, Hutchings, and Barrowman 1997; Walters and Maguire 1996), a surprising amount of confidence is still expressed in the results produced by VPA. This often leads many individuals to accept the data in the fishing box with little question. Ecological factors such as inter-specific interactions (competition, predation), density-dependent habitat selection, density-dependent migratory behaviour, and the effects of fishing on age-specific weights, distribution patterns, and age at maturity receive comparatively little attention. Such information has not been considered essential for stock assessment; such data have not historically been part of one of the boxes. In addition, most individuals involved in stock assessment reviews are neither ecologists nor population biologists.

These observations should be interpreted not as criticisms of those involved in stock assessment but as suggestions for improvement. Despite the problems associated with multispecies VPAs (Hilborn and Walters 1992) and the practical limitations of defining ecosystem-based management strategies, there is a clear
and urgent need to include basic behaviour, ecology, population biology, and life history research in the stock assessments of commercially harvested fishes.

Conclusion

The observation that over 90 per cent of the world’s fish stocks have been over-exploited (Alverson et al. 1994) underscores the fact that the effects of fishing are consistently underestimated and poorly understood by those charged with fisheries management (see also Pauly, this volume). What are the effects of fishing on the population biology of commercially harvested fishes? This is a central question facing fisheries science in the aftermath of the collapse of northern cod.

Fishing represents the cumulative mortality effected by multiple predators (i.e., various types of fishing gear). The different age- and size-specific mortality rates effected by these predators produce a multitude of biological responses that may appear to be the product of environmental change. For example, as discussed above, declines in age-specific weight, rather than being a consequence of a lack of prey or increased physiological stress, can result from increasing fish mortality on the fastest-growing individuals of age classes partially recruited to the fishery. Similarly, spatial changes in distribution, rather than reflecting ecosystem change, may reflect density-dependent changes in habitat selection (for example, Swain and Wade 1993). This does not mean that the environment does not influence fish biology and behaviour. But any legitimate examination of temporal changes in northern cod, or in any other fish species, prior to the northern cod fishing moratorium is incomplete if it fails to account fully for the potential influence of the single factor known to effect the greatest mortality of commercially harvested species — fishing.

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