IMPROVING THE MANAGEMENT OF THE ATLANTIC COD FISHERY BY UPDATING STOCK ASSESSMENTS AND ENFORCING COMPLIANCE

by

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Masters project submitted in partial fulfillment of the
requirements for the Master of Environmental Management degree in
the Nicholas School of the Environment and Earth Sciences of
Duke University
2006

Abstract

Management of Atlantic cod, *Gadus morhua*, has become increasingly stringent since the implementation of the first groundfish fishery management plan (FMP) in 1977, yet overfished stock status is evidence of ineffective management. This management relies on fish surveys and computer models to assess the stock, and various regulations to control the level of catch. This masters project investigates the assessment and management practices of the Unites States and Canada (focusing on the former) and provides practical modifications to remedy errors and improve the current Multispecies FMP.

The cod stock assessment model includes two assumptions about the species: cod are non-migratory, and cod natural mortality has remained the same since its last evaluation 28 years ago. I present two studies that contradict the assumption that cod are non-migratory, and provide three reasons that cod natural mortality has increased: heightened competition and predation, habitat damage, and genetic modification resulting from selective harvest.

To avoid the overfishing that results, I recommend that the model equation be changed to include migration frequency and utilize an increased value for the natural mortality parameter. Until necessary studies to correct the model are completed, stock assessors should add an uncertainty parameter into the equation that buffers against error resulting from inaccurate model specification.

Prioritization of economic concerns, overconfidence in the effort-reduction program, and ineffective monitoring have routinely produced cod landings that surpass the target total allowable catch (TAC). Recent landings below the target TAC are due to low biomass rather than management success. I propose four recommendations to improve the management process: 1) decrease target TACs; 2) restrict trawler vessel days-at-sea and fishing areas; 3) improve monitoring; and 4) fund a fisher retraining service.

The status of the Atlantic cod fishery indicates the need for a different management regime. The New England Fishery Management Council should act now to transform the cod fishery from the best example of management failure to the best example of collapsed stock recovery. The science and technology to implement these recommendations is ready and waiting.

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Introduction

The Atlantic Cod

The Atlantic cod, *Gadus morhua*, is a demersal gadoid fish distributed in the northwest Atlantic from Greenland to North Carolina. In US waters, cod densities are highest on Georges Bank and in the western Gulf of Maine. Cod are iteroparous batch-spawners, with large females able to produce between three and nine million eggs per spawning season. Spawning occurs near the seafloor during winter and spring, peaking in March. Georges Bank, the perimeter of the Gulf of Maine, and southern New England waters serve as prime spawning grounds. The pelagic eggs, between 1.2 and 1.7mm in diameter, drift for an average of two to three weeks before hatching larvae between 3.3 and 5.7mm in length. Larvae are pelagic, occur from near-surface to depths of 75m, and feed on zooplankton. Larvae are most abundant on Georges Bank and in southern New England. Transformation to the juvenile stage occurs at lengths greater than 2.0cm and descent to benthic habitats occurs at lengths of 2.5-7.0cm. After one year, juveniles reach a mean length of 26cm. Median age at sexual maturity is 1.7-2.3 years and at lengths of 32-41cm. Most cod enter the fishery after two to five years. Attaining ages of twenty years, cod can grow to lengths of 130cm and weights of 55-77lbs. Although an opportunistic species overall, early juvenile cod consume primarily pelagic invertebrates, medium cod consume primarily benthic invertebrates and fish, and large cod consume primarily fish. Predation on cod varies by life stage: yolk sac larvae are prey to zooplankton predators; older larvae are prey to planktivorous fishes, particularly Atlantic herring and Atlantic mackerel; juveniles are prey to many piscivorous fish including dogfish, silver hake, larger cod, and sculpin; and small adults are prey to dogfish, winter hake, silver hake, sea raven, squid, Atlantic halibut, fourspot flounder, and large adult cod. Due to their size, large adult cod have few predators other than large sharks (NMFS 2004a).

The Atlantic Cod Fishery

For centuries, Atlantic groundfish stocks supported a fishery that shaped the economies and cultures of New England and Maritime Canada. While supplemented by other groundfish such as haddock, flounder, and redfish, cod formed the foundation of a fishery that started in the 16th century (Fogarty & Murawski 1998). In recent years, the New England cod fishery has generated nearly $31 million in revenue, making it the sixth most valuable commercial species (2002 figure); and cod landings in Maritime Canada have generated nearly $17 million, the second highest value for groundfish species (1999 figure) (Gibson 2003; DFO 2000).

Cod generate high market value due to their fleshy white meat. Were it not for the collapse of the stocks, the fishery would rank among the most economically and socially valuable in the United States. Based on long term maximum sustainable yield estimates, rebuilding the entire Northeast large-mesh groundfish fishery would raise revenue from $105 million (2000 figure) to $425 million (NEFMC 2001), of which cod would be a significant contributor.

The industry provides a way of life to many Americans and Canadians. In 2004, active groundfish licenses in New England and Maritime Canada numbered 915 and 700, respectively (NEFMC 2005; DFO 2004).[1] Each active license represents jobs for vessel captains and crew members. Each processing plant—numbering 194 in New England in 1995 and over 100 in Maritime Canada in 1999—supplies tens of hundreds of employment opportunities (NEFMC 1998; DFO 2000). Jobs for the greater fishing industry include seafood wholesalers, boat builders, gear builders, vessel and engine repairmen, baiters, bait sellers, dock workers, and managers. Industry participants and their communities rely heavily on the health of the groundfish stocks, particularly cod.

Atlantic Cod Management

Three governance bodies have jurisdiction for the management of Atlantic cod in New England and Maritime Canada (Figure 1). In the US, the New England Fishery Management Council manages two cod stocks: Gulf of Maine (GoM), and Georges Bank and southward (GB). In Canada, the Division of Fisheries and Oceans and the Maritime Region Director General manages one stock: 4X. Since 2002, a joint US/Canada co-management council, the Transboundary Management Guidance Committee, has managed an area known as the Eastern GB Resource Sharing Area (RSA). Each management body has different decision-making processes, management tools, fishing regulations, and monitoring and enforcement plans. (See Appendix 1 for more on the structure and operation of each governance body.)

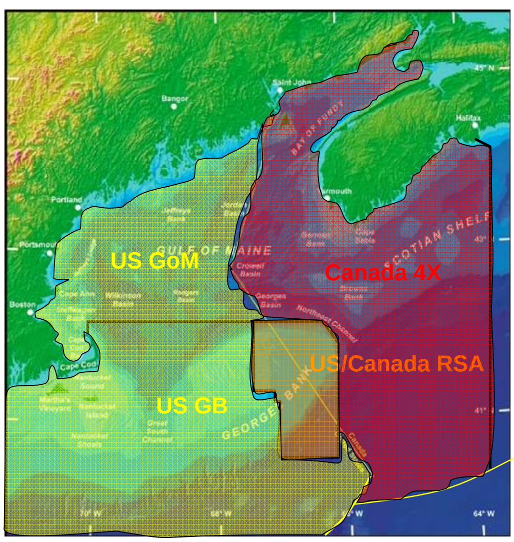

Figure 1. Management of Atlantic cod. Yellow area = US management (GoM = Gulf of Maine; GB= Georges Bank and Southward). Red area = Canadian management (4X). Orange area = joint US/Canada management (RSA = Resource Sharing Area). (Background map courtesy of Census of Marine Life (http://www.usm.maine.edu/gulfofmaine-census/Images/map-gulfofmaine.jpg.)

[1] The cod fishery of both countries is under an aggressive reduction program. In 1999, licenses numbered 1646 in New England and 1080 in Maritime Canada (NEFMC 2005; DFO 2000).

Atlantic Cod Stock Status

Despite the importance of Atlantic cod and the multiple management bodies striving for a sustainable fishery, the cod population continues to decline. A 2005 groundfish stock assessment documented 25% and 21% decreases in the 2004 GB and GoM cod spawning stock biomass from 2001 (NEFSC 2005). The assessment estimated the 2005 spawning stock biomasses to be approximately 10% and 23% of the target for GB and GoM cod,[2] and fishing mortality rates to be considerably larger than the projected maximum sustainable mortality level for both stocks[3] (NEFSC 2005). By the definitions of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), GB and GoM cod continue to be overfished and experience overfishing (Figure 2).

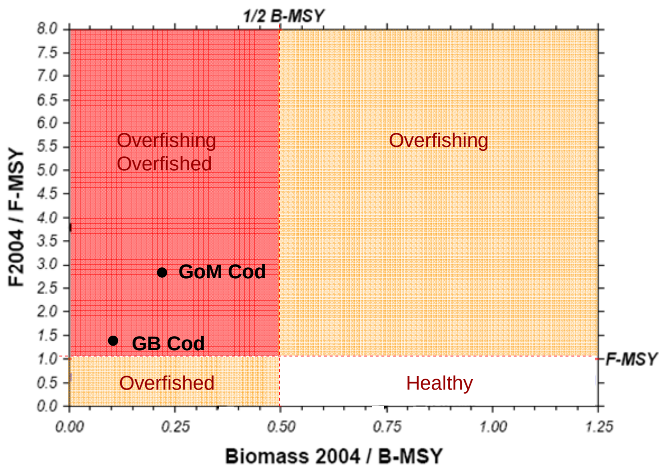

Figure 2. Atlantic cod stock status in US waters, 2004. Two cod stocks assessed: Gulf of Maine (GoM) and Georges Bank and southward (GB). Both stocks are overfished and experiencing overfishing as defined by the MSFCMA. (Adapted from NEFSC 2005.)

In Canada, the Atlantic cod stocks collapsed in the early 1990s, leading to widespread moratoria on cod fishing. Currently, Canadian fishery managers classify seven of the nine federally managed cod stocks as overfished, banning direct commercial harvest. Cod fishing continues at reduced level in two areas: eastern Georges Bank (now included in the RSA) and the Western Scotian Shelf, including the Bay of Fundy (i.e. zone 4X). At 7,000mt, the total allowable catch for the 2004-2005 fishing season is a diminutive fraction of the landings (~100,000-250,000mt) recorded in the 1960s and 1970s (SC 2003).

An additional independent study on fish declines has confirmed these results. Considering the extinction risk of large predatory fishes, Myers and Worm (2005) conducted a comprehensive analysis to estimate fish biomass loss. By comparing empirical Bayes estimates of carrying capacity for each population with current estimates of spawning stock biomass from recent assessments, they estimated that 20 of 21 Atlantic cod stocks have declined to 0.1-10% of their original abundance. The researchers

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[2] Ratio of actual spawning stock biomass to target spawning stock biomass: 22,564mt:216,780mt for GB cod and 18,800mt:82,830mt for GoM cod.

[3] For GB cod, F=0.24 and F_{msy}=0.175. For GoM cod, F=0.63 and F_{msy}=0.225.

estimated that the GB, GoM, and Western Scotian shelf stocks (those relevant to this study) have lost 90-99% of their original biomass (Myers & Worm 2005).

Stock Assessment

Development of fishery management plans (FMPs) that will succeed in achieving management goals requires accurate resource assessment, the starting point for determining control measures. Understanding the processes, such as environmental influence, interspecies interaction, and intraspecific density-dependence that regulate population size, is essential for interpreting resource assessment data. Population dynamics, the study of population size change, uses an equation similar to that by Russell (1924):

$$B_{t+1} = B_t + (R+G) – (C+D)$$

where B=biomass, R=recruitment, G=somatic growth, C=catch, and D=natural mortality.

Fish stock assessment applies statistical and mathematical tools to relevant data in order to obtain a quantitative understanding of the status of the stock under two primary objectives: estimate stock size, and estimate the effect of management alternatives on stock size. The stock assessment process has five steps (NRC 1998):

1) Definition of the stock;
2) Choice of data collection procedures and collection of data;
3) Choice of an assessment model and its parameters and conduct of assessment;
4) Evaluation of alternative actions and specification of performance indicators; and
5) Presentation of results.

From a management perspective, a stock is that part of a species' population within which the effects of exploitation on population structure are recognizable (Metcalfe & Pawson 2004). Identification of individual stocks within a species range, as well as knowledge of their spatial distribution and dynamics, is important for rational fisheries management (Metcalfe & Pawson 2004). A National Research Council Committee on Fish Stock Assessment Methods admitted that stocks, while based on the interbreeding capacity of the species, are often further defined by political boundaries, which often results in management units that do not reflect biological qualities or the spatial heterogeneity of fish distributions (NRC 1998).

Formerly, stock assessments relied primarily on commercial catch data. These assessments generated economic performance and efficiency measures from catch-per-unit-effort data. Application of these data to biological assessment proved to be riddled with error, thus analyses now use a combination of commercial catch and direct survey data for abundance and biomass estimation (Gunderson 1993). Fisheries-dependent data provide information on fish length, age, gender, maturity, and fecundity. Fisheries-independent data are necessary to sample distribution and abundance because they sample randomly across the distribution of the stock, unlike fisheries-dependent data. Fisheries-independent surveys are designed to minimize error and operate under several basic assumptions (Gunderson 1993):

1. The entire population of the target species is in the survey area at the time of the survey, and will be censured only a single time;
2. The target species is completely vulnerable to the sampling gear being employed, with no gear avoidance or size selectivity;
3. The area sampled by the gear is known exactly; and
4. The sites selected for sampling are a random, representative selection, and the mean abundance at these sites can be extrapolated to the entire survey area.

The New England Region has the longest running continuous time series of fisheries independent trawl surveys. Since 1963 and 1968, the Northeast Fisheries Science Center (NEFSC) has conducted annual autumn and spring surveys. Additionally, Canadian fisheries scientists have conducted trawl surveys on Georges Bank each spring since 1986. The NEFSC uses a stratified-random sampling design to trawl over 300 stations in thirty-minute sets for each survey, spanning ocean environment from 30 to 1200 feet deep between Cape Hatteras, North Carolina and the Canadian boarder. The trawl gear samples for cod eggs, larvae, juveniles, and adults. All fish in each tow are identified, weighed, and counted, and all (or a sub-sample) are measured to determine the length composition of the catch. Researchers analyze stomach content, collect scales, otoliths, and fin rays for aging, and record sex and state of sexual maturity.

Using data collected over a series of years, assessors next select, fit, test, and run a computer model to estimate instantaneous fishing mortality, stock size, spawning stock biomass, and year-one fish recruitment. A tuned virtual population analysis (VPA) model, also known as a cohort analysis model, reconstructs, or “back calculates,” the history of the stock in terms of the biomass and fishing mortality of each year-class of fish. Before certain data can be used to build the model (e.g. fishing effort, landings-per-unit-effort, trawl survey catch), they must be standardized for area, season, tonnage, class, depth, and gear. These calculations are often performed using a generalized linear model. Data (other than that used to build the model) are used to fit and test the model in a process called ADAPT calibration (Parrack 1986). The model runs with estimated values for recruitment, somatic growth, and catch and an assumed value for natural mortality. Parameters for immigration or emigration are not included in the model (NEFSC 2001).

Despite numerous improvements, this stock assessment process in New England has been flawed for years as shown by retrospective analyses evaluating the performance of past model results. Stock assessments have reported (NEFSC 2001):

> Estimates of SSB [spawning stock biomass] are consistently overestimated, and estimates of fishing mortality (F) are consistently underestimated.

While stock assessment scientists admit that this pattern may result from uncertainty regarding migration of cod and an unrepresentative estimate of natural mortality in the assessment model, appropriate responses to remedy the problem remain absent. This statement was the impetus for my research, and I'll cover the topics of migration and natural mortality next.

Atlantic Cod Stock Assessment Analysis

Migration of Atlantic Cod

Effective fisheries management requires consistent management of fish throughout their range rather than in a piecemeal fashion. Consistent management of a stock is relatively straightforward when the stock's distribution is certain and the fish exhibit minimal movement throughout life. Management becomes more complex when fish inhabit different environments between life stages or display large movements within a life stage.

While able to assess cod distribution and abundance, survey trawls cannot distinguish stocks, and document fish or fish population movement with certainty. Lacking scientific evidence, the default setting has been to manage stocks in units based on political or geographical boundaries. In such a case, management objectives for the defined units are based on a closed system approach that requires migration between adjacent stocks to be sufficiently low so as to avoid confounding stock assessments (Hunt *et al.* 1999).

Tagging studies, in which fish are caught, marked, released, and re-caught, provide a method of examining fish movement and defining stocks. As early as 1923, scientists began mark-recapture studies on Atlantic cod (Hunt *et al.* 1999). By analyzing this early cod tagging data, Wise, in 1963, proposed the existence of four separate groups of cod in the New England area, which would become the basis of management: Gulf of Maine, Georges Bank, Southern New England, and Mid-Atlantic coastal cod (Wise 1963). Due to the difficulty in distinguishing cod from the latter three groups, US fisheries management combined them into one stock, resulting in the current management of two stocks: the Gulf of Maine, and Georges Bank and Southward.

Cod management will be inconsistent if migration between the currently defined stock units (two US, two Canadian, and one US/Canadian) is enough to render the spatial units erroneous. Due to migration, assessments may misestimate resource abundance and management may misestimate fishing pressure. For example, aggregate movement into an area just before a resource survey could lead to overestimation of stock biomass and underestimation of fishing mortality. Overall, overfishing can result from improper assumption of migratory behavior.

In general, cod in New England and Maritime Canada is treated as a non-migratory species, undertaking only minor seasonal movements in reaction to changing temperature (NMFS 2004a). Under the assumption that migration of cod between stocks is negligible or cancels itself out, on average, over the assessment time series, the assessment model excludes values for immigration or emigration. Converse to the assumption, recent stock assessments have noted that a retrospective pattern for overestimating biomass and underestimating fishing mortality may be influenced by cod migration (NEFSC 2001). Evaluating the current stock definitions requires answering two questions: 1) Is there evidence of interchange of fish at a geographic scale larger than the one used to define a stock boundary? and 2) If interchange does occur, what are the impacts on population dynamics and on the assumptions used in models to estimate population parameters? (Hunt *et al.* 1999).

Early analyses in the Gulf of Maine region indicated substantial movement within the Canadian 4X cod stock area and, to a lesser extent, to and from adjacent areas of Georges Bank and Gulf of Maine (Templeman 1962 and Hunt and Neilson 1993 in Hunt *et al.* 1999). However, these analyses did not account for spatial differences in fishing effort and landings, making the interpretations uncertain. A 1999 report that did weigh the recapture data of 2,400 tags between 1984 and 1997 by effort and landings found that the extent of movement by cod in the Gulf of Maine area is substantial, with cod crossing the stock boundaries between 4X (Canadian), 5Z (GB) and 5Y (GoM) (Hunt *et al.* 1999). Specifically, researchers calculated an exchange rate of about 15% between 4X and 5Z and a somewhat higher rate between 4X and 5Y. Despite this, the Essential Fish Habitat Source Document for cod, used by US managers, concludes that the GB and GoM stocks are "relatively distinct" (NMFS 2004a). Apparently, the science was still inadequate or the politics too complex to compel managers into changing the stock definitions.

The report did have two consequences: 1) US and Canadian managers collaborated to form the Transboundary Management Guidance Committee to co-manage cod, haddock, and yellowtail flounder in the Eastern Georges Bank Resource Sharing Area (see Appendix 1 for more details); and 2) scientists from the NEFSC and their research partners established the Northeast Regional Cod Tagging Program (NRCTP) to further test the assumption of negligible movement between stocks and maybe convince managers of its importance (J.J. Hunt, St. Andrews Biological Station, pers. comm.; J. Brodziak, NEFSC, pers. comm.). Project coordinators carefully designed the sampling protocol to produce a more spatially and temporally broad dataset for the whole region.

Now in its third year, the NRCTP has recaptured over 5,800 tagged cod (from over 114,000 tagged and released) and the preliminary results indicate that cod display large movement (as great as 720 miles) in and out of synch with seasonal cues (NRCTP 2005). Average cod displacement is approximately 174 miles after being at-large for 100-300 days, meaning that an average cod could swim from western GB or GoM across the EEZ to Canadian fishing grounds one or more times a year. Release and recapture data has yet to be weighted, thus no stock mixing rates are clear. Regardless, at least one program analyst believes that the cod movement shown in the tagging data will be sufficient to prove the present management assumption on negligible movement incorrect (J. Brodziak, NEFSC, pers. comm.).

Natural Mortality of Atlantic Cod

Stock assessment requires an estimation of an instantaneous natural mortality parameter (M). Natural mortality of Georges Bank and Gulf of Maine cod is assumed to be 0.20, meaning that each year after reaching one year of age, each cod has a 20% chance of dying from natural causes before the end of the year. This M value is the conventional value for all Northwest Atlantic cod stock assessments derived by Paloheimo and Koehle in 1968 and last reviewed by Minet in 1978 (NEFSC 2001). To date, no action has been taken to reassess this value despite management's recognition of the influence of incorrect natural mortality assumptions on stock assessment accuracy (NEFSC 2001). The following sections consider three biological reasons that warrant the use of a larger M value in cod stock assessments.

I. Increased Competition and Predation

During the 1960s and early 1970s, fleets from eastern Europe, Asia, and elsewhere heavily targeted fish stocks off New England alongside the domestic US and Canadian fleet. The harvesting capacity of the distant water fleet substantially exceeded that of the domestic. Reported landings from Georges Bank and Southward of groundfish, pelagic fish, and other species (primarily elasmobranches) peaked at about 1.9 billion lbs in 1973 as the fleets' combined effort drove the Northwest Atlantic fishery into decline (Fogarty & Murawski 1998). Atlantic herring and mackerel dominated the pelagic fish landings, while cod, haddock, silver and red hake, and various flounders composed the groundfish landings.

After the forced removal of the foreign fleets in 1976 with the establishment of the 200 mile exclusive fishing zone, the overall biomass of Georges Bank groundfish recovered to its former level as shown by research vessel trawl catch (Fogarty & Murawski 1998). However, the composition of the community differed dramatically from its original state. Of the benthic species, gadids had continued to decline, while small elasmobranches (dogfish and skates), flatfish (flounders, plaice, and halibut), and benthic crustaceans (shrimp) had increased (Figure 3) (Fogarty & Murawski 1998; Worm & Myers 2003). Pelagic herring and mackerel also increased steadily to historically high levels after 1984 (Fogarty & Murawski 1998). Several theories exist to explain the differential recovery rates:

1) As the community redeveloped, selective-fishing pressure kept some species at low levels, while allowing other species to return (Murawski & Idoine 1992). Gadids, particularly cod, continued as a main target despite declining numbers. Market demand kept prices high enough to make fishing for cod economically attractive despite a decreased catch-per-unit-effort. In contrast, dogfish and skates had little-to-no market value, leaving fishermen without an incentive to target them, but rather to dodge areas where

they were commonly found and avoid getting "dogged-up." While fishing gears are not truly selective, fishermen do target fish of particular size, inhabiting certain depths. Before the invention of rock-hoppers and the tickler chains, more flatfish likely escaped trawl gear than benthic gadids, and skates and dogfish may have been able to avoid catch or survive discard better than other species.

2) The reduction in cod allowed its competitors and predators to increase (similar to that which has happened in other areas) resulting in increased natural mortality (Fogarty & Murawski 1998; Frank *et al*. 2005). The upper limit for biomass on Georges Bank is keyed to energetic constraints, which indicates the potential for competitive pressure for resources (Fogarty & Murawski 1998). Although a skewed decline in species biomass might be expected to lead to decreased intra- and inter-specific competition, decoupling of the pelagic and benthic systems driven by the biomass removal may have resulted in a an energy depleted system, thus decreasing resources and re-increasing competition (Choi *et* al. 2004). Stomach-content studies and feeding guild cluster analyses indicate moderate-to-high levels of diet overlap between spiny dogfish and gadids, between overexploited teleosts and small elasmobranches and underutilized teleosts, and a high potential for competition between gadids of high commercial importance and low-to-nonexistent commercial importance (Grosslein *et al.* 1980; Langton 1983; Fogarty & Murawski 1998). Therefore, an increase in skates and dogfish increases competitive pressure on cod due to the limiting nature of food resources. Additionally, dogfish and winter skates prey on juvenile cod, thus an increase in their number increases predation on cod (NEFSC 2004a).

3) Unfavorable abiotic conditions reduced primary productivity constraining cod recruitment and growth (Choi *et* al. 2004) and increasing natural mortality. After the foreign fleets vacated national waters in 1976, gadids experienced a small increase in biomass, but within several years, low biomass resumed (Fogarty & Murawski 1998). The second biomass decrease results from a combination of two factors: the domestic fleet grew to compensate for the missing foreign fleet's effort; and, stratification of the water column increased, primary production decreased, and bottomwater temperature decreased, all of which limited the recruitment and growth of the benthic community (Choi *et* al. 2004).

(Although the stock assessment model does not apply the 20% natural mortality parameter to cod eggs and larvae (meaning decreased recruitment does not indicate the need for a higher M value), decreased recruitment lowers the number of cod getting to age one (when the parameter is applied). The model should take into account the decreased recruitment resulting from poor abiotic conditions (Choi *et* al. 2004); increased crustacean, dogfish, herring, and mackerel predation on cod eggs and larvae (Köster & Möllmann 2000); and decreased egg and larval survival resulting from truncated cod size, earlier onset of maturation, and condensed spawning season (Murawski *et al.* 2001; Hutchings & Myers 1993).)

Whether it's a result of one or all of the above theories, cod are experiencing increased natural mortality. The strength of some of these interactions remains uncertain due to the background of natural environmental variability and anthropogenic disturbance. Regardless, it has been suggested that the collapse of a top-predator (cod) has created an alternative stable state, from which the recovery of cod is not certain (Myers & Worm 2005). Competition and predation are two important influences on natural mortality. The change is community structure supports the idea that natural mortality is greater than in 1978 and an M value considerably larger than 0.2 should be used in assessment models.

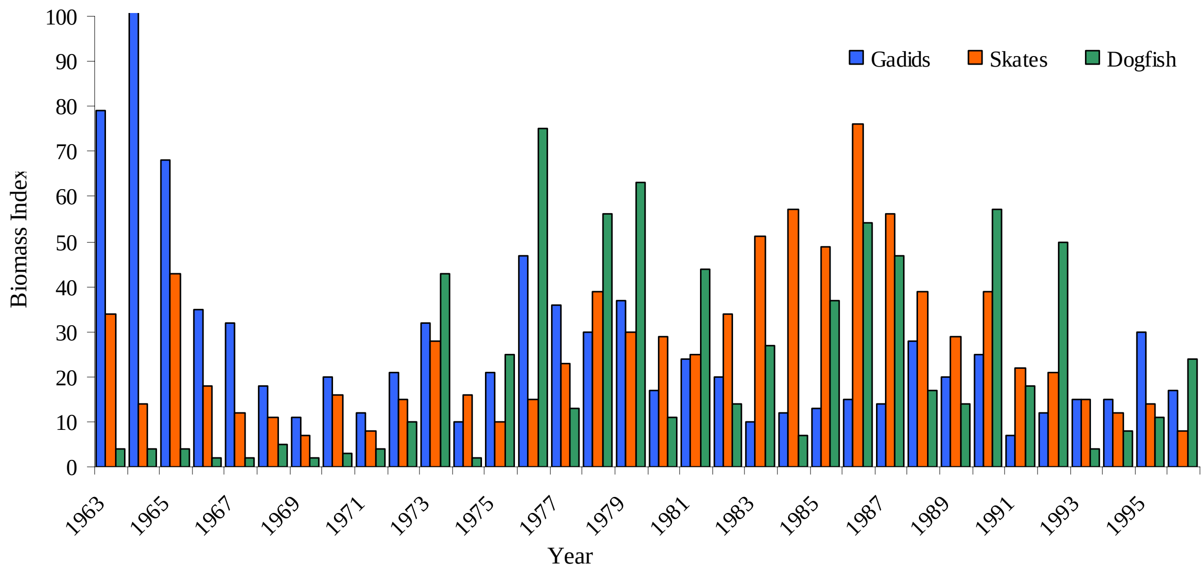

Figure 3. Relative biomass of gadids, skates, and dogfish, 1963-1996. (Adapted from Fogarty & Murawski 1998.)

II. Habitat Degradation and Loss

Habitat degradation and loss rank as the greatest threats to the environment. Fisheries managers have become increasingly concerned about these threats since the 1990s (Dayton *et al.* 1995). As a result, the 1996 Sustainable Fisheries Act amendments to the MSFCMA mandated the identification and consideration of Essential Fish Habitat (EFH), defined as those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity (NMFS 2004a). The maintenance of whole system integrity, including biotic and abiotic elements, is one of the guiding principles for ecosystem-based management.

The 2004 EFH Source Document for Atlantic cod states that the knowledge of habitat requirements for the species is scant beyond the distribution and relative abundance levels, yet recent studies are beginning to associate certain life stages with certain substrate types, as shown by survey data and experimental studies (NMFS 2004a). Seafloor substrate is the base of a bottom-up mechanism: sediment type, grain size and geometry, and nutrient and oxygen content can influence recruitment, competition, reproduction, and survival of organisms (Valiela 1995; DeAlteris *et al.* 2000). Research vessel trawl data shows that pelagic juveniles and recently-settled benthic juveniles of cod have a widespread distribution on Georges Bank, appearing among sand, gravelly-sand, and gravel pavement substrates (NMFS 2004a). Within a month, however, juveniles are present predominantly on the gravel pavement habitat on the northeast part of GB and are absent from the sandy bottoms. Likewise, off Nova Scotia and Newfoundland, juveniles settle in all habitats—sand, seagrass, cobble, and rock reef—but density is higher in more complex habitats (Tupper & Boutilier 1995; Gregory & Anderson 1997).

These studies related the observed pattern of higher juvenile and young cod density among more complex substrates to increased survivorship (NMFS 2004a; Tupper & Boutilier 1995; Gregory & Anderson 1997). A complex seafloor enables better predator avoidance and decreased predator efficiency by providing more refugia and a more cryptic background. In the presence of predators, juvenile cod, the prey of many piscivorous fish, have been observed to shift their substrate preference to a variety of complex substrates and vegetation (NMFS 2004a). Adult cod, while prey to few, have also shown preference to course sediments over finer mud and silt substrates in some studies (NMFS 2004a), perhaps due to improved foraging among more complex substrates. As substrata complexity increases, so does young cod survival from predation. Any action that decreases this structural complexity also increases the natural mortality of Atlantic cod.

Fishing, itself, is such an action. Fishing gear, substrate, and disturbance regime determine the degree of seafloor damage resulting from direct physical contact and indirect effects. Physical contact of the fishing gear with the seafloor can move, mix, and crush the substrate. Indirectly, fishing can reduce species diversity and functional complexity through several methods: large bodied and fragile taxa that add dimensional complexity can be partially or completely crushed under the weight of the gear; re-suspension of surface sediments that remobilizes contaminants and radionucleoides or exposes the anoxic lower sediment layers can harm, kill, or avert inhabitants; and seabed-mixing followed by the resettling of fine sediments can decrease recruitment and colonization by sessile organisms that prefer harder substrates (Collie *et al*. 2000; Jennings *et al.* 2001).

Due to their mobile nature and high degree of physical contact with the seafloor, mobile bottom-tending gears[4] rank as the most destructive gear type to benthic communities and habitats, while demersal fixed-gears[5] are significantly less destructive (Jennings *et al.* 2001; Valemarsen & Suuronen 2001). In New England, fishing for cod is almost completely performed with three gears: otter trawl, gillnet, and hook. Mobile otter trawl landings typically surpass fixed gear landings in GoM and GB by a factor of 2:1,[6] meaning that the more destructive gear type dominates the cod fishery (NEFSC 2004b).

Benthic fishing occurs on a seafloor of variable composition, classified as sand, gravel, sand-gravel, mud, sandy-mud, etc. based on the dominance or co-dominance of a particular sediment type. In general, habitats that are three-dimensional yet susceptible to leveling (i.e. gravel bottoms) tend to be

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[4] These gear types include bottom trawls, beam trawls, epifaunal dredges, infaunal dredges, and demersal seines.
[5] These gear types include bottom-set gillnets, demersal longlines, traps and pots.
[6] For example, otter trawl landed 63% of the all commercially landed cod in 2004, while gillnet, hook, and other landed, 31%, 3% and 3%, respectively (NMFS 2004b).

more sensitive to fishing disturbance than those naturally level and without emergent structures; and environments with a high degree of natural variation (i.e. sandy seafloors with high bottom currents) tend to be better suited to handle manmade disturbance (Collie *et al.* 2000; USGS 2001). Therefore, the structurally complex substrates that cod prefer and are key to juvenile survival are also those that are most susceptible to damage.

Regarding disturbance regime, more intense and more frequent disturbance events lead to more destructive results. An intermediate degree of disturbance will theoretically maximize species diversity, but more than that will lead to decreased diversity and often an environment dominated by fast-growing opportunistic species. Disturbance may be great in particular areas because the frequency of disturbance from fishing is spatially heterogeneous. Fishing effort was historically concentrated in areas where catches were high or expected to be high, and gear damage was low. While fishermen still target areas with high fish density, gear modifications, such as rock hoppers, have all but eliminated the natural refuges for fish afforded by terrain too rough for pre-modified gear. As a whole, the Gulf of Maine and Georges Bank are subject to high levels of fishery related disturbance. Between 1984 and 1990, Auster *et al*. (1996) estimate that the entire area of the GoM was trawled once annually and GB three to four times annually. Because fishing is not conducted evenly, estimates of fishing effort show distinct intensely fished areas (Fogarty & Murawski 2005). These areas often coincide with areas of gravel and gravelly-sand substrate that juvenile and young cod prefer.

Studies have shown that extensive trawling has decreased the structural complexity and biodiversity on areas of Georges Bank (Collie *et al*. 2000) and the Gulf of Maine (Auster *et al*. 1996). Using side scan sonar surveys[7] of fishing grounds on Georges Bank, the United States Geological Survey and the National Marine Fisheries Service have documented extensive scarring of the bottom by both groundfish trawls and scallop dredges (USGS 2003). Photo and video transects of undisturbed or lightly fished areas of GB and GoM reveal structurally complex benthic habitats abundant with foliose bryozoans, hydrozoans, and tube-building worms that further increase complexity (Collie *et al.* 1997; Auster *et al*. 1996). These areas exhibit high species diversity of polychaetes, shrimp, brittle stars, mussels, and small fishes. Conversely, heavily fished areas display lower species diversity, reduced habitat complexity, and are often dominated by few resistant or opportunistic species. These effects are most pronounced in intensely fished areas.

Cod fishermen demonstrate their preference for the structurally complex habitats that support greater cod populations by fishing there more often, but in doing so they decrease the substrate complexity which affords them higher catches there. Those areas that are the most disturbed are also those most susceptible to damage from fishing gear and those most important to juvenile cod survival.

[7] Side scan sonar: a sonar system dragged behind a research vessel. The sonar produces sound energy that bounces off of the seafloor and is then picked up by a receiver. This reflected energy is used to create a picture of the underwater topography of the area.

By reducing substrate complexity, trawling increases juvenile and young cod mortality due to predation. The extensive trawling on GB and within the GoM results in decreased cod survival and reveals that the M value used in stock assessment models is underestimated.

III. Selective Harvest

Fisheries management has largely ignored the possibility of evolutionary change to fish stocks because short-term ecological processes dominate fisheries science. Recently, fisheries scientists have raised an alarm about the "Darwinian consequences of selective harvest" (Conover & Munch 2002). By this, Conover and Munch (2002) mean that the selective removal of large fish can favor genotypes with traits that are unfavorable to the sustainability of stocks. Under the earlier notion on the inexhaustibility of the ocean, its vast interconnectedness, and the enormous fecundity of fish, evolutionary change caused by exploitation was thought impossible. However, Law and Stokes's review on the evolutionary impacts of fishing concludes that the heritability values for traits under selection due to exploitation are most often between 0.2 and 0.3, a magnitude capable of leading to observable evolution over decades of selective harvest (Law and Stokes 2005).

Conover and Munch (2002) conducted an experiment to demonstrate the heritability of certain traits in hopes of increasing the body of evidence that could influence management to consider the potential for size-selective fishing to influence population productivity. They harvested Atlantic silversides, fish with similar traits as cod (high fecundity, small egg size, external fertilization, spawning en masse, and pelagic larvae) except for small size and a short generation time that facilitated the experiment. Using captive populations, they harvested for six generations using three protocols: 1) taking the largest 90% of fish, 2) taking the smallest 90% of fish, and 3) taking a random selection of 90% of fish. Results for the large-harvested populations included decreased biomass yield, decreased mean weight of harvested individuals, decreased spawning stock biomass, decreased larval growth rate, and decreased egg size, which the researchers attribute to genetic change in somatic growth by juvenile fish. While the experiment had an extreme harvesting regime (90%) and lacked the natural variability, overlapping generations, and longer generation time that would be expected of cod in the wild, cod's decrease in size at age, earlier age at maturity, and failure to rebound from a 90-99% biomass loss (Myers & Worm 2005) are consistent with the evolutionary response documented by Conover and Munch.

Fishermen harvest cod in a size selective manner to maximize profits and comply with minimum size regulations, currently set at 22 inches. As a result, the highly exploited cod stocks display truncated size and age distributions and few larger/older individuals (Conover & Munch 2002; Murawski *et al.* 2001). By selectively harvesting larger individuals, fishermen inadvertently provide a selective advantage to phenotypes with greater rates of reproduction early in life at the expense of growth and survival (Law & Stokes 2005). As noted in cod stock assessments and indicated in the recently developed maturation reaction-norm analyses, the results include a decline in mean weight-at-age and earlier age-at-maturation (NEFSC 2004a). Variable age at first spawning is a source of diversity that has been progressively reduced by increasing exploitation. Historically, cod matured between the ages of one and five, a range that must have some adaptive significance or the population would all mature at the earliest time possible (Murawski *et al*. 2001).

What do these changes mean for the life history of cod? There has been an increasing amount of research on the effects of maternal size and age on reproduction, specifically on egg, larvae and juvenile survival. Research indicates considerable reduction in hatching success for recruit spawners compared to repeat spawners—a nearly five fold difference between first and second time spawners, and an even greater difference with third time spawners (Trippel 1998; Solemdal *et al*. 1995). A 1998 study by Marteinsdottir and Steinarsson found that the size and age of female Icelandic cod correlated to the size of their eggs and newly hatched larvae (older and larger cod spawned larger eggs and hatched larger larvae). Murawski *et al.* (2001) review the influence of egg diameter, finding a positive correlation with numerous parameters of egg and larval viability including larval dry weight, yolk weight, percent of larva comprised of yolk, hatching percentage, resulting larval length, percent of larvae feeding on day five, percent of larvae with a swim bladder on day ten and specific growth rate of fifteen-day-old larvae.

What does this mean for the survival of cod after year one, the time at which the assessment model begins to apply the 20% natural mortality rate? A 1996 study by Chambers and Leggett answers this question by modeling growth of cod hatchlings starting at different sizes. They find that initial hatchling size accounts for as much as 35% of the size variation observed months after hatching in natural populations. Decreased juvenile size and increased time as small fishes (due to decreased somatic growth) increase the vulnerability of fish to predation and increases natural mortality. As a result of selective harvesting, the assumed value for natural mortality is underestimated in the cod stock assessment model.

Recommendations to Improve Atlantic Cod Stock Assessment

Fish stocks are inherently dynamic: they change over time and respond to management regulations differently over time. Despite the advances to fisheries management attained by stock assessment, there remains uncertainty and error in their application. Consequently, fisheries management requires decision-making and risk-taking (Hilborn 1992).

With the difficulty inherent in fisheries research, any practice than can improve the precision or accuracy of stock assessment should be utilized. Understanding the life history of a species is central to understanding how fishing and the environment affect a population (Jennings *et al*. 2001). If the life history of cod is different from that assumed in the models, then the products of the model—estimates of stock size, spawning stock biomass, fishing mortality, and recruitment—will be incorrect. These model products form the basis for fisheries management and if wrong the Council cannot manage the resource to the best of its ability.

As such, I recommend that the Council:

1. Incorporate migration into stock assessments;
2. Correct the natural mortality parameter used in stock assessments; and
3. Add an uncertainty parameter into stock assessments until recommendations two and three can be fulfilled.

Scientists use research vessel bottom trawl survey data to assess stock status. Survey data provides a snapshot of resource distribution that without considerable movement of the stock can be analyzed and averaged to generate resource abundance for the year (Gavaris & Murawski 2004). However, when stocks exhibit significant migration, averaged survey data that lacks an instantaneous measurement of resource distribution does not truly reflect the distribution of fish. To remedy this situation, the ongoing research on cod migration by the Northeast Regional Cod Tagging Program must be completed and incorporated into the stock assessment process.

The difference between knowing that something needs to change in the assessment process and actually changing it is significant. Despite the uncertainty intrinsic in the assessment process, any action to change this traditional practice is viewed with skepticism and requires high scientific certainty in the research that suggests a change is necessary. Attaining certainty with tagging studies is difficult because they are complex and must account for temporal and spatial differences in tag deployment, fishing effort, tag-induced mortality, reporting rate, and accuracy. The burden of proof rests on the shoulders of those that want to change the system rather than those that want it kept the same even when the current system is known to be inadequate.

Incorporating cod migration into assessments has the potential to enlarge or reduce biomass estimates; however, proponents of the fishing industry will assume that biomass estimates will be reduced and result in lower target TACs and increasingly restrictive fishing regulations. As seen in the past, there will be political pressure for more economically and socially oriented measures than those that are ecologically centered. The potential for migration to significantly effect model outputs has been suggested in past assessments (NEFSC 2001) and research (Hunt *et al.* 1999), but failed to elicit immediate Council attention.

Will the results from the Northeast Regional Cod Tagging Program be treated differently? If the science does confidently support migration of cod between areas and the Council ignores it, then an environmental organization or other interested group should champion the issue and bring suit against NMFS. The court would be pressed to rule for the plaintiff because National Standards 2 and 3 of the MSFCMA mandate the use of the best scientific information available and that, to the extent practicable, an individual stock of fish be managed as a unit throughout its range, and interrelated stocks of fish be managed as a unit or in close coordination.[8] Interested groups have filed and won lawsuits against NMFS (via the Secretary of Commerce) for allowing FMPs that did not adhere to the ten National Standards (Kalo *et al*. 2002).

If the tagging programs provide scientifically sound and peer reviewed data indicating substantial movement, there are at least two ways to adjust the assessments to incorporate migration information: 1) combine the fishery-dependent and fishery-independent data for the two stocks and assess them as a combined unit, using the current VPA model, apportioning fishing mortality rate and stock size to each substock area post-hoc, if area-specific values are needed; and 2) use the cod tagging data to estimate exchange rates, on average, between the stocks, and apply a Two-box VPA approach, which in essence runs a tuned VPA for each stock area including exchange rate parameters to account for migratory effects (J. Brodziak, NEFSC, pers. comm.). This second approach has been developed by Clay Porch at the Southeast Fisheries Science Center for assessments of Atlantic bluefin tuna.

While different, neither method suggests that the stocks simply be combined and assessed together. Rather, each method would incorporate cod migration between the areas into the assessment. Assessing the cod populations as one conglomerate whole would be incorrect because it is important to have spatially defined allowable catches. Spatially defined catch limits are necessary for the preservation of genetic diversity of cod subpopulations. Recent genetics research has shown that distinct subpopulations occur between inshore and offshore areas, between Georges Bank and Nantucket Shoals, and between Georges Bank and Browns Bank (NMFS 2004a). This research suggests that a system with a TAC for the whole area would lead to faster depletion of those substocks that are perceived to be most abundant since fishermen harvest in non-random patterns. Monitoring of total landings that are not spatially defined would not indicate that one area was being overfished, while another under-exploited. Ideally, cod would be spatially assessed with migration rates between the current stock units and between subpopulation areas, and TACs would be assigned for each of those areas, to avoid the depletion of local populations.

Natural mortality is not an independent factor, but one that fluctuates within limits set by abiotic and biotic factors (Begon *et al*. 1996). Altered community composition, degraded benthic habitat, and selective exploitation are increasing the natural mortality of cod through increased predation and competition, decreased juvenile survival, and reduced growth rates. These influences have altered cod's natural mortality since its last estimate in 1978. Therefore, the assumed value of M needs to be increased in stock assessment models.

Adjusting M to more accurately reflect the natural mortality rate of cod requires either a study of cod natural mortality in an area of the ocean where each of the factors has affected cod and where fishing

[8] 16 U.S.C. §1851 (a) (2) and 16 U.S.C. §1851 (a) (3).

mortality is absent, or additional research on each of the factors to determine a quantity by which cod natural mortality has increased as a result of each factor. The current closed areas on Georges Bank and within the Gulf of Maine may provide such a location for the first potential research project, although the migration of cod would compromise the precision of such efforts (NRC 2001). After cod migration is quantified using the data obtained via the Northeast Regional Cod Tagging Program, the study may be possible. The cod tagging program will likely require several more years before providing conclusive migration frequency results, and an additional study of natural mortality would take another several years. Likewise, studying the effect of the three factors on cod natural mortality would take considerable time and financial resources. In the interim, cod fishing would continue at the prescribed rate, resulting in continued overfishing because of the model's unrealistic parameters.

Given the extremely depleted status of cod, time is of the essence. Each fishing year where the TAC is set on inaccurate assessments drives the stock into further depletion from which recovery becomes increasingly difficult. We require more immediate action involving migration and the value of M for model assessment in order to avert additional unexplained overexploitation of the cod resource. It is better to have a Type I statistical error in which we conclude there is an effect when really there is none, than a Type II statistical error in which we conclude that there is no effect when there really is one. Type I errors result in a loss of revenue from which recovery is fast, while Type II errors result in damage to the species or ecosystem from which recovery is slow (Dayton *et al*. 1995). The Council must act before scientific consensus is achieved to have effective management, and its action must be to air on the side of caution. In applying the precautionary principle, managers must increase the value of M to the highest value that scientists think it could be after decades of influence by the indirect effects of fishing. Again, National Standard 2 of the MSFCMA requires that fisheries management incorporate the best scientific information into stock assessments. While the best scientific information will be less certain in the beginning regarding natural mortality, it will become more certain as studies on cod natural mortality are completed.

To avoid Type II error until the research on migration and natural mortality are complete, we can amend the current stock assessment model with an uncertainty parameter that buffers against the error resulting from inaccurate model specification. This parameter would remedy the recent pattern of stock size overestimation and fishing mortality underestimation in stock assessment results. The use of such an uncertainty parameter is not new to resource management; for example, the management of marine mammals uses the Potential Biological Removal equation in which an extra "recovery factor" between 0.1 and 1.0 is inserted to cushion for uncertainty.[9] Marine mammal management also develops acceptable take limits based on the *minimum* population estimate, rather than the *average* population estimate as done with fish stock assessments. Cod stock assessment and management aimed at rebuilding the

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[9] Marine Mammal Protection Act: 16 U.S.C. §1362 (20).

population would benefit from the use of both these conservation techniques used in marine mammal management. Given the overfished and overfishing status of cod, the use of conservative management is appropriate.

Conservative and experimental approaches to management will be met by skepticism from the fishing industry because it will involve a short-term reduction in yield (because the indirect effects of fishing that increase natural mortality requires that the level of fishing mortality be reduced), without guaranteed increase in yield in the future (Ludwig *et al*. 1993). A fisheries system that uses active adaptive management, in which a combined approach of formal stock assessment with empirical management experimentation, may provide the best method to balance biological and economic needs. Without action to account for cod migration and the harmful consequences of altered community composition, habitat degradation and selective harvesting, the recovery of the cod stocks will continue to falter.

One management tool that deserves attention here is the marine reserve, a form of spatial management. Reserves can offer various levels of protection, excluding all or just some types of fishing and other maritime activities. Benefits of marine reserves stem from their ability to be simple and enforceable after boundaries are established and recognized; have regulations that are tailored to specific habitats; support conservation of the full range of marine resources, including habitat, biological diversity, and exploited species; provide areas for education and research on marine ecosystems; and provide "control" sites for determining natural mortality rates for different life-history stages (NRC 2001). Proper reserve design is essential to their functioning—without consideration for source-sink population structure, species life history traits, and environmental characteristic, reserves are unlikely to achieve stated goals, and instead will decrease political will to increase the existing reserve network (Crowder *et al*. 2000).

The reserves in New England waters, if properly sited, should help to protect the large, fecund females so important to cod biomass, as well as protect benthic habitat from additional damage. Closed Areas I and II on Georges Bank and the Western Gulf of Maine Closed Area provide protection to large numbers of cod eggs, larvae, juveniles, and adults (NMFS 2004a). Closed Area II on Georges Bank also encompasses some of the gravely-sand and gravel pavement substrate that is essential fish habitat for cod. Conversely, reserves are not likely to protect adult cod that migrate extensively, aid cod larvae and juveniles that are the subject of increased predation or competition, or reverse the genetic pressure that generated truncated size range, earlier onset of maturity, and decreased growth rate (Law & Stokes 2005). The high density of fishing effort around the closed areas suggests greater catch rates around the reserves, supporting the idea that reserves will enhance fishery catch through spillover of adults. However, to achieve protection for species that display large movement, marine reserves must cover substantial areas.

Due to the high degree of movement shown in the cod tagging data, the marine reserves on Georges Bank and in the Gulf of Maine should be increased to offer greater protection to the Atlantic cod resource.

Atlantic Cod Management Analysis

Due to cod migration and underestimated natural mortality, stock assessments do not reflect the true abundance of the cod population. Regardless, the assessment acts as the platform from which the process to determine specific management measures for the stock begins. This process is described below.

Annual Management Steps:

1) Conduct Stock Assessment (see *Stock Assessment* section);
2) Based on stock assessment and Biological Reference Points (BRPs), determine desired fishing mortality (F) for next fishing year (May-April);
   (BRPs include MSY,[10] SSB_{msy}[11] and F_{msy}[12] and are used to advise managers on harvest strategies to minimize the risk of recruitment overfishing. They are periodically updated: NEFSC scientists last updated the BRPs in 2002 (NEFSC 2002), which were included in the 2003 FMP Amendment 13.)
3) Based on F, determine target total allowable catch (TAC);
   (Target TACs were first introduced in the 1996 Amendment 7 to the FMP. Target TACs are meant to provide a measure by which to evaluate the effectiveness of the rebuilding program, and serve as a benchmark from which the Council can make measured adjustments as stocks rebuild. If a target TAC is reached in any period (year or otherwise), the Council may take action to restrict catches in the next time period so long as it is fair and equitable to different user groups. The basis for the GB cod target TAC is $F_{0.1}$,[13] whereas the basis for the GoM cod target TAC started at F_{max},[14] but in 2000 the Council changed it to $F_{0.1}$ as well.)
4) Based on target TAC and days-at-sea (DAS) for vessels, determine trip limits;
   (DAS were first implemented in the 1994 Amendment 5 to the FMP. Managers needed an averaged 50% reduction in F to eliminate overfishing of all the stocks, and knowing that increased mesh size or larger closed areas would not achieve this, they began an effort reduction program to reduce historical DAS level to 50% over a 5-7 year period, or a 10% reduction per year. In subsequent actions, the program was intensified because the level of mortality was not declining as hoped, and DAS were divided into three categories: A, B, and C, for which additional rules were made. Trip limits are in effect separately for GB and GoM cod, although GoM cod trip limits were used two years prior to GB cod trip limits (disregarding the short-lived trip limits used in the original FMP). Originally, trip limits consisted of a daily limit with no maximum on the number of days for a trip, but since a 1999 Interim Rule, limits have consisted of a daily limit with a maximum trip limit. Amendment 13 put the daily/trip limits at 800/4,000lbs for GoM cod and 1,000/10,000lbs for GB cod.)
5) Enforcement of DAS and trip limits via vessel and dealer reporting systems;
   (Mandatory reporting of landings and effort data by vessel were first implemented in Amendment 5 using logbooks and a call-in system. While the Council supported electronic vessel monitoring

[10] Maximum Sustainable Yield (MSY) is the largest average catch that can be taken in the long-term from a stock, which corresponds to the yield expected from fishing at F_{msy}.
[11] SSB_{msy} is the spawning stock biomass (total weight of sexually mature fish in the population) needed to achieve MSY.
[12] F_{msy} is the fishing mortality rate which, if applied constantly, would result in MSY.
[13] $F_{0.1}$ is defined as the fishing mortality rate where the increase in yield-per-recruit for an increase in a unit of effort is only 10% of the yield-per-recruit produced by the first unit of effort on the exploited stock (i.e. the slope of the yield-per-recruit curve for the $F_{0.1}$ rate is 1/10 the slope of the curve at its origin).
[14] F_{max} is defined as the rate of fishing mortality that produces the maximum level of yield per recruit. This is the point beyond which growth overfishing begins.

systems, VMS usage remains largely voluntary for vessels and only in Amendment 13 were electronic dealer reportings required for vessel landings data within 24hrs for large dealers. Each report is linked to a specific vessel through a trip identification number that is provided to the vessel by NMFS when the vessel declares a trip. Trip notifications must be made through either a Vessel Reporting System or by telephone confirmation with NMFS before and after the trip.)

6) When vessels land more than the daily/trip limit, they are forced to account for the overage by running the DAS clock for a duration that makes the overage legal;
   (The running clock was first implemented in Framework 20 when a trip limit was mandated for GoM cod; however, it allowed for vessels to fish for other species while the clock ran, meaning that cod was still caught as bycatch. Framework 24 remedied this loophole—capable of undermining the system—by mandating that vessels stay in port while the DAS clock ran to account for the overage. Under an Interim Action in 2000, all trips between 3 and 15 hours long count as 15 hours and rules were enacted to prevent front loading of the DAS clock.)
7) Monitoring of landings and DAS usage by NMFS Northeast Regional Office's Fisheries Monitoring and Analysis Section, located in Gloucester, MA.
8) Potential management measure adjustment when the target TAC is reached or expected to be reached before the end of fishing year.
   (The Regional Administrator can reduce trip limits, amend closure areas, or change other gear regulations to slow approach to, or surpass of, the target TAC. She can not reduce the DAS allocated; they are already on an annual reduction course. This is not a hard TAC that shuts down the fishery when reached.)

Under this system, the Council has been almost wholly unsuccessful in restricting cod landings to below the target TAC; this has resulting in the continued status of cod as overfished and experiencing overfishing. Cod landings have exceeded the target TAC for eight of the nine years that they have been used (Figure 4). Only in the 2004-2005 fishing year were cod landings kept below the target TAC, which had been increased for the year despite the previous year's being exceeded by 72 percent (Figure 5).

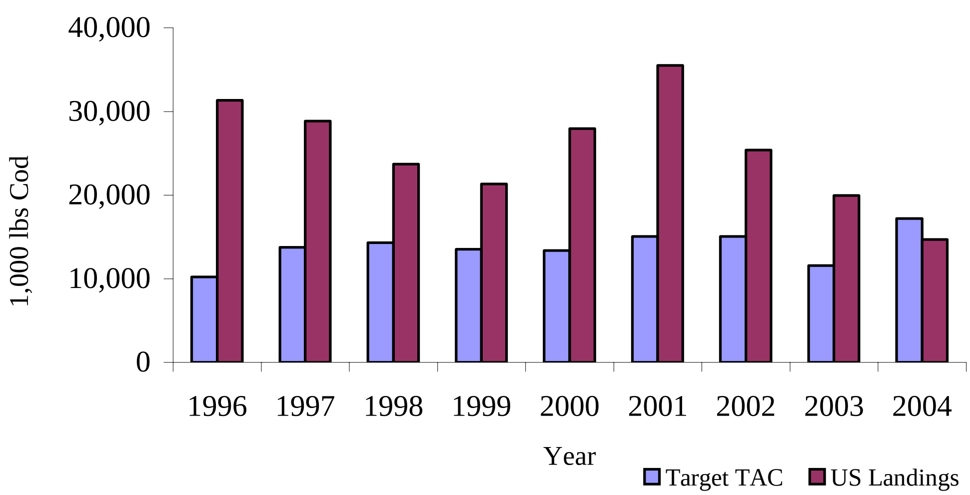

Figure 4. Combined GB and GoM cod target TAC and US landings from 1996-2004.

The failure to keep landings below the target TAC arises from a combination of factors:

1) Desire to gradually reduce fishing effort for socio-economic reasons (i.e. keep fishers working and reduce economic loss);
2) Overconfidence in the management tools, specifically the ability of the effort-reduction program to reduce fishing mortality; and
3) Noncompliance and inadequate enforcement.

The economic and social influence on fisheries management is not likely to change. The MSFCMA states that conservation and management measures must take into account the importance of fishery resources to fishing communities in order to provide for the sustained participation of such communities and to the extent practicable minimize adverse economic impacts on such communities.[15] This mandate, in addition to the difficulty achieving National Standard 1 that says conservation and management measures must prevent overfishing while also achieving optimum yield, has created considerable conflict among stakeholders (Brodziak *et al.* 2004).

So long as the Council must consider the economic and social consequences of management measures on the community, it is unlikely that management measures will be as protective as possible or proceed as quickly as possible. For example, the effort reduction program was phased in over a period of ten years (1994-2004) because of the mandate to minimize adverse economic consequences.[16] Nearly all Council proposals aimed at bringing the Multispecies FMP into compliance with MSFCMA and SFA biological requirements have negative socio-economic consequences, particularly when considering drastically depleted stocks. When a resource has been overfished as long as cod, the most pervasive management problem is how to rebuild the stock while maintaining viable commercial fisheries (Brodziak *et al.* 2004).

Due to the conflicting objectives and values between conservation and short-term economic and social concerns, tightening of any control measure is met with great opposition from the majority of the industry. Although environmental organizations and recreational fishing interests have become more empowered in recent years, the Council receives considerable pressure from the commercial fishing industry to promote their needs. Additionally, many Council members, themselves, represent certain sectors of the commercial fishing industry. This often results in decisions that implement less restrictive fishing measures than those originally proposed. When this happens, the Council is often criticized for ignoring scientific information. When regulations implemented by the Council are thought to fall short of the National Standards, the defendant of any lawsuit is NMFS because it is directly responsible for fisheries management. As a result, the Council lacks accountability in the management process and will likely continue to yield to political pressure for economic and social factor prioritization.

[15] 16 USC §1851: a (8).
[16] See Figure 6 for allocated and used DAS between 1994 and 2004.

The second hindrance to accurately managing landings involves overestimating the decrease in fishing mortality that results from effort reduction. When first proposing the effort reduction program in Amendment 5, the Council admitted that the relationship between the desired 50% reduction in fishing mortality and the mandated 50% reduction in effort had yet to be precisely established due to the imprecision of the estimates and assumptions made in the models (NEFMC 1993). Additionally, the use of days-at-sea as a proxy for effort has been criticized (P. Parker, CCCHFA, pers. comm..), as has the assumed consistency in effort and catch-per-unit-effort between vessels.

Model uncertainty has resulted in the Council's need to accelerate the effort reduction program several times, enlarge existing and implement additional temporary and permanent closure areas, and increase gear mesh size. (See Appendix 2 for a summary of the major multispecies regulations since 1977.) While these measures do function to reduce fishing mortality, they are ad hoc regulations implemented only after the existing effort reduction regulations have failed to meet stated goals and the damage had been done. The inherent uncertainty in models will not change. Models are always an abstraction of something natural for a purpose (i.e. understanding, prediction, management), for which absolute validity can never be determined. Even when a model's results match real observations, we have not validated the underlying assumptions within the model (Martin 1996).

The commercial fishing industry will use the 2004 landings to target TAC data to show that the effort reduction program, having achieved the fishing effort rate to realize the management goal, can now cease. Industry representatives may use trends, such as those shown in Figure 5, to say that both the number of vessels and the number of DAS used loosely correspond to the percent that landings have exceeded the target TAC in past years, and that days-at-sea allocated should be increased because fishermen did not land as much as they were allocated. But, the real reason that landings did not exceed the target TAC is that it is nearly impossible with the degree of stock depletion: if the fish aren't there, they can't be caught. Georges Bank and Gulf of Maine cod are heavily overfished. For this reason, the level of effort, although reduced to 50% as mandated (Figure 6), does not correspond to a 50% fishing mortality reduction. Georges Bank cod are subject to a fishing mortality (F) of 0.24 while F_{msy} is 0.175, and GoM cod are subject to a fishing mortality (F) of 0.63 while F_{msy} is 0.225 (NEFSC 2005). Additional days-at-sea allocations would only increase the fishing mortality rate and drive the stock into further depletion, especially if the target TACs are being set too high as this paper suggests in previous sections.

If the stocks do recover and DAS are still used to control effort, the effort to mortality ratio and model assumptions will again make the number of DAS required to attain the desired fishing mortality and target TAC highly uncertain. Under such a circumstance, the Council needs to take a precautionary stance to avoid the reversal of a biomass building trend by refusing to increase the DAS allowance as high as models suggest and the fishing industry desires.

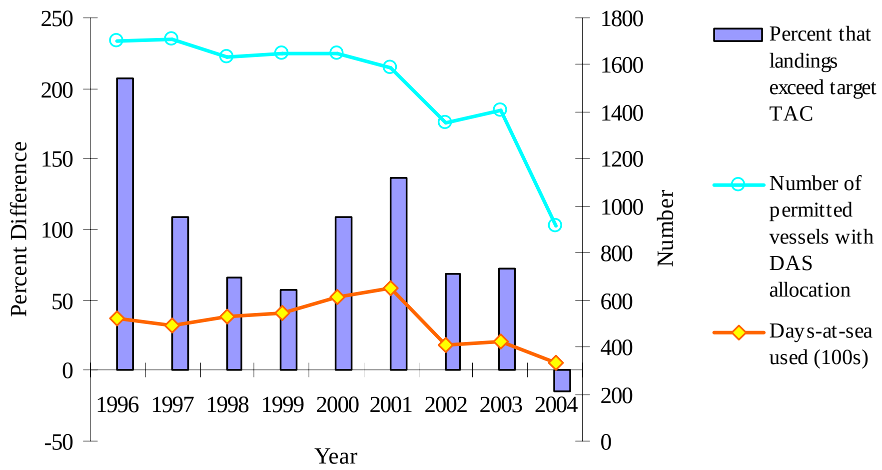

Figure 5. Relationship between target TAC overage, number of vessels fishing for cod, and days-at-sea used by vessels fishing for cod, 1996-2004. (Years are in fishing years, that is, May-April.)

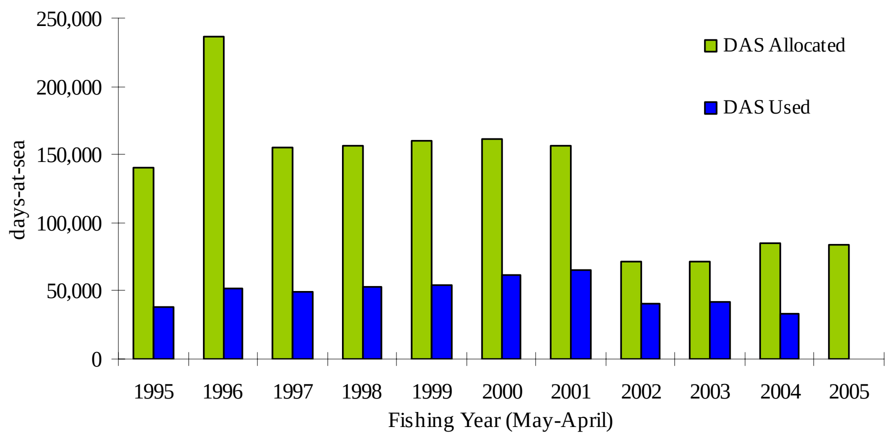

Figure 6. Days-at-sea allocated and used in the Northeast Multispecies Fishery, 1994-2005. (NMFS 2004a.)

Effective fisheries management is hampered by noncompliance. Fishers have an incentive to cheat because of the potential financial advantage. Noncompliance occurs despite the management tools used for enforcement, which has a long history of inadequacy in fisheries management. Managers abandoned trip limits in 1982 because of noncompliance. Under this management system, fish were frequently mislabeled and landings misreported because NMFS did not have the capacity to monitor daily landings per vessel. In Amendment 2, managers eliminated the scheduled increase in codend mesh size because of compliance and enforcement issues and instead adopted other measures they felt could better be controlled. For the development of Amendment 5, the Technical Monitoring Group (TMG) concluded that the previous FMP was making only minor progress towards achieving its objectives due in large part to the regulations' difficult enforcement, unlikelihood of being enforced, and ease of subversion (NEFMC 1993). Decreasing fishing mortality required an effort reduction program because the mesh size that would be required to reduce mortality to the same level was substantial, and minimal compliance was expected to make its implementation ineffective. The TMG also noted the need for an examination of the effectiveness and enforceability of other measures, particularly closed areas and catch limits. In Framework 30, enforcement agents commented on the inadequate compliance with trip limits due to cost and logistical difficulty of enforcement (NEFMC 1999). Also, in the process of developing Amendment 9, several written opinions from the public comment process highlighted the inability of management to enforce trip limits, and for trip limits to control the practice of high grading (NEFMC 1998: Appendix 4[17]).

Noncompliance and inadequate enforcement continues today. Difficulties with enforcement have made target TACs hard to control. Enforcement of target TACs and DAS usage requires monitoring at two levels: 1) daily monitoring of trip limits and days-at-sea usage, and 2) monitoring of the cumulative catch in reference to the target TAC, and vessel DAS usage in reference to vessel allocation.

The US Coast Guard (USCG) and the National Oceanic and Atmospheric Administration (NOAA) are the main enforcers of regulations for national fish stocks, including cod. The USCG maintains an at-sea presence to enforce regulations within the nation's 3.36 million square mile EEZ, while NOAA leads shore-side enforcement through vessel trip and landings reporting systems (USCG 2004).

The United States Coast Guard is authorized to assist in the enforcement of all applicable laws on, under, and over the high seas and national waters.[18] As a protector of national natural resources, the USCG strives to eliminate environmental damage and the degradation of natural resources associated with maritime transportation, fishing, and recreational boating. The budget to achieve this goal is partitioned into two sectors: Environmental Protection and Living Marine Resources. Fisheries enforcement is part of Living Marine Resources, to which typically 8-10% of the operation budget for the USCG is allocated.[19]

Under the ten-year Fisheries Enforcement Strategic Plan, called Ocean Guardian, the USCG's fisheries priorities are, in order of importance: 1) prevent encroachment of the US EEZ and internal waters from foreign fishing vessels; 2) enforce domestic fishing, marine mammal and endangered species laws and FMP regulations at-sea; and 3) ensure compliance with international living marine resource agreements (USCG 2004). The strategic framework encompasses four key concepts: simple, enforceable, and safe regulations; effective levels of physical at-sea presence; application of technology; and productive partnerships among fisheries managers, the fishing industry, and all enforcement agencies.

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[17] Letters submitted July 13, 1998 from Connors & Farrell Attorneys representing the Cape Cod Commercial Hook Fishermen's Association, and July 16, 1998 from USCG Captain RJ Brown, Chief, Office of Law Enforcement and Intelligence.

[18] 14 USC §2.

[19] Some budgetary statistics are available at: http://www.uscg.mil/hq/g-cp/comrel/factfile/index.htm.

Regarding enforcement of domestic fishing regulations, USCG personnel monitor closed areas and board vessels to check for compliance with permits, minimum size limits, gear restrictions, and other regulations. Fisheries Enforcement conducts at-sea vessel boarding with a flat target compliance rate of 97% per year.

By applying the actual compliance levels to the number of groundfish permitted vessels in New England, we see that the number of noncompliant vessels has ranged between 23 and 69 in the last five years, and has been relatively stable at about 40 for the last three years (Table 1). It is unlikely that this number of noncompliance events is responsible for the sizeable target TAC overages occurring in past years.

While the compliance rates are only a few tenths below the 97% goal, the USCG points to a variety of economic conditions and variables beyond their control (and expected to persist for the foreseeable future) that create incentives for fishermen to violate the law. These factors include hurricane damage, high fuel costs, complex regulations, lower days-at-sea allocations, and lucrative seafood prices in some fisheries (USCG 2006). In 2004, the majority of violations originated in two fisheries: the shrimp fishery in the Gulf of Mexico, and the multispecies fishery in the North Atlantic (USCG 2005).

The agency attributes the lack of compliance in the North Atlantic to the increasing regulatory complexity. To increase the compliance level, the Coast Guard plans to boost fisheries intelligence through increased use of the Vessel Monitoring System and increased industry-agency and agency-agency relationships. If the level of noncompliance in New England is enough to undermine management objectives then enforcement efforts will need to be ramped up in order to achieve the target compliance rate, which also should be subject to annual increases now that the 97% rate is known to be achievable. This will require greater at-sea presence to enforce gear and fish size regulation and either at-sea or remote vessel monitoring of closed areas. The USCG Fisheries Enforcement division will require a greater budget allocation in order to effectively monitor New England groundfish vessels.

Table 1. Compliance and enforcement statistics from the USCG. Number of domestic fishing vessels boarded, national target vessel compliance rate, and national actual vessel compliance rate for calendar years 2000-2005 (USCG 2005; USCG 2006). The approximate number of noncompliant vessels in New England is obtained by multiplying the national compliance rate by the average number of permitted fishing vessels for the two fishing years that overlap with the listed calendar year.

Year	**# Fisheries Boardings**	**Target Compliance**	**Actual Compliance**	**Approximate # of noncompliant vessels in New England**
2000	6492	97.0%	95.8%	69
2001	6592	97.0%	98.6%	23
2002	4121	97.0%	97.3%	40
2003	3408	97.0%	97.1%	40
2004	4560	97.0%	96.3%	43
2005	6076	97.0%	96.4%	NA

The National Marine Fisheries Service's primary method for enforcing target TACs is through landings and effort reporting. With Amendment 5, the Council first mandated logbooks for all vessels fishing under a multispecies permit in order to monitor landings. Fishers were to complete logbooks for all trips (not just those landing groundfish), fill them out before the end of every trip, and submit them to NMFS on a monthly basis. The Regional Administrator could require an observer on any vessel, and this acted as the only incentive for honest reporting. To monitor effort (as required for the effort reduction program) the Council proposed the use of electronic vessel monitoring systems (VMS) for any vessel fishing under the individual allocation of DAS[20], and either VMS or an electronic card monitoring system for all other vessels landing more than the possession limit of groundfish. Until the time that VMS could become operational, NMFS established a call-in system for use (NEFMC 1993).

Shortly before the Council convened to work on Framework 25 in 1998, NMFS completed its field experiment and concluded that the system was operational. Accordingly, VMS became one of the issues for consideration in the framework process. While the Council espoused a desire to implement mandatory VMS for individual DAS permit holders, they were concerned about the unknown added costs of purchase, installation, and updating that fishermen would be subject to amidst a period of expected declining revenue, as well as the inequity of requiring VMS for individual DAS vessels but not for fleet DAS vessels. As the call-in system "seem[ed] to be working as a mechanism for monitoring DAS," the Council opted to delay mandatory use of VMS for one year, until May 1 1999 (NEFMC 1998b).

By the time of Amendment 9, the Council had even more concerns about mandatory VMS and opted to delay implementation but with no specific deadline to confront their uncertainties. These included: equity among permit categories, effectiveness for location monitoring, cost uncertainty, cost control/vendor competition, cost/benefit for small boats, efficacy of hourly tracking, and electrical power requirement (NEFMC 1998). Thus, managers continue to monitor DAS usage with VMS for those boats that have voluntarily chosen to use it, and with telephone notification for those vessels using the older call-in system. DAS usage by vessels using the call-in system is subject to enforcement by at-sea USCG patrol officers.

While vessels are not yet required to have electronic VMS, the 2003 Amendment 13 requires electronic dealer reporting of vessel landings data within 24hours, replacing the paper reporting previously performed by dealers that was slow and inefficient (NEFMC 2003). Each report is linked to a specific vessel through a trip identification number that is provided to the vessel by NMFS when the vessel declares a trip. Dealer reports are collected by NMFS and monitored by the New England

[20] With the implementation of the effort reduction program in Amendment 5, each vessel had a choice of two alternative systems: 1) a fleet-wide requirement where all vessels declare blocks of time out of groundfish fishing (no less than 20 days each and including one block March 1- May 31) and layover at the dock one day for each two days of groundfish fishing to stay below a predetermined number of opportunity days; or 2) an individual allocation program based on reductions of 10% per year from an initial baseline determined from historical vessel performance, and requiring one annual 20-day block out of groundfish fishing March 1 - May 31.

Regional Office Fisheries Monitoring and Analysis Section, in Gloucester, MA. When a vessel exceeds the daily or trip limit for cod, the Northeast Regional Office orders it to stay in port for the appropriate time to account for the overage.

The problem with enforcement does not stem from DAS overage: since implemented, DAS usage is consistently below allocated DAS (Figure 6). Instead, the monitoring of cod catch rates appears to be inadequate. The Preliminary Cod Landings data as compiled by the Fisheries Monitoring and Analysis Section are released online six to seven times per year; however, each release is two to three months behind the period for which landings data is compiled[21]. For example, cod landings data for May through June of 2005 was not compiled and posted until September of 2005. Given the large number of vessels fishing for cod and the large number of dealers in New England it is expected that assembling landings data takes time, but given the importance of this data for monitoring approach to the target TAC, the extent of the delay is unacceptable. This landings data is that that may be used by the Regional Administrator (RA) of the NEFMC to impose reduced trip limits if she expects the target TAC to be reached before the end of the fishing year.

In reality, the RA seldom uses this power and when she has, it has failed to keep landings below the target TAC for that year. For example, under Framework 27 the GoM cod daily trip limit was set at 200lbs, and the RA was permitted to reduce the limit to between 5 and 100 lbs if necessary. Twenty-seven days later, the RA reduced the GoM daily trip limit to 30lbs until an Interim Rule two months later altered the trip limit to a 100lb daily/500lb trip maximum. Regardless, in the 1999-2000 fishing year fishermen were permitted to surpass the GoM cod target TAC by 179% (Figure 5). Additionally, the target TAC did not include discards and recreational landings, so this percent overage is conservative. Only in the 2005-2006 fishing year did the Council include discards and recreationally caught cod in the setting of the GoM cod target TAC. Georges Bank cod target TAC setting continues to omit discard and recreational landing information.

To remedy target TAC overage, hard TACs (which close the fishery when reached) have been suggested. In Amendment 13 the Council considered but rejected a proposal for implementing hard TACs. The Council was concerned that the alternative would lead to an unsafe derby fishery and either excessive discarding (if possession of a species was prohibited when a TAC was reached) or a sacrifice in the yield from healthy fish stocks (if groundfish fishing was prohibited when a TAC was reached). Additionally, the measure would be administratively difficult and costly given the twenty stocks that would require careful monitoring. In the Original FMP from 1979 the Council had adopted hard TACs and it proved to be an abject failure, leading to an unsafe fishery in which the resources were not protected and the fishery unstable (NEFMC 2003).

[21] See Preliminary Cod Landings by Stock Area, available at: < http://www.nero.noaa.gov/ro/fso/mul.htm>.

The recent use of hard TACs in the Eastern US/Canada Resource Sharing Area has also failed. While allocated a quota of 666,000 lbs of cod from the RSA in the first year of the agreement, US fishermen were permitted to land 2,205,000 lbs of cod, or approximately 333% of their TAC (Table 2). On the other hand, Canadian fishermen landed only 10% more than their TAC. It appears that the DFO's dockside monitoring program is far superior to that of NMFS, which, given Canada's long time use of hard TACs, is not surprising.

Table 2. US and Canadian quota and landings figures for fishing year 2004-2005 in the Resource Sharing Area (TRAC 2005.)

	Quota	Landed	% over Quota
	(1000 lbs)	(1000 lbs)	
Canada	2205	2426	110.0
USA	662	2205	333.1

Individual transferable quotas (ITQs) are another management option that have been considered by the Council. In Canada, the ITQ system is meet with criticism from some fishermen that claim it had an unfair initial allocation plan and is an ineffective control measure that results in consolidation of quotas in the hands of a few and high discarding (D. Theriault, Canadian fisherman, pers. comm.).

Recommendations to Improve Atlantic Cod Management

Under the MSFCMA, the New England Fishery Management Council has a legal mandate and responsibility to combat these problems in the fishery management system. Using the available science and management tools and to avoid legal action against NMFS, I recommend that the Council:

1) Decrease target TACs;
2) Restrict trawling DAS and fishing areas;
3) Improve monitoring; and
4) Fund a fisher retraining service.

The NEFMC has a legal requirement to prevent overfishing and rebuild Atlantic cod from its overfished state. While the 2004 landings were within the target TAC, this is an indication of inadequate fish abundance rather than management success (NEFSC 2005). Even when adhered to, recent target TACs have failed to end overfishing, and consequently need to be lowered until cod recovers from its depleted state. This action will require the Council to resist considerable industry pressure to do otherwise, but if it fails to do so and allow overfishing to continue, NMFS will be sued as has occurred in the past. While a lawsuit would incite the Council to decrease the target TACs, the fishery would continue as is until the lawsuit concluded. This time delay would only exacerbate cod's situation. It would be better to have something else trigger responsible action by the Council, such as public outcry, or a Secretary of Commerce that does his job as intended and does not approve FMPs that are out of compliance with the National Standards of the MSFCMA.

Additionally, the Council needs to implement a moratorium on vessel entrants or decide on an appropriate target fleet size. Lacking a capitalization goal when (and if) stocks recover will lead to new entrants using the substantial amount of latent effort (DAS) that currently exists (Brodziak *et al.* 2004). Use of latent effort would undermine the DAS effort reductions. A fleet size goal is necessary to avoid another overcapitalized, subsidy-supported, over-harvesting fishery caused by a lack of inhibition on investment when conditions are favorable, but strong pressure not to disinvest when the tide reverses. This pattern, the ratchet effect (Ludwig *et al*. 1993), consistently produces unsustainable fisheries.

When the target TAC is reduced (as recommended above), the DAS used by the fleet will also require a reduction. Rather than spread this reduction equally across the fishery and hurt each vessel economically, I argue that certain vessels—those doing the most damage to the cod stocks and their environment—should be those targeted for DAS reduction. In the last seven fishing years (1997/98-2004/05), benthic trawling has taken 57-70% of the total catch. In this same time series (except for the 2004/05 when the target TAC was not reached), benthic trawling has been responsible for taking 92-155% of the target TAC (NMFS 2004b). Clearly, trawling is responsible for landing the most fish and bringing the landings close to or above the target TAC. To reduce the DAS of trawlers would therefore be the most effective way of keeping landings below the target TAC. Typically, the smaller fishing vessels that do less damage to the fishery and ecosystem are most harmed by increased fishing regulations due to their smaller profit. Here is a means of avoiding this unfair situation that is justified by the data.

Reducing trawler DAS will have the added benefit of reducing the damage to the sea floor. The extent of trawling will still suffice to cause unwelcome damage to essential fish habitat necessary for cod viability. Recognizing the damaging nature of mobile trawl gear, more areas essential to cod viability need to be closed to this gear type. While it is unlawful to discriminate between gear types, there is a method to restrict trawl gear: closed areas can be implemented to protect substrate essential to fish, and special access permits can only be issued to gear types that have minimal environmental damage, such as benthic longlines and handgear.

Increasing restrictions will only increase fishers' incentive to cheat in order to increase profits. The only method to reduce this incentive is to have an effective enforcement system. With a high rate of at-sea compliance, the USCG attributes some of the illegal fishing in the Northeast to the increasing regulatory complexity. If accurate, the Council must find more effective ways to educate fishermen on the laws. Mandatory port meetings for all multispecies permit holders should be financed by NMFS to demonstrate the available tools for staying informed on current regulations. Whether informed of regulations or not, fishers could be told by onshore enforcement agents when they are fishing illegally (ex. when in closed areas) through vessel monitoring systems with a communication capacity. This technology exists, but implementation has been slow due to the Council's wavering support of its use. All vessels must be fitted with approved vessel monitoring systems.

To prevent deliberate at-sea noncompliance that electronic vessel monitoring cannot identify requires greater at-sea enforcement to meet the Coast Guards 97% target compliance rate. The USCG should also have a steadily increasing compliance target rate. If deliberate noncompliance continues, greater financial penalties for law breakers must be demanded.

The delay in receiving and amassing landings data provides the greatest difficulty for onshore enforcement. With an average two month delay to compile the results, landings data are not available to the Regional Administrator in time to decrease fishing mortality in order to slow the approach to the target TAC. To shorten the time lapse will require electronic vessel reporting systems for all vessels (technology that is already in use for electronic dealer reporting) and more financial resources for the onshore monitoring division of the New England Regional Office of NMFS.

If, on the other hand, the Regional Administrator is failing to reduce trip limits and slow the approach to the target TAC, not because of a lack of data, but because of the ease at which target TACs can be surpassed without reprisal, we have a different problem. While hard TACs often generate a race to fish and discarding practices that target TACs do not, hard TACs may be necessary to prevent overfishing from continuing. A hard TAC system in which the TAC is split evenly among months (except those when spawning closes the fishery) would reduce the derby fishing as well as provide for landings throughout the year thus creating a steady market value. Additionally, the RA would keep her ability to reduce trip limits when fishing mortality is too large. Under hard TACs, a high rate of observer coverage provides the only tool to decrease discarding practices. However, catching legal sized cod is hard enough now that this might not be necessary for some years until the fish return in greater abundance and fishers would be selective about keeping the best fish. When (and if) this occurs, the burden could be on the fishers to finance an observer program, such as is done in the Alaskan pollock fishery. As undesirable as hard TACs may be to the industry, they might at least provide an effective threat (leveraged in a law suit) to get the Regional Administrator to act sooner as cod landings approach the TAC.

Lastly, a fisher retraining service or buyout program is necessary because all of my recommendations thus far will likely put fishers out of work or lower their income. Rather than have a governance structure that continues to blame the fishermen for the state of cod, I suggest that we take responsibility for mismanaging our resources and assist the fishers whose livelihoods have been ruined.

The Fate of the Fishery

The managers of Atlantic cod have failed to meet the overriding objectives of fisheries management, because: 1) the cod fishery supports a catch amount far below optimal yield, and 2) the fishery has altered the integrity of the ecosystem in both its structure and function (Dayton *et al*. 1995). It would be naïve to consider returning the cod fishery to sustainability an easy task and imprudent to ignore that it might be impossible given the degree of its depletion (Ludwig *et al*. 1993).

Undoubtedly, without making changes to the fishery, Atlantic cod will continue to serve as the best example of the failure of our fisheries management. Instead, we should act now to create the best example of how to recover a collapsed stock. To move toward this goal, the recommendations that I have made to tackle the problems overlooked by management as of yet should be incorporated into the stock's assessment and management as soon as possible.

Incorporating these recommendations can be done without the time-lapse that appears to be inherent between the need for and the completion of science necessary for a decision. Generally, it is too easy for unwilling managers to espouse a need to wait for the science to become available or the technology to become cheaper before taking action. In the case of Atlantic cod, the result has been continued overfishing of an already overfished species. It is not my objective to stress this past failure but rather indicate the amount of strong, peer-reviewed science that already exists and can be put to use by the Council to improve the status of Atlantic cod. The changes recommended in this review are practical and, given an adequate dose of political will and funding, could be implemented quickly through precautionary methods.

The fate of the cod fishery depends on the willingness of the managers to take the science and technology that we have and use it, rather than let it gather dust on a bookshelf. The National Marine Fisheries Service has a responsibility to the fishers and the general public to do this, and in doing so ensure a long-term future for the Atlantic cod fishery.

Acknowledgements

This masters project would not have happened without the support of many individuals. Thank you to the dedicated staff at the Cape Cod Commercial Hook Fishermen's Association, specifically Paul Parker and Tom Rudolph, for provided great insight into the Atlantic cod fishery. Thank you to the David Brower Endowment Fund for supporting my summer at the Hook. Thank you to Dan Rittschof for his tremendous guidance, provoking questions, and honesty; to Larry Crowder, Steve Roady, and the rest of the excellect faculty at Duke. Additional thanks to John Brodziak, Joseph Hunt, Dwayne Theriault, and the New England Fishery Management Council staff. Undying gratitude to William Meserve for always being there for me and instilling a drive for excellence. Lastly, thank you to Michael Bean, the best Housemates ever, and all my friends for their assistance and patience. The best of luck to all of you.

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Appendix 1. Management of Atlantic Cod

United States Management of Atlantic Cod

The US system for fisheries management has heavy bottom-up influence through the regional council process but with top-down control because the final approval of fishery management plans (FMPs) comes from the Secretary of Commerce via the national office of NOAA's National Marine Fisheries Service (Cicin-Sain & Knecht 2000). The Magnuson-Stevens Fishery Conservation and Management Act,[22] approved by Congress in 1976 and later amended in 1996 under the title of the Sustainable Fisheries Act, mandates the development of FMPs that adhere to ten National Standards before approval can be granted by the national office.[23] Atlantic cod management is under the jurisdiction of the New England Fishery Management Council (NEFMC). The Council has eighteen voting members: the Northeast Regional Administrator (RA); principle state officials from each of the five New England coastal states[24]; and twelve members nominated by the governors of the coastal states and appointed by the Secretary of Commerce, each serving in three year terms for a maximum of three consecutive terms.[25]

The Council develops FMPs with input from numerous internal and external panels. The Groundfish Oversight Committee[26] reviews the Multispecies FMP and develops potential measures and recommendation for the Council's review. The Groundfish Committee receives input and advice from the Groundfish Advisory Panel (AP) and the Groundfish Plan Development Team (PDT). The AP,[27] representing industry, the scientific community, environmental organizations and other sectors, makes recommendations based on economic, social, and ecological factors. Consisting of scientists, managers, or other experts with knowledge of groundfish biology, ecology, or management, the PDT analyzes biological and ecological findings on groundfish stocks to make recommendations to the Groundfish Committee via issue papers and alternative measures. The PDT and Groundfish Oversight Committee use stock assessment data generated by the Northeast Fisheries Science Center (NEFSC) and synthesized by the Northeast Regional Stock Assessment Workshop (SAW) or the Groundfish Assessment Review

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[22] 16 U.S.C. §1801-1882.

[23] The SFA was regarded as greatly enhancing the conservational qualities of the MSFCMA. Specifically, the SFA altered National Standard 1 to include the goal of optimum yield; added National standards 8, 9 and 10 regarding the inclusion of community consequences, reducing bycatch to the extent practicable and promoting safety; required annual reports to congress from the Secretary of commerce on the status of stocks; and required FMPs to specify objectives and measurable criteria for identifying the timing and location of overfishing and how to rebuild, to use a standardized methodology for reporting and assessing type and amount of bycatch , and to include a description of the fishing sectors and their landing trends.

[24] Maine, New Hampshire, Massachusetts, Rhode Island and Connecticut.

[25] In addition, four non-voting members sit on the Council from: US Coast Guard, US Fish and Wildlife Service, US Department of State and the Atlantic States Marine Fisheries Commission. The Council also has a sixteen person staff including an executive director, deputy director, financial officer, office manager, several secretary/webmasters, and nine analysts (mostly fishery but also economic, and ecosystem approach analysts).

[26] The Groundfish Oversight Committee is composed of ten members, nine from the NEFMC and one from the Mid-Atlantic FMC.

[27] The Advisory Panel has thirteen members selected by the Oversight Committee.

Meeting (GARM). The Stock Assessment Workshop provides peer-reviewed summary information and benchmark assessments to the PDT and Groundfish Committee. Since SAW is responsible for assessing all managed stocks and can not assess groundfish every year but usually every 2 to 5 years, GARM attempts to provide peer reviewed assessment updates on an annual basis.

The Council implemented the Northeast Multispecies (Large Mesh/Groundfish) FMP in 1986, which has seen thirteen amendments and forty framework revisions. The FMP defines two Atlantic cod stocks for management: the Gulf of Maine, and Georges Bank and southward. The Council assesses the stocks independently and sets separate target TACs. The FMP mandates multiple control measures to attain the target TAC including effort control via days-at-sea, trip/daily limits, gear restrictions (ex. mesh size, hook size), and rolling, seasonal and year-round closed areas.

Canadian Management of Atlantic Cod

The Division of Fisheries and Ocean (DFO) is responsible for developing and implementing policies and programs in support of Canada's economic, ecological, and scientific interests in oceans and inland waters. Under the auspices of the Fisheries Act[28], the Minister of the DFO has authority and responsibility for the management of Canadian fisheries, but after recognizing the ineffectiveness of complete top-down management, more bottom-up input has been incorporated. Within the DFO, multiple sectors[29] provide consultation and input to the Minister. Six regional divisions manage Canada's fisheries. The Canadian Atlantic cod fishery is under the jurisdiction of the Maritimes Region Director General (RDG) who receives assistance from regional sector heads[30] in formulating recommendations to pass on to the Minister.

Multiple external committees also provide information and recommendations that feed into the RDG's recommendations to the Minister. Regional advisory committees, based on the fleets and their management structure, represent industry views.[31] Additional advisory groups include the Regional Advisory Process (RAP), the Gulf of Maine Advisory Committee (GOMAC), the Atlantic Fisheries Policy Review (AFPR), the External Advisory Board (EAB), and the Fisheries Resource Conservation Council (FRCC). Established in 1993, the Regional Advisory Process (RAP) provides the DFO peer-reviewed information on the status of the fisheries, habitat, and marine mammal resources throughout Canada via Stock Status Reports. In the Maritimes Region, the RAP addresses issues in the Bay of

[28] R.S.C. 1985, c. F-14 .
[29] These include: the Assistant Deputy Ministers of Fisheries and Aquaculture Management, Oceans and Habitat Management, Policy, and Science. These officials provide advise to the Minister via the Deputy Minister.
[30] These include the Maritimes Region Directors of Fisheries Management, Oceans and Environment, Policy and Economics, and Science; and from the Maritimes Area Directors of Eastern Nova Scotia, Southwest Nova Scotia and Southwest New Brunswick.
[31] For example, several advisory committees are the Fixed Gear Advisory Committee, the Scotia-Fundy ITQ Committee, the Groundfish Enterprise Allocation Council and the Mid-shore Groundfish Vessel Owners Committee.

Fundy, on the Scotian Shelf, and on Georges Bank. The Fisheries Resource Conservation Council (FRCC), created in 1993 to represent scientific, academic, and industrial interests, makes written recommendations to the Minister for management plans through conducting public hearings and reviewing methodologies, stock assessments, and proposed management measures. The Gulf of Maine Advisory Committee (GOMAC), a joint industry-DFO advisory body, considers information from the FRCC, Transboundary Management Guidance Committee (see Joint US/Canada Management section), and elsewhere to make recommendations to the Minister. The Atlantic Fisheries Policy Review (AFPR)[32] was recently created to review Canadian fisheries policy following the passage of the Oceans Act.[33]

The western Scotian Shelf of Maritime Canada has the only remaining cod fishery after widespread moratoria starting in 1992. The cod fishery is managed as two stocks with boundaries designated by the Northwest Atlantic Fisheries Organization: (1) that portion of area 5Ze on Georges Bank which is on the Canadian side of the exclusive economic zone (EEZ), and (2) area 4X, adjacent to area 5Ze and extending northward along the EEZ to the border between Maine and New Brunswick and east to Halifax, Nova Scotia. The Groundfish Integrated Fisheries Management Plan for the Scotia-Fundy Maritimes Region defines the cod stock areas (4X and 5Z) and specifies management regulations. Announced in 2002, the plan will remain in effect until 2007. The DFO develops annual management plans with updated quotas and new measures in consultation with the fishing industry. Multi-stakeholder consultation also occurs on an ongoing basis to ensure successful implementation of plans. Management measures include an overall TAC for cod, individual or community TAC shares (Individual Transferable Quotas and Enterprise Allocations), dockside monitoring, observer coverage, gear restrictions, seasonal and permanent closed areas, bycatch rules, and size limits.

Joint US-Canada Management of Atlantic Cod

The value of the groundfish resource created tension between Canada and the US during the delineation of fishery resource zones. After eight years of debate, the International Court of Justice determined the placement of the line on the eastern end of Georges Bank in 1984. While settling this line dissolved some of the conflict between the two nations, stock decline in the 1990s raised concern that cod were still susceptible to unsustainable harvesting. Scientists from Canada and the US began sharing assessment information and consulting one another. In particular, scientists and managers were concerned that cod on the eastern end of GB exhibited transboundary movement and were thus subject to exploitation by both nations. On August 4th, 1994, the United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks adopted The Fish Stocks Agreement (formally referred to as the Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the

[32] A non-decision-making External Advisory Board of 20-30 members functions as a sounding board for AFRP generated ideas, and an Independent Panel on Access Criteria reviews access decision-making criteria.
[33] 1996, c. 31.

Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks) (United Nations, 1995). The Fish Stocks Agreement stipulates that suitable measures be taken to manage and conserve transboundary fish stocks. Although the US is not a signatory to the Law of the Sea Convention (Canada is), the DFO and NMFS collaborated to co-manage the transboundary groundfish of GB.

This decision precipitated the formation of the Transboundary Assessment Working Group (TAWG) in 1998 which includes scientist from both nations and completes stock assessments using DFO and NMFS research vessel bottom trawl survey data. Also in 1998, the Transboundary Resource Assessment Committee (TRAC), again with US and Canadian scientific representation, started reviewing TAWG assessments and projections to produce TRAC Status Reports for use by the Transboundary Management Guidance Committee (TMGC), formed in 2000. The TMGC, composed of 12 members, four industry and two government representatives from each country, uses the Status Reports to develop recommendations (in the form of harvest strategies, resource sharing, and management processes) to share with the DFO and the NEFMC.

One of the first responsibilities of the TRAC involved the development of a proposal to specify the area for co-management, a resource allocation scheme, and specific harvest quantities. With DFO and NEFMC support, the proposal culminated in the US/Canada Resource Sharing Understanding, which defined the eastern Georges Bank RSA, delivered an allocation scheme based on the relevant resources' distributions and the historical participation of the two countries in exploitation of the resources, and proposed a Year 1 TAC. Important features of the allocation scheme include: a flexible resource distribution factor based on cod distribution; a constant resource utilization factor based on historical use per country (40% USA; 60% Canada); and a shift in the weighting of resource utilization to resource distribution from an initial ratio in 2002 of 40:60 to 10:90 by 2010. While the RSA Understanding allocates a portion of the stock to each country, it does not mandate a particular regulation or set of regulations that both countries must use to keep landings within their allocated TAC (TRAC 2005).

Importantly, no law-binding statute mandates US and Canadian cooperation for the management of groundfish on Georges Bank. The nations voluntarily worked together to develop the RSA and an agreement for management. While Canada is a signatory of The Law of the Sea Convention and The Fish Stocks Agreement, international agreements of this sort are voluntary and non-binding and participation and adherence is subject to the will of each country. The New England Regional Management Council formally adopted the US/Canada Resource Sharing Understanding in Amendment 13 to the Multispecies FMP; however, subsequent amendments could delete it from the FMP. While unlikely, extreme disagreement between the US and Canada over management of the resources could potentially result in disbanding of the RSA understanding.

Appendix 2. Major multispecies regulations relevant to Gulf of Maine and Georges Bank cod

Original FMP	1977	Included only cod, haddock and yellowtail flounder; used individual species quotas allocated by vessel class. While catch of species decreased, there was no limit to number of participants, so race for fish resulted with the quotas for GoM and GB cod being caught within 5-6 months. Thus trip or weekly catch limits implemented but no enforcement results in significant misreporting.
Interim Plan	1982	Quota-based management system eliminated (want more reliable fishery data, flexibility for fishermen, and industry support) for plan with minimum fish sizes (cod 17") and codend mesh size (5-1/2"). Small mesh fishing allowed in GoM under Optional Settlement Plan (OSP). Seasonal GB closed areas implemented to protect spawning fish (to become CA I and CAII).
Northeast Multispecies FMP	1986	Inclusion of 7 other species. Set biological targets in terms of percent maximum spawning potential and allowed Council to increase size limits and control F to meet targets. Cod size limit at 17". CAI enlarged & SNE Regulated Mesh Area (RMA) established to help reduce F. Exempted Fishing Program (EFP) replaced OSP and reduced area and time period for small net fishing in GoM.
Amendment 1	1987	Cod size limit changed to 19". Large mesh area increase to south. Mesh size and SNE RMA regulations tightened.
Amendment 2	1989	Eliminated scheduled increase in codend mesh size because of compliance and enforcement issues. EFP subject to trip bycatch limits and stricter non-reporting penalties. Seasonal large mesh area established on Nantucket Shoals to protect cod. Mesh size regulations applied to whole of net (rather than codend only). Recreational size limits matched to commercial. Trawlers excluded from CAII during the closure to improve enforcement.
Amendment 3	1989	Established Flexible Area Action System to enable Council and NMFS to respond quickly to protect concentrations of juvenile, sub-legal and spawning fish. System regarded as ineffective.
Amendment 4	1991	More restrictions added to EFP. Gear restrictions in Northern Shrimp fishery. Scallop dredge vessels excluded from SNE RMA.
Emergency action	1994 (Jan.)	Expansion of CAII in area and time (from Jan. to June, rather than Feb-May). Prohibition on pair-trawling for multispecies.
Amendment 5	1994	Emergency action regulations adopted year-round. Starts effort reduction program to reduce historical DAS level to 50% over 5-7 year period (10% reduction per year) because need 50% reduction in F to eliminate overfishing and further mesh size limits not capable of doing so. Moratorium on new entrants to multispecies fishery during stock rebuilding period. Exceptions to moratorium and effort reduction for <45' vessels, those using <4,500 hooks and those landing <500lbs. Mandatory reporting of landings and effort data. Increase mesh to 6" diamond in GB and GoM RMA. Seasonal 6" square mesh limit to protect juvenile cod on Nantucket Lightship Area. CAI suspended for mobile gear, operation for gillnets; CAII expanded in space, to be extended in time (Jan to June) in 3 years time. Framework system created to allow changes to regulations in a timely manner without going through the plan amendment process.
Amendment 6	1994	Secretarial Amendment: Implementation of Jan. 1994 Emergency Actions on a permanent basis.
Emergency Action	1994 (Dec.)	Year-round closure of redefined CAI, CAII, Nantucket Lightship CA. No scallop vessels in CAs. Prohibition of retaining regulated species with small mesh. Increase in SNE mesh size to 6".
Framework 9	1995	Implementation of Dec. 1994 Emergency actions on a permanent basis
Amendment 7	1996	Establishment of annual target TAC for cod (not a hard TAC), and expands framework provisions to set annual TACs. Allows for council to take remedial action in following year (reduced effort) if target TAC exceeded in current year. Accelerates the day-at-sea effort reduction program. Eliminates significant exemptions for certain vessels from effort reduction implemented in Amendment 5. Provides incentives to fish exclusively with mesh larger than minimum required. Implements seasonal GoM CAs. Establishes multispecies permit for limited access sea scallop vessels.
Framework 20	1997	Implementation of GoM cod daily trip limit of 1,000lbs. Vessels must not fish for cod while running DAS clock to account for overage.

Framework 24	1998	Remedies a loophole in FW20 that allowed for fishing on other species while cod clock ran: vessels must remain in port and run clock to account for cod overage. Implementation of DAS carry-over provision.
Framework 25	1998	Reduces GoM cod daily trip limit to 700lbs and adds ability of Regional Administrator to reduce to between 400 and 700 when 50% TAC reached. Implements GoM Inshore CA, year-round Western GoM CA, and seasonal offshore Cashes Ledge CA.
Framework 16	1999	Expansion of GoM Inshore CA. Additional of seasonal inshore GoM and GB area closures.
Framework 27	1999	Reduces GoM cod daily trip limit reduced to 200lbs with mechanism for RA to reduce to between 5 and 100lbs further if necessary (reduced to 30lbs 27 days later); in essence created a bycatch only cod fishery in GoM. Makes alterations to some CAs in duration or size. Scallop dredge exemption to GoM RMA and Cashes CA. Increases GoM/GB/SNE square mesh size to 6.5".
Amendment 9	1999	Includes new overfishing definitions. Sets Optimum Yields to bring plan into complete compliance with the Sustainable Fisheries Act.
Interim Rule	1999	Revises GoM cod limit to 100lb/day & 500lb/trip. DAS running clock revised: cod overage limit to 1 day.
Framework 30	1999	Establishes GB cod limit of 2,000lbs/20,000lbs.
Framework 31	2000	Revises GoM cod limit to 400lbs/4,000lbs. Adds February inshore GoM CA. Extends running clock measure.
Framework 33	2000	Adds GB seasonal CA, two 1-month conditional GoM CAs.
Interim Actions	2002 (May & Aug.)	Restrictions to vessels using more than 25% of DAS between May-July 2002. Modification of DAS clock (all vessel trips 3-15 hrs counted as 15hrs). Prohibition on front loading the DAS clock. Establishes "used DAS baseline" and reduces 20% from baseline. Freeze on Handgear permits & trip limit reduction. Cashes Ledge CA made year-round. Rolling CA III and IV expanded. Eliminates GoM Jan. & Feb. CAs. Increase GoM trawl codend and gillnet mesh to 6.5" and GB gillnet mesh to 6.5". Increase SNE trawl codend mesh to 7"/6.5" square/diamond and gillnet mesh to 6.5". Limitations on day & trip gillnets. Longline gear restrictions re: fairlead rollers, hook size and number of hooks. Increases cod size limit to 22". Increases GoM cod limit to 500lbs. /4,000lbs.
Amendment 13	2004	Formal rebuilding plans for overfished stocks. Categorizes DAS (A, B, C) based on permit history FY1996-2001. Reduced DAS that can target any stock (A-DAS) by 40%. Includes DAS lease and transfer provisions. Changes to gear requirements. Adopts US/Canada Resource Sharing Understanding. Adopts process for implementing voluntary sectors and special access programs that use B-DAS. Continues 2002 Interim actions for rolling closures, year-round closures and fish limits. Revises GoM cod limit to 800lbs. /4,000lbs, and GB cod limit to 1,000lbs. /10,000lbs. Adopts daily electronic dealer reporting of landings linked to vessel by a trip identification number.
Framework 40 A & B	2004	Implements and modifies allocation criteria for CAI Hook Gear Haddock SAP for the GB Cod Hook Sector (Sector). Implements Eastern U.S./Canada Haddock SAP Pilot Program. Implements and modifies provisions for the CAII Yellowtail Flounder SAP. Permits vessels to fish on same trip inside and outside Western US/Canada Area. Revises the DAS Leasing and Transfer Programs. Establishes a DAS credit for vessels standing by an entangled whale. Removes the net limit for trip gillnet vessels.
Framework 41	2004	Authorizes fishing in the CAI Hook Gear Haddock SAP by vessels that are not in the GB Cod Hook Sector.