SEASONAL MARINE PROTECTED AREAS WITHIN THE CONTEXT OF SPATIO-TEMPORAL VARIATION IN THE NORTHERN COD FISHERY

JEFFREY A. HUTCHINGS
Science Branch, Department of Fisheries & Oceans, P.O. Box 5667, St. John’s, Newfoundland A1C 5X1 Canada
* Present address: Department of Biology, Dalhousie University, Halifax, Nova Scotia B3H 4J1 Canada

SUMMARY
The collapse of Northern Cod, Gadus morhua, in the latter half of the 20th century coincided with large-scale spatial and temporal changes in the harvest of this stock. The advent of factory trawlers was associated with extraordinary harvests during prespawning and spawning periods from previously unfished offshore waters off southern Labrador and northeastern Newfoundland. The demographic consequences of this overexploitation on Northern Cod are summarized. The rationale for establishing a seasonal Marine Protected Area for the protection of prespawning and spawning cod is presented and its merits discussed.

1. INTRODUCTION
The recent collapse of groundfish stocks off eastern Canada has prompted critical evaluation of the means by which commercial fisheries are managed (1-3). Seasonal or permanent closure of marine habitat may increase the likelihood that commercially exploited fish populations can be maintained at sustainable levels (4). To evaluate the ameliorative potential of such Marine Protected Areas (MPAs), the following questions are among those that need to be addressed for each fishery: To what degree is harvest-induced mortality related to temporal and spatial variation in fishing effort and fishing gear? To which life stage should such habitat protection be directed? How can MPAs be established in a manner compatible with the interests of most fishers? Should the closure of specific areas to exploitation be seasonal or permanent, and how might such a decision depend upon the migratory nature of the species being harvested?

My objective is to consider how MPAs might be useful as a conservation measure in the management of Northern Cod. This fishery includes NAFO (Northwest Atlantic Fishery Organization) Divisions 2J, 3K, and 3L, and extends from southern Labrador to northern Grand Bank off Newfoundland (Fig. 1). There has been no directed commercial exploitation of Northern Cod since July 1992. Should it re-open, the reasonably extensive biological, demographic, and harvesting data that exist for this 500-year-old fishery may serve as an empirical framework upon which the relative merits of MPAs can be assessed for this stock in particular and for demersal fishes in general.
Figure 1. Northwest Atlantic off Newfoundland and Labrador. The northern cod stock is delineated by Northwest Atlantic Fishery Organizations 2J, 3K, and 3L.
2. TEMPORAL AND SPATIAL VARIATION IN THE NORTHERN COD FISHERY

2.1 Historical Perspective

Atlantic cod have probably been fished in Newfoundland waters since the late 1400s (5). Since the voyages of John Cabot on behalf of the English Crown (1497, 1498) and Gaspar Corte-Réal of Portugal (1500, 1501), extant documents record the presence of fishers from Portugal as early as 1506, French fishers from Brittany and Normandy as early as 1508, and the Basques and English from the 1520s (6).

From the early 16th century, two cod fisheries coexisted in Newfoundland: the bank fishery and the shore fishery. The bank fishery of the 16th and 17th centuries was prosecuted by the French, Basques, and Portuguese (although primarily by the French after 1585) whose plentiful supplies of salt and domestic market permitted heavy salting of cod ("green" cod) and storage in the ships' holds prior to their transport to European markets (5, 7, 8). Judging from the shape of the Grand Bank depicted in contemporary cartography (9) and based upon historical accounts of the French fishery (7), the bank fishery of the 16th and 17th centuries was concentrated primarily on southern Grand Bank with almost no penetration into the northern half of 3L, i.e., northern Grand Bank. The shore fishery was initially conducted by the French, Basques, Portuguese, and English on the east coast from the Bonavista Peninsula south to Cape Race (southeastern tip of Newfoundland; by the 1600s, this fishery was restricted to the English) and by the French on the south coast in Placentia and Fortune bays until 1713 and on the west and northeast coasts until 1904 (10-12). This fishery constituted the harvest of fish from near-shore waters and subsequent drying of split cod by a combination of sun, salt, and wind either on pebble beaches (e.g., Placentia Bay) or on shore-based, wooden stages or "flakes". Although the bank fishery began as early as March and the shore fishery as early as May, most fishing occurred from June to mid August with both fisheries having ended by October (5-8, 9-12).

Two spatial changes to the Northern Cod fishery occurred in the 18th century. The first was the advent of the English bank fishery following the Treaty of Utrecht in 1713 (10-12). This may have been the first time that any significant fishing took place on northern Grand Bank (although initially the English bankers fished the same southern banks as the French from whom they learned the necessary skills) (11). The English (later British and Newfoundland) bank fishery ended in the 1840s before being resurrected in the late 1870s (8). Secondly, from the mid 1700s, declining catch rates in eastern Newfoundland prompted fishers and their families to fish off Labrador every summer rather than in the bays (e.g., Conception and Trinity bays) in which they resided (8, 13). These "stationer" (land-based) and "floater" (ship-based) fishermen prosecuted an inshore fishery (hand and line trawls, traps from the 1870s) that peaked in the late 1800s and ended in the 1950s (13).

Thus, from c1500 to the mid 1950s, the Northern Cod fishery was restricted largely to coastal Newfoundland and Labrador. Temporally, most fishing occurred from May through September. Despite the variety of fishing gear available (e.g., baited or unbaited, single-hooked handlines, multi-hooked line trawls, cotton gill nets, cod traps), 60 to 75% of Northern Cod caught in coastal Newfoundland in the late 1950s,
Table 1. Average annual offshore (mobile gear) and inshore (fixed gear) landings of northern cod (metric tonnes), by NAFO Division, for selected time periods from 1954 to 1991. Offshore gillnet catches are indicated in parentheses. Data are from ICNAF Statistical Bulletins.

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as represented by the Bonavista fishery, were fished by baited (line trawls) or unbaited (jiggers) hook-and-line gear (14-16).

2.2 Inshore Fishery Since 1954

Temporally, the inshore fishery for Northern Cod changed little from 1954 to 1991 (Table 1). Largely because of the constraints imposed by ice, the more northerly the waters, the later the annual start of the fishery: May in 3L, June in 3K, and July in 2J. In general, most of the annual inshore catch was taken from June through September (90-100% in 2J, 89-95% in 3K, and 86-94% in 3L; Table 1).

The period 1954 to 1991 bridged two significant spatial elements of the inshore fishery. The aforementioned Labrador migratory fishery, which had its beginnings in the mid 1700s, ended in 1954 (13). The second spatial shift occurred in 1986 when, in response to declining catch rates in nearshore waters, fishers began setting gillnets in offshore areas throughout 2J3KL (3). The most significant of these offshore gillnet fisheries was that on Virgin Rocks in central Grand Bank (Fig. 1) where annual landings reached 18,000 t (metric tonnes) in 1990 (25% of the fixed-gear landings in 3L), up from nil in 1985. (Portugal prosecuted a gillnet fishery on Virgin Rocks from 1971 to 1990 with an average annual harvest of 1,500 t) (17).

Inshore catches of Northern Cod declined from north to south (Table 1). For the 1954 to 1991 period, catches in 3L were 1.5 to 2.0 times greater than those in 3K with catches in 2J being considerably less (15 to 67%) than those in 3K. Overall, inshore catches in 2J3KL declined by two-thirds from 1954 to 1977, dropping from an average annual harvest of 156,511 t (1954-59) to 50,334 t (1972-77). Following the extension of Canada's jurisdiction to 200 miles in 1977, average annual inshore landings increased to 85,896 t (1978-81) and to 92,709 t (1982-86) before declining 16% to an average 78,329 t from 1987 to 1991 (offshore gillnets excluded). It should be noted that this increase and then decline in inshore catches in the 1980s was associated with significant increases in fishing effort (3,18).

2.3 Offshore Fishery Since 1954

The most significant technological influence on the exploitation of Northern Cod was the introduction of extremely large (often larger than 2,000 Gross Registered Tons) stern, otter trawlers to the offshore waters from southern Labrador to Grand Bank. The first of these “factory freezer” vessels, whose ground trawls could haul up to 60 t per 30 minute tow, were those from Great Britain (1954), the Soviet Union (1956), and West Germany (1957) (19). The rapid growth of the factory trawler industry and the exceedingly high harvesting efficiency commanded by such vessels signalled the beginning of the demographic collapse of Northern Cod (3).

Offshore catches in Division 2J off Labrador throughout the 1960s (164,000 t to 405,000 t per annum) greatly exceeded the entire inshore catches of the 1950s throughout 2J3KL and almost always exceeded the combined offshore catches in 3K and 3L (17,20). Declining catches in 2J in the early 1970s were associated with increased catches in 3K. This spatial change in effort from 2J to 3K may have been the only significant one by the factory trawler fishery. Following the establishment of the 200 mile limit, annual offshore catches in 2J were approximately one order of magnitude less than those of the 1960s; those in 3K and 3L had declined by about one-half (Table 1).
Seasonally, the offshore factory trawler fishery was prosecuted during the second half of each year in the 1950s with almost no fishing occurring during winter (Table 1). Although offshore activity was evident from January through March in 3L from 1960 to the early 1970s, catches tended to be distributed fairly evenly from April through September. Probably as a consequence of mixed quotas (because of bycatches, once the quota for one species was reached, fishing for all other species had to cease), catches throughout the 1980s were evenly distributed among all months of the year. As in 3L, catches in 3K throughout the 1960s were distributed fairly evenly among months. But in the early 1970s, there was a clear seasonal shift to a winter/spring fishery in 3K, a practice maintained to 1991. The fishery in 2J shifted to a winter/spring fishery somewhat earlier than in 3K.

In summary, the offshore fishery for Northern Cod began in the mid-1950s and, with the exception of the 1978-82 period in 3K and 3L, offshore catches always exceeded inshore catches within each Division (by as much as two orders of magnitude in 2J from 1969 to 1972). The large offshore winter/spring fisheries in 2J and 3K generally resulted in 90% of the annual harvests of cod being caught in these areas by May. Offshore catches in 3L were more equitably distributed throughout the year.

3. THE DEMOGRAPHIC COLLAPSE OF NORTHERN COD

The enormous catches of the offshore factory trawlers in the 1960s initiated the demographic collapse of Northern Cod (3). Annual estimates of realized population growth ($r$) indicate that the stock was rarely sustainable at the age-specific survival and fecundity rates experienced since 1962 (the first year for which numbers-at-age data are available). Between 1962 and 1977, (1) harvestable biomass (i.e., cod older than age 2 yr) had declined 82% from 2,961,000 t to 526,000 t, (2) spawner biomass had declined 94% from 1.6 million t to 93,000 t, and (3) numbers of recruits to the fishery (i.e., 3-yr-old cod) had declined 84% from 1 billion to 168 million individuals. In addition to the dramatic decline in population size, the progressive loss of older fish concomitant with the high fishing mortalities imposed on the stock (annual survival probabilities for reproductive individuals declined from 60 to 30% between 1962 and 1977) effected a dramatic collapse in the stock's age structure. Perhaps the best example of this collapse was the reduction in the fecundity contribution of older fish to the population (most Northern Cod are capable of reproduction by age 7 yr). In 1962, it is estimated that 10- to 14-yr-old produced almost half the number of eggs in this stock (3). By 1977, their fecundity contribution had declined to less than one-fifth of the total; in 1991, it had declined to one-tenth!

Northern Cod were on the verge of commercial extinction when Canada extended its fisheries jurisdiction to 200 miles in 1977. However, the large reduction in offshore catches, effected by the reduced harvests of non-Canadian vessels, resulted in a halving of the fishing-induced mortality on this stock. Coupled with fortuitously high recruitment from the 1978 to 1981 year classes (high relative to the spawner biomass in each year), harvestable biomass had doubled its 1977 level by 1985 (1,140,000 t). By 1990, however, harvestable biomass had declined to less than the 1977 level (488,000 t). Declining survival probabilities in the 1980s were associated with increased fishing effort (inshore and offshore), declining catch rates, and spatial...
shifts in gillnetting effort from areas of low (inshore) to high (offshore) catch rates, all of which were indicative of a stock in decline (3).

Environmental factors played no discernable role in the collapse relative to that played by exploitation (3). Water temperature was associated neither with juvenile nor adult abundance nor with adult distribution by depth. Although the cold water temperatures of the early 1990s were experienced in the early 1970s and mid 1980s, these latter periods were not associated with collapses in cod abundance. Furthermore, harvests equivalent to those of the past decade were sustainable in the 19th and early 20th centuries in a considerably colder environment.

4. SEASONAL SPAWNING AREA CLOSURES

The decline of Northern Cod began in the early 1960s with the rapid growth of the offshore trawler industry (3). For much of the next three decades, offshore catches were concentrated during the first half of each year (Table 1). Given that the fishery was not regulated until 1973 (21), the very large winter/spring catches of the unregulated fishery in the 1960s and early 1970s must have reflected very high catch rates. The seasonal pattern of trawler exploitation suggests, then, that offshore cod are most highly concentrated during winter and early spring - months that encompass the prespawning and spawning periods of Northern Cod. Research maturation data indicate that most spawning takes place from March through June in 2J and 3K and from April through July in 3L (22); mean date of spawning can vary by a month or more from one year to the next (23). Research data also indicate that spawning occurs in inshore bays and in offshore waters throughout the continental shelf, and to a lesser degree on the continental slope, from southern Labrador to Grand Bank (24).

The observation that Northern Cod catches were highest during or immediately preceding spawning suggests that exploitation during the reproductive period may have been a contributing factor to the decline of the stock. Although empirical data are lacking, trawling may deleteriously influence reproductive success by disrupting spawning behaviour, fertilization success, and/or increasing egg and larval mortality (25). It is not possible, however, to distinguish such effects on the cod collapse from that imposed by the enormity of the catches during the 1960s and 1970s.

Seasonal closures of a fishery, particularly during periods of high catch rates, can act as a conservation measure by reducing overall fishing mortality. This was the basis for imposing seasonal spawning area closures for haddock, *Melanogrammus aeglefinus*, on Browns Bank and Georges Bank, immediately south of Nova Scotia, in 1970 (26). As with Northern Cod, haddock are highly concentrated when in prespawning and spawning aggregations. By preventing the trawler fleet from fishing during spawning, it was hoped that annual catch rates would be reduced and lead to lower annual catches and reduced fishing mortality. As Halliday (26) noted, “the rationale for spawning season and area closure was not only because they were the spawning season and area per se, but also because they were the season and area of peak catch rates, and hence this closure could be expected to have a large impact in reducing catches, or at least spreading them more evenly throughout the year.” The establishment of seasonal MPAs for haddock was widely supported by Canadian and American fishers (26).

Similar rationale could be used to establish a seasonal MPA for Northern Cod
should the fishery be re-opened. The period of highest offshore catch rates coincides with the prespawning and spawning periods. If trawlers are part of the future Northern Cod fishery, it may be biologically prudent to limit their operation to the months of June through December. A similar ban on inshore fishing during the months of January through May would conform to historical temporal patterns in this fishery. In effect, this temporal closure of offshore waters would re-establish the temporal and much of the spatial refuge enjoyed by Northern Cod prior to the introduction of factory trawlers in the 1950s. The main economic cost to a trawler ban in winter and spring would be a reduced capability of fish plants to operate throughout the year.

A seasonal ban on cod exploitation may have several positive effects in addition to a reduction in overall catch rate. For example, the inshore fishery should benefit from increased “escapement” of cod migrating from offshore to coastal waters. The absence of bottom trawling for cod in 2J3KL during winter and spring should also reduce fishing mortality on species commonly caught as by-catch in addition to reducing any deleterious effects that trawling may have on other fish assemblages and on bottom-dwelling invertebrates. Although the relative contribution made by the offshore cod concentrations to geographically distinct inshore sectors is not well known (27), the prevention of fishing from January through May would reduce the variance in exploitation rates experienced by different “substocks” should such substocks exist.

Seasonal MPAs have considerable merit when assessed against the effectiveness of other forms of regulatory control such as by-catch limitations and catch quotas. From an enforcement perspective, MPAs may be more cost effective (4,26) and would be less susceptible to error than quotas; compliance with the former determined by an absence of vessels, compliance with the latter determined with an unknown measure of uncertainty. And although it has not been demonstrated that the protection of spawning Northern Cod is of intrinsic biological benefit, such a benefit cannot be justifiably discounted. Furthermore, all else being equal, it is clear that a seasonal MPA would reduce fishing mortality on species caught as by-catch.

The commercial extinction of “renewable” resources such as Northern Cod should compel us to understand fully the causes of such collapses, to modify management strategies to prevent future collapses, to recognize the tremendous uncertainty associated with the indices of stock health and abundance upon which catch quotas are based, and to err on the side of conservation. As part of this evaluation process, the merits of establishing seasonal or permanent MPAs warrant consideration.

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