C. STOCK ASSESSMENT OF POLLOCK IN US WATERS FOR 2010

By: Northern Demersal Working Group (see Introduction for participant list)

Executive Summary

Terms of Reference:

1. Characterize the commercial and recreational catch including landings, effort, LPUE and discards. Describe the uncertainty in these sources of data, including consideration of stock definition.
2. Characterize the survey data that are being used in the assessment (e.g., regional indices of abundance, recruitment, state surveys, age-length data, etc.). Describe the uncertainty in these sources of data, including consideration of stock definition.
3. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and characterize the uncertainty of those estimates.
4. Update or redefine biological reference points (BRPs; estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, and F_{MSY}; and estimates of their uncertainty). Comment on the scientific adequacy of existing and redefined BRPs.
5. Evaluate stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 4).
6. Evaluate pollock diet composition data and its implications for population level consumption by pollock.
7. Develop and apply analytical approaches and data that can be used for conducting single and multi-year stock projections and for computing candidate ABCs (Acceptable Biological Catch).
    a. Provide numerical short-term projections (through 2017). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. In carrying out projections, consider a range of assumptions to examine important sources of uncertainty in the assessment.
    b. Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.
    c. For a range of candidate ABC scenarios, compute probabilities of rebuilding the stock by 2017.
    d. Describe this stock's vulnerability to becoming overfished, and how this could affect the choice of ABC.
8. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

A new assessment model (ASAP, Legault and Restrepo 1998) is accepted as the best model for determining stock status for pollock (*Pollachius virens*). The base model for pollock estimates that spawning stock biomass in 2009 (SSB_{2009}) is 196,000 mt and the average fishing mortality on ages 5-7 ($F_{5\text{-}7}$) is 0.07. The criteria for determining stock status are based on reference points that use F40% as a proxy for FMSY, with SSBMSY calculated from projections at $F_{40\%}$. The overfishing criterion, calculated as the average F on ages 5-7, is $F_{40\%(5-7)}$=0.25 (this corresponds to a fully selected F of 0.41). The proxy for SSB_{MSY}, the B_{TARGET}, is estimated at 91,000 mt, with 5th and 95th percentiles spanning 71,000 to 118,000 mt. One half of SSB_{MSY} is the $B_{THRESHOLD}$ (45,500 mt). Comparing the current 2009 estimates of SSB and F to the MSY reference points, the stock is not overfished and overfishing is not occurring.

If the previous assessment model (AIM) had been used, the stock status would have been overfished with overfishing occurring. The new assessment model (ASAP) incorporates age structure and age-related biological processes, additional survey indices and their estimated variances, time-varying selectivity, commercial discards, and recreational landings and discards. The age-specific selectivities, and their evolution through time, are an important improvement. The fishery at the beginning of the time series exploited young, immature pollock, whereas the current fishery primarily exploits larger, mature fish. For all of these reasons, it is recommended that the previous assessment model, AIM, not be used for the current or for future assessments of pollock.

Previous assessments of pollock assumed a variety of stock definitions. Recent assessments of pollock in US waters are for “the portion of the unit stock of pollock primarily within the USA EEZ (NAFO Subareas 5&6) including a portion of eastern Georges Bank (Subdivision 5Zc) that is under Canadian management jurisdiction" (Mayo and Terceiro 2005). Canadian stock assessments treat the management unit within the Canadian EEZ separately (NEFSC 2002a). A review of information on population structure of pollock off the northeast US supports several alternative hypotheses of stock definition. Given uncertainties in stock structure and the considerable management implications, the Working Group developed a slightly refined stock definition that reflects the US jurisdictional unit (catch and survey information from current US waters).

Prior to 2000, pollock were assessed using virtual population analysis (VPA; e.g., Clark et al. 1981; Mayo and Clark 1984; Mayo and Figuerido 1993). Since 2000, pollock have been assessed using an index-based approach (Mayo 2001). The index approach was not designed for sophisticated projections, and performed poorly in recent projections to determine annual catch limits. For this benchmark assessment, an age-based approach to assessing pollock was attempted by updating fishery and survey catch-at-age and applying an Age-Structured Assessment Program (ASAP, Legault and Restrepo 1998). The revised stock definition, and transition to an age-based assessment, required a revision of the overfishing definition. Similar to most other groundfish managed under the Northeast Multispecies Fishery Management Plan (NEFSC 2002a), F_{MSY} is approximated as the fishing mortality that is expected to conserve 40% of maximum spawning potential ($F_{40\%}$, Clark 1991, 1993).

The role of pollock in the ecosystem was assessed using diet data. Estimates of pollock abundance were used to model pollock consumption. Results suggest that small pollock consume small invertebrates, primarily Euphausids, and large pollock prey on a mix of fish and invertebrates. Pollock is an ecologically important piscivore, but does not appear to be a dominant piscivore. Pollock is not a major prey species for any predator species.

Further research is needed to experimentally determine size-based selectivity of fishing gears, determine assessment and management units that most accurately reflect biological population structure, explore alternative survey techniques for off-bottom and hard-bottom habitats, and evaluate quality of age determination of old fish. The selectivity is especially important to resolve, as the ASAP model with dome-shaped survey and fishery selectivity implies the existence of a large biomass (35 – 70% of total) of pollock (i.e. cryptic biomass) that neither current surveys nor the fishery can confirm. Assuming full survey selectivity for ages 6 and above reduces stock biomass and associated biomass reference points by 20 – 50%. Notwithstanding this, the stock did not appear to be overfished in either case. Under the full selectivity assumption, long-term catches can be expected to be reduced by approximately 30%.

Introduction

Northern Demersal Working Group Meetings

Three meetings were held in preparation of the 2010 pollock assessment:

1. *Meeting with Pollock Fishermen* - January 22 2010 – MADMF Annisquam River Marine Fisheries Field Station, Gloucester MA (Appendix C1 includes a summary of the discussions). Participants included commercial fishermen (Terry Alexander, Richard Burgess, Matt Carter, Bill Gerencer, Bert Jongerden, Tom Kelley, Stephanie Neto, Jackie O'Dell, Frank Patania, Maggie Raymond, Mike Russo, Arthur Sawyer, Mike Walsh) and staff from the Northeast Fisheries Science Center (Liz Brooks, Steve Cadrin, Eric Thunberg) and the New England Fishery Management Council (Anne Hawkins, Tom Nies). A summary of the discussions is in Appendix C1.
2. *Data Meeting* - February 22-23 2010, NEFSC Woods Hole MA. Participants included Steve Cadrin (chair), Liz Brooks (lead assessment scientist), rapporteurs (Jessica Blaylock, Dan Goethel, Anne Hawkins, Kathy Sosebee, Susan Wigley) and others (Larry Alade, Russ Brown, Jon Deroba, Bill Duffy, Bill Gerencer, Jon Hare, Michael Jones, Richard Merrick, Tim Miller, Tom Nies, Paul Nitschke, Jackie O'Dell, Mike Palmer, Rebecca Rademeyer, Paul Rago, Dave Richardson, Fred Serchuk, Michelle Traver).
3. *Model Meeting* – March 29-April 2 2010, NEFSC Woods Hole MA. Participants included Steve Cadrin (chair), Liz Brooks (lead assessment scientist), rapporteurs (Jessica Blaylock, Bill Duffy, Dan Goethel, Anne Hawkins, Tom Nies, Julie Nyeland, Gary Shepherd) and others (Doug Butterworth, Rebecca Rademeyer, Richie Canastra, Laurel Col, Bret Elger, Jon Deroba, Jon Hare, Joe Idoine, Robert Gamble, Bill Gerencer, Michael Jones, Chris Legault, Jason Link, Rich McBride, Tim Miller, Paul Nitschke, Loretta O'Brien, Jim Odlin, Mike Palmer, Paul Rago, Maggie Raymond, Dave Richardson, Mike Russo, Brian Smith, Mark Terceiro). The group met by correspondence after the meeting, including a WebEx meeting on April 30 2010 to review the report and updated analyses with the full set of available data.

This Working Group (WG) report includes products from all three meetings and contributions from all participants.

Biology

Pollock are abundant on the western Scotian Shelf and in the Gulf of Maine (Mayo 1998; Figure C1). A major spawning area exists in the western Gulf of Maine and on Georges Bank, and several areas have been identified on the Scotian Shelf (Mayo et al. 1989a, Cargnelli et al. 1999). Spawning occurs from November through February with a peak in December (Collette and Klein Mac-Phee 2002). Juvenile pollock are common in inshore areas, but move offshore as they grow older. More than 50% of pollock are sexually mature by age 4 and maturation is essentially complete by age 6 (Mayo et al. 1989b). Pollock grow to a maximum length of 110 cm and maximum weight of 16 kg (Mayo 1998).

Fishery Regulations

A brief overview of New England groundfish management from 1977 to the present is provided as contextual information to help interpret fishery patterns and model results. The modern period of groundfish management began with implementation of the Magnuson-Stevens Act (M-S Act) in 1977. Since that time, all fishing for groundfish stocks within the U.S. Exclusive Economic Zone has been by U.S. vessels – no foreign fishing has been allowed. The management history can be broadly divided into four periods prior to 2010. Note that this discussion gives a broad overview. There were numerous other restrictions on gear, fishing practices, possession limits, etc. during all of these periods. Table C1 summarizes major elements of the federal groundfish management program since 1977.

1977–1981 - The first management plan used hard quotas for cod, haddock, and yellowtail flounder. There were various trip limits for these species. Catches of other groundfish stocks were not directly controlled. The fishery was open access – there were no limits on the number of permits. Minimum mesh size and minimum fish size regulations were also adopted, and seasonal closures to protect spawning fish were used.

1982–1993 - The quota system was abandoned in mid-1981 and replaced by a system that relied on technical measures (minimum mesh requirements, minimum legal sizes, etc.) and seasonal closures to protect spawning fish. There were complicated programs that allowed using mesh smaller than the minimum size to target other species. The fishery continued to be an open access fishery. Over time, the number of stocks subject to the plan increased. Mortality targets based on spawning potential were adopted.

1994–2003 - In response to stock declines and widespread overfishing, the number of permits was limited and a system of limiting fishing opportunities in the form of days-at-sea (DAS) was phased in over several years (Amendments 5 and 7). The DAS allocations did not constrain all permits and DAS use actually increased until 2001 (see Figure C2). DAS allocations remained unchanged from 1997 through 2001, but were reduced by a court order in 2002. The effort control system became more complex and used trip limits, seasonal and year-round closures, mesh size changes, and gear requirements. Various "exempted fisheries" were developed to facilitate targeting non-groundfish stocks. "Target TACS" (TTACs) for five stocks were adopted as a metric to evaluate the effectiveness of management measures, but exceeding these targets did not result in closing the fishery. The system for reporting catches was also completely revised in 1994 with the adoption of Amendment 5.

2004–2009 - Formal rebuilding programs were adopted that met requirements of the M-S Act. The DAS allocations were reduced in 2004, 2006, and 2009 (Amendment 13 and Framework 42). DAS were also categorized (identified as A, B, and C) with restrictions on each. Category A DAS could be used to target any stock; Category B DAS could only be used in certain programs designed to target healthy stocks, and Category C DAS could not be used but indicated a potential for future access. Several programs called SAPs (Special Access Programs) allowed targeting healthy stocks (primarily GB haddock) and the use of Category B DAS. Leasing of DAS between permits was adopted, which facilitated the transfer of fishing opportunities between permits. "Hard" (as opposed to target) quotas were adopted for a few programs and a few management units (GB yellowtail flounder was the only stock with a hard quota for all fishing).

A fifth period is expected to begin in 2010 with the expansion of a catch share program that will result in most of the fishery being subject to hard quotas. A key component is the formation of voluntary, self-selecting organizations identified as "sectors."

The WG identified regulations that were expected to affect fishery selectivity. Potential changes in selectivity might be anticipated after increases in minimum mesh sizes (1982-1983, 1994 and 1998) and after increases in minimum legal size of pollock (1986 to 1989). The working group agreed that changes in management regulations would be one consideration in the development of the assessment model, and specifically in the determination of blocks of years when selectivity could be assumed constant.

Assessment History

The first analytical stock assessment completed for the Gulf of Maine, Georges Bank and Scotian Shelf (ICNAF areas 5 and 4VWX) was in 1976. Results from catch curves indicated that fishing mortality in the 1970s exceeded the level associated with maximum yield-per-recruit (ICNAF 1976). After the international boundary was defined in 1984, Canada assessed pollock on the Scotian Shelf (4VWX) separately, but the US continued to assess pollock in 4VWX and 5. The Scotian Shelf, Georges Bank and Gulf of Maine stock was assessed using virtual population analysis beginning in 1981 and continuing through the mid-1990s (Clark et al. 1982; Mayo and Clark 1984; Mayo et al. 1989b, Mayo and Figuerido 1993, Mayo 1998). Spawning stock biomass had been declining since the mid-1980s, and fishing mortality was estimated to be 0.72 for ages 6+ in 1992, above $F_{20\%}$=0.65 (Mayo and Figuerido 1993).

The analytical assessment was replaced with an index-based assessment (Mayo 2001) that used total commercial landings in NAFO areas 4VWX, 5, and 6, and the NEFSC fall survey. Recent assessments of pollock in US waters are for "the portion of the unit stock of pollock primarily within the USA EEZ (NAFO Subareas 5 and 6) including a portion of eastern Georges Bank (Subdivision 5Zc) that is under Canadian management jurisdiction" (NEFSC 2002b). The overfishing criterion was defined as the relative exploitation rate that allowed replacement, and the overfished criterion was based on the general magnitude of NEFSC fall survey biomass index from the 1980s (NEFSC 2002b). In 2001 and 2005, the index assessment determined that the stock was not overfished, and overfishing was not occurring (NEFSC 2002a, Mayo and Terceiro 2005). In 2006-2007, the fall survey index decreased, and the 2008 index-based assessment determined that the stock was overfished and overfishing was occurring (NEFSC 2008). The index-based assessment was updated with 2008 catch and survey data, but results were rejected as a basis for catch advice in 2009 (Multispecies Plan Development Team and New England Scientific and Statistical Committee 2009).

Stock Definition

Geographic Variation –

Mayo et al. (1989a, 1989b) found no significant differences in allozyme frequencies between fish in US and Canadian waters, but allozyme differences among coastal and marine populations are rare, even for many populations that are now considered to be reproductively isolated according to more sensitive genetic markers.

Two studies found morphological differences between western Scotian Shelf and Georges Bank-Gulf of Maine. McGlade (1983) concluded that meristics were significantly different between areas 5 and 4X. McGlade and Boulding (1986) also reported differences between areas 5 and 4X using morphometrics. Growth rates on the Scotian Shelf were different between pollock in 4X and 4VW Neilson et al. (2006), but growth of pollock in US and Canadian waters has not been compared.

Geographic Distribution and Patterns of Abundance –

Larval distributions indicate three relatively discrete spawning areas: 1) in the Gulf of Maine, 2) on the western Scotian Shelf, and 3) on the eastern Scotian Shelf (Figure C3; from Richardson & Hare WG presentation). Pollock larvae were rarely found in samples over the deep waters of the Gulf of Maine indicating limited mixing during early life stages of fish from US and Canadian waters.

NEFSC trawl surveys indicate a generally continuous distribution of pollock across the Gulf of Maine and western Scotian shelf (Figure C4). This indicates that it is likely that mixing occurs during adult life stages, although the rate of mixing cannot be determined. Despite large inter-annual variations in survey indices, abundance trends from NEFSC and DFO surveys generally agree. All show a general pattern of high abundance early in the time series, declines during the middle period (early and mid 1980s), with some increases in recent years. There is more divergence among surveys in recent years.

Much of the catch from US waters appears to be from the western and central Gulf of Maine, with some landings near the US/Canadian boundary of Georges Bank (see section on fishing effort). These landings are probably a mixture of fish spawned in both 4X and 5. Canadian landings trends appear to differ between the Eastern and Western Scotian Shelf components (between 4X and 4VW).

Tagging –

Three main tagging studies have been carried out for Pollock in US waters. An historical study was undertaken by Schroeder from 1923-1927. While only a subset of this data has been examined to date, a preliminary evaluation of the data found less than 100 recaptures from nearly 3800 releases. The data from the Schroeder study was hand written in journals with locations generally specified by landmark; thus, both the release and recovery locations are fairly imprecise, although the general direction of movement can be inferred and some mixing is suggested between US waters and the Scotian Shelf (Figure C5). More recent studies were carried out by Clay et al. (1989) and Neilson et al. (2003, 2006). The general pattern of release and recovery locations indicated relatively high connectivity (~16%) between fish tagged on the western Bay of Fundy (4Xs) and recaptured in the western Gulf of Maine. This is in contrast to fish tagged on the eastern Bay of Fundy (4Xr), which had very few recoveries in US Waters (~4%, primarily the northeast edge of Georges Bank). The tagging took place between 1978-1984, with recoveries from 1979-1990. Both Neilson et al. (2006) and Steele (1963) suggest a population of fish in the western Bay of Fundy that migrate for spawning purposes to the southern Gulf of Maine (Figures C6a and C6b). Neilson (2006) suggests that this is a small fraction of the overall western Canadian pollock stock. Mixing between 4X and 4VW was less frequent, and mixing of pollock in 4VW and those in 5 is limited. Tagging data suggests that pollock in the US and on the Western Scotian Shelf could be considered a unit stock based on historical estimates of movement, however, the fish on the eastern Scotian Shelf appear to be a separate stock unit.

Multidisciplinary Studies –

Neilson et al. (2006) synthesized much of the data available on pollock stock structure and concluded that there was enough evidence to suggest that three stocks existed: 1) western

Gulf of Maine coastal population; 2) western Scotian Shelf and Bay of Fundy and 3) eastern Scotian Shelf.

The WG concluded that pollock within US waters should be treated as a single stock (i.e. areas 5 and 6 were the same stock), because the majority of fish appeared to be located in the Gulf of Maine, with some fish and landings on Georges Bank and few pollock south and west of the Great South Channel. The more difficult decision was to determine the relationship between US and Scotian Shelf stocks. The objectives of stock assessment and fishery management were also considered by the WG. For management purposes, assessment of pollock in US waters would be ideal, if the population dynamics of pollock in US waters is not influenced by connectivity with the Scotian Shelf. For the purposes of stock assessment, population dynamics should be primarily influenced by processes within the stock area, all catch from the assessment unit should be accounted for, and all survey data should be representative of the stock.

Scientific information on population structure of pollock off New England provides equivocal evidence for three possible hypotheses about the appropriate assessment unit:

1. *US portion of NAFO areas 5 and 6 (Gulf of Maine and Georges Bank)* – This is the assessment unit evaluated by the 2008 assessment (GARM III). Assessment of pollock in areas 5 and 6 is supported by larval distributions, morphology and recent survey trends. Larval distribution suggests that spawning in the area from southwest Gulf of Maine to Georges Bank is distinct from another spawning area on the western Scotian Shelf (MARMAP data presented by D. Richardson and J. Hare). Morphometry is significantly different between the western Gulf of Maine and the Scotian Shelf (McGlade and Boulding 1986). Recent trends in surveys of the western Scotian Shelf and in areas 5 and 6 provide different perspectives of stock development. A recent multidisciplinary review of stock structure that was focused on the Canadian maritimes (Nielsen et al. 2006) concluded that there are three stocks of pollock in the area: 1) "the western Scotian Shelf (including the eastern Bay of)", 2) "on the eastern Scotian Shelf" and 3) "a coastal population in the western Gulf of Maine that overlaps into Canadian waters." From a practical perspective, a stock assessment based on catch and survey data in US waters would support evaluation of US catch limits without the need to forecast Canadian catch.
2. *NAFO areas 4Xo-s, 5 and 6 (Gulf of Maine, Georges Bank, and the western Scotian Shelf)* – Combined assessment of Georges Bank, the Gulf of Maine and the western Scotian Shelf is supported by tagging data, fishery distributions, long-term survey trends, and growth rates. Considerable movement of juveniles and adults among all three areas is documented by tagging data (Schroeder 1923-27, unpublished; Clay et al. 1989; Nielsen et al. 2006). Most recent US fishery catch is from the western Gulf of Maine, with a small amount of catch on NE Georges Bank adjacent to the international boundary. Unlike the divergent trends in recent survey indices, US and Canadian surveys both suggest a relatively abundant stock in the 1980s, depletion in the early 1990s, and rebuilding since the mid 1990s. Growth rates appear to be different between the eastern and western Scotian Shelf (Clay et al. 1989). Assessment of a transboundary resource would pose considerable uncertainty for fishery management with respect to management objectives, allocations and projected catch.
3. *NAFO areas 4VWX, 5 and 6 (Gulf of Maine, Georges Bank, and the Scotian Shelf)* – Combined assessment of the entire US and Scotian Shelf is supported by genetics, tagging and survey distributions. Analysis of allozymes suggests no genetic differences among these areas (Mayo et al. 1989a, 1989b). Tagging data suggest some connectivity

between US waters with the entire Scotian Shelf (Nielsen et al. 2006). Survey data suggests a continuous distribution of pollock along the Scotian Shelf. Assessment of pollock in NAFO areas 4VWX, 5 and 6 would be difficult, because no single survey covers the entire distribution of the resource and would complicate management, because Canada assesses and manages eastern and western Scotian Shelf as separate units.

Given uncertainties in stock structure and the considerable management implications, the Working Group decided to develop an assessment that reflects the US management unit (option 1 above, with US catch and survey information from survey strata that are in US waters: strata 13-30, 36-40). This U.S. management unit complements the Canadian management unit on the Scotian Shelf and Canadian portions of Georges Bank and the Gulf of Maine (Stone et al. 2009).

The Fishery

TOR 1: Commercial and Recreational Catch

Characterize the commercial and recreational catch including landings, effort, LPUE and discards. Describe the uncertainty in these sources of data, including consideration of stock definition.

Commercial Catch

Pollock were traditionally landed as bycatch in various demersal otter trawl fisheries, but directed otter trawl effort increased during the 1980s, peaking in 1986 and 1987 (Mayo 1998). Directed effort by US trawlers declined in the 1990s and early 2000's, but there have been recent increases in landings that may reflect increased targeting of pollock. Similar trends have also occurred in the U.S. winter gillnet fishery.

U.S. commercial landings increased from approximately 4,000mt per year in the late 1960s to a peak of 24,000mt in 1986 (Figure C7, Table C2). Landings rapidly decreased to 4,000mt in 1996, and generally increased to 10,000mt in 2008. Historical landings were primarily from trawl fisheries, but contributions from gillnet fisheries generally increased, and the recent fishery landings are split 60%-40% between trawl and gillnet fisheries, respectively (Figure C7). Among the thirteen species managed by the Northeast Multispecies Fishery Management Plan, pollock was second only to cod in landed weight from 1996 through 2008. From 2006 to 2008, pollock landings were higher than those of any other groundfish in this multispecies fishery. Pollock is relatively low in value, however, with the annual average price never exceeding $1.00/per pound during this period. From 1996 to 2008 pollock ranked seventh in landed value. In recent years its revenue contribution increased with the increase in landings and it has ranked in the top five species for revenues since 2006.

Landings were mostly from unclassified market category until minimum legal size regulations were imposed in the late 1980s. At that point, the majority of landings were from the 'large' market category (Figure C8). In the last decade, landings from 'medium' and 'small' market categories went from being about equal to about 3:1 in favor of the 'medium' category. Landings by market category should be considered with caution because there is uncertainty regarding which lengths/weights were used as cull points throughout the time series. In particular, the 'medium' market category is primarily used in Portland, Maine, and it is unclear whether these fish would be have been classified as 'small' or 'large' had they been landed in a different port. Consequently, it might be more appropriate to consider landings by size composition (catch at age) only instead of market category. Historically, this was more of a winter fishery, with higher landings in quarters 1 and 4. More recently, landings have been approximately equally distributed among seasons (Figure C9).

Port samples of size and age structure are summarized in Table C3. Sampling intensity has been good since the early 1980s. Landed catch at age shows some relatively strong year-classes in the 1970s and 1980s (Figure C10). Age-based analyses begin in 1970, based on the availability of commercial catch at age data. At the data meeting, the working group decided that age-based analyses should attempt to model ages 1 to 12+, as had been done in earlier VPA analyses. The motivation for this decision was that pollock are fully mature by age 7, and even though they are still growing at age 12, the weight of the 12+ groups would be derived from empirical observations. This decision was revised at the model meeting to aggregate the data with a 9+ group.

Commercial discards (D) were estimated using the Standardized Bycatch Reporting Methodology (Wigley et al. 2007) in which the ratio of discarded pounds of pollock ($d_{pollock}$) to kept pounds of all species ($k_{all\_species}$) for each fleet is sampled by observers at sea, and the ratio is expanded to total pollock discards according to commercial landings of all species ($K_{all\_species}$) by fleet.

$$D = \frac{d_{pollock}}{k_{all-species}} K_{all\_species} \qquad \text{(C.1)}$$

Estimates of pollock discards were stratified by NAFO areas (5 and 6), gear (otter trawl and gillnet), and mesh (small, large, extra-large). Discards were estimated for years 1989 to 2008 (data were not available for 2009, so an assumed value equal to 2008 discards was used). The estimates of discards ranged from 1% to 8% of US commercial landings, with an average of 3% for all years estimated. The four fleets that account for nearly all pollock discards were small-mesh otter trawl, large-mesh otter trawl, large-mesh gillnet, and extra-large mesh gillnet (Table C4). Estimates of pollock discards from other fleets (longline, handline, small-mesh gillnet, scallop dredge and midwater trawls) were excluded from discard estimation because of periods with low sampling intensity and apparently low magnitude of pollock discards. Discards from the shrimp fishery were also considered to be negligible.

Discard estimates for small-mesh otter trawl in 1994 and 1997 were approximated using discard observations from adjacent years. Discards were assumed to be negligible before 1989, because estimated discards are a small portion of catch, there were few reasons to discard pollock before 1989, and there is no viable alternative for estimating historical discards. According to fishermen, there was no market for small pollock in some ports prior to the mid 1980s, which suggests that some discarding might have occurred on fish below a landable size prior to 1989. However, more extensive analysis based on landed and survey size distributions by port or survey strata would be needed to evaluate landed trends and to consider appropriate methods to hindcast historical discards.

Commercial Fishing Effort

Two data sources are available to provide information on the location of fishing effort: fishing vessel logbooks and fishery observer reports. Each vessel operator submits a Vessel Trip Report (VTR) at the end of each trip that includes position, fishing activity, and catch information. Reporting regulations require only that the VTR indicate the general area of fishing activity in a statistical area. While the regulations require submitting a separate VTR page for every statistical area fished, compliance with this requirement is uneven. VTR information thus provides an overview of reported general trip level fishing activity but does not provide precise fishing location information.

Observer reports provide detailed fishing information on a tow-by-tow (or haul-by-haul) basis, but not all trips are observed, and not all tows on every trip are observed. Levels of observer coverage in the groundfish fishery were generally low prior to 2000, but have increased in recent years. Changing priorities can modify the distribution of trips over time. As a result, drawing conclusions from observer data can be difficult because the observations are influenced not only by the distribution of fishing activity but by the allocation of observer resources. Observer data remains the best source of precise location information and detailed fishing activity.

The goals of these examinations were to: 1) determine if there is evidence in the geographic distribution of fishing activity to support identification of different stock or management units for pollock within the U.S. Exclusive Economic Zone; 2) determine if large pollock catches are associated with specific areas; and 3) determine if there is evidence of changes in the distribution of pollock catches.

VTR Database Analyses

Data –

The VTR database was queried to select all fishing trips that landed any pollock during the years 1996 through 2008 (the latest year for which complete VTR data was available). For each such trip, other data elements were retrieved including the year and month of landing, latitude and longitude where the haul began, gear code, days absent, trip ID and permit number. Data elements were not selected for other fields for this exercise.

To facilitate analysis the data was plotted using ArcGis© and maps were created showing the number of trips that caught pollock and the total weight of pollock caught for each year. Each subtrip was binned into a ten-minute square based on the reported location of the beginning of the haul. The ten-minute squares were color coded based on the difference between the average number of subtrips in a square and the value of the specific square. This difference is measured in standard deviation units from the mean number of subtrips in a square for each year.

Results –

The number of sub-trips in each ten-minute area per year that caught pollock is shown in Figure C11. The total weight of pollock caught in each ten-minute area per year is shown in Figure C12. A comparison of the two figures suggests that an increase in pollock landings is not necessarily closely associated with an increase in number of trips. Large pollock catches were reported in areas with few reported trips.

It appears that the range of pollock declined between 1996 and 2008, since the offshore areas that experienced high pollock trips in the early years seem to have fewer in 2004-2008. However, many fewer trips were reported in this area in 2004-2008 compared with the inshore area. It therefore does not necessarily follow that the range is contracting.

The analysis suggests that pollock are widely distributed in the deep water areas of the Gulf of Maine and Georges Bank. There seem to be areas with larger pollock catches (landings) relative to the number of trips taken further offshore. It is difficult to determine from these figures whether the presence of pollock is continuous in the Gulf of Maine and the northern side of Georges Bank, or whether there could be distinct areas with high concentrations.

Observer Database Analyses

Data –

The observer database was queried to select all trawl (negear=050) and sink gillnet (negear=100) tows from trips that landed any of the regulated groundfish species or monkfish during the years 1989 through 2009. A single record was created for each such tow that summarized total caught weight (in live weight) and the weight caught of the regulated groundfish species, monkfish, and skates. Other data elements retrieved were the year, quarter, and month of landing, position haul began, gear code, and target species. Data elements were not selected for gear characteristics, soak time, vessel size, or haul duration for this exercise.

The number of trawl tows selected by this query varied over time. From 1989 through 2000 the average number of tows that met the selection criteria was 1,713. The average increased to 4,208 during 2001-2003, and then tripled to 13,365 from 2004 through 2009. The peak year was 2005 (23,064 observed tows selected). The increases since 2002 are the result of increased funding for the observer program and are not related to an increase in fishing effort. On the contrary, groundfish fishing activity declined by over 50 percent from 2001 to 2009. Most of the analyses focus on the period since 2002 when there were increased levels of observer coverage.

The number of sink gillnet hauls observed over time was more consistent than was the case for trawl tows. From 1989 to 2000 the average number observed was 1,661, while from 2001 through 2009 it was 1,663. The peak year was 1991, with 4,175 observed hauls selected, while the low was 1989, with 348. From 1999 through 2002 the average was 607. These more consistent coverage levels are likely due to interested in observing sink gillnet activity to document marine mammal interactions. Because of the more consistent coverage, the sink gillnet analyses that follow will consider the 1992-1999 and 2002-2009 time periods.

To facilitate analysis the data was also plotted using ArcGis© and each tow was binned into a ten-minute square based on the location of the beginning of the haul. The number of squares with a tow gives a simple metric of the geographic extent of observer coverage in a year (but this metric is difficult to interpret because of changing observer coverage).

Trawl Results –

The number of ten-minute squares with an observed tow increases as the number of observed tows increases. Up to about 4,000 observed tows, the number of ten-minute squares increases rapidly in a linear fashion (R^2=0.81, with the slope significant $p<0.01$). The increase slows considerably above this number of observed tows but the slope remains significant. This suggests that there are only small increases in the geographic distribution of observed tows once observer effort is sufficient to observe over 4,000 – 6,000 trawl tows. A similar relationship holds for the number of ten-minute squares with an observed pollock tow below 4,000 observed tows; above 4,000 observed tows, there was a slower increase and the slope of the increase is marginally not significant ($p=0.055$). A similar relationship was noted between the number of observed tows and the number of ten-minute squares with an observed pollock tow. Additional analyses will focus on the period 2002 through 2009 since these years have more observations and there is less influence on the results from changes in levels of observer coverage.

It appears that the range of pollock declined between 2002 and 2009, because the number of squares with an observed pollock tow declined from 50 percent of the squares with an observed tow to 33 percent of the squares with an observed tow. However, this interpretation ignores that the distribution of observer coverage also changed: tows were observed in 317 ten-minute squares in 2002 and 546 in 2009. When squares with an observed tow in both years are considered (258), the number of tows with an observed pollock tow increased slightly from 134 in 2002 to 139 in 2009.

Pollock were observed in tows throughout the Gulf of Maine and the northern part of Georges Bank. Generally, where there are many observed tows, there are many observed tows with pollock. Only in the shallower areas of Georges Bank is there much difference between the location of observed tows and the location of observed pollock tows. Large pollock tows, however, are more localized. They tend to be located along the 50 and 100 fathom depth contours on the north side of Georges Bank and then extend north along the western edge of the western Gulf of Maine closed area (which is near the 100 fathom curve). The presence of pollock seems to be continuous in the Gulf of Maine and then northern side of Georges Bank, a fact that cannot be determined from the VTR data alone.

Two additional analyses were performed to identify areas with pollock concentrations. In the first, catches on all observed tows in each ten-minute square were combined and the total catch of pollock as a percentage of total observed catch in that square was determined (Figure C13). From 2007 through 2009 the number of squares where pollock catch was more than half the observed catch increased. The areas also seem relatively constant over time, primarily along the 100 fathom curve east of Cape Cod and the western Gulf of Maine closed area.

Sink Gillnet Results –

The number of ten-minute squares with an observed haul increases as the number of observed tows increases. As was the case with trawl observations, there seem to be two rates. Up to about 1,300 observed tows, the number of ten-minute squares increases rapidly in a linear fashion (R^2=0.91, with the slope significant p=0.00). Above this number of observed trips the slope of the regression is nearly flat but is not significant (p=0.142). Unlike trawl tows, the number of observed hauls with pollock does not seem related to the number of observed hauls.

Pollock were observed in hauls throughout the Gulf of Maine and the northern part of Georges Bank. When the location of observed sink gillnet hauls during 1992-1999 is compared to 2002-2009, one change is obvious. In the early 1990's sink gillnet hauls were observed along the entire coast of Maine. Pollock were frequently caught in the coastal areas east of 69-30W longitude. There were large hauls observed along the 100 fathom curve as far east as the Hague Line that divides U.S. and Canadian waters. Beginning in 1994, there were dramatically fewer observed sink gillnet hauls in these eastern areas. There was a slight increase in 1995, but then there were almost no observed hauls in the area through the end of the first period, and then through the 2002-2009 period examined. Sink gillnet observed hauls in 2004 – 2009 that caught pollock were concentrated in the inshore Gulf of Maine area off Massachusetts, New Hampshire, and southern Maine and the 100 fathom curve in the central Gulf of Maine. Effort as indicated by observed sink gillnet hauls did not extend into the northeastern part of the Gulf of Maine where it was common in the early 1990's.

Figure C14 shows pollock as a percent of observed sink gillnet catch from 2001-2009. There are few ten-minute squares where pollock was more than 25 percent of the observed catch. The instances where this does occur tend to be along the 100-fathom curve in the central Gulf of Maine. The obvious change in the distribution of observed sink gills after 1994/1995, as well as the change in the distribution of hauls catching pollock, warranted further investigation. The changes could reflect a shift in the distribution of pollock that is not evident from the trawl data because there are fewer observations in the early 1990's. The timing of the change, however, also suggests that it could be related to the adoption of a limited entry program in the fishery in 1994. The program is often criticized for not awarding permits to small boat fishermen from the coastal communities of eastern Maine.

To determine if the regulatory change may be responsible for the lack of observed sink gillnet trips off eastern Maine after 1994/1995, the landing port for trips that had observed hauls north of 43°30'N and east of 69°30'W was determined. During the 1989-1993 period before the regulatory change, almost all of the hauls were on trips that landed in coastal Maine ports by vessels that claimed a Maine homeport. The permit database was queried to determine whether these vessels received a limited access multispecies permit in 1994; most did not. The absence of observed sink gillnet hauls in this area after 1994/1995 can be attributed, at least in part, to the fact that vessels that fished with sink gillnets in the area in 1992 and 1993 did not receive a limited access permit when that program was adopted in 1994.

The VTR data indicate that pollock is caught by vessels widely distributed in the Gulf of Maine and Georges Bank. There are areas that produce larger pollock catches on a fairly consistent basis. The observer tow-by-tow data – both trawl tows and sink gillnet hauls - suggests pollock is continuously distributed throughout the area. The sink gillnet observed hauls seem to indicate that pollock is no longer caught in the inshore areas off the eastern coast of Maine. This may reflect the fact that vessels from Maine that fished in this area before 1994 did not receive limited access multispecies permits when Amendment 5 was implemented in 1994. It is also clear from the VTR and observer information that there has been little groundfish fishing activity inside the 100 fathom curve off eastern Maine in recent years. Because of varying levels of observer effort and numbers of reported VTR trips, this investigation did not draw conclusions on possible changes in the geographic distribution of fishing effort over time.

The WG concluded that CPUE trends have limitations due to changes in regulations over time (DAS, area closures, etc); however, trends in nominal effort (number of trips and/or number of days absent) might be useful for interpretation purposes only (not for use in model).

Recreational Catch

The time series of recreational catch is highly variable from year to year (Figure C15, Table C2). Recreational catch peaked at 1867mt in 2008, which is consistent with fishermen's accounts of encountering large numbers of pollock in that year. However, recreational catch of pollock decreased in 2009 to 896mt. Since 2001, the shore component decreased relative to the party/charter and private/rental components, with the private/rental component accounting for 50% or more of the recreational pollock catch. Recreational catch is small relative to commercial landings and has generally been 10% or less. However, from 2000-2004, recreational catch is estimated to have contributed 15-24% of total catch (commercial catch was near the lowest values in the time series for these same years, Table C2). There are no recreational catch estimates from the statistically designed sampling program (MRFSS) prior to 1981.

A tagging study (Clay et al. 1989) estimated 16% total mortality from a hook fishery in a three-month period, 11% of which was attributed to tagging of fish. That study suggested that neither 100% mortality nor 100% survival would be an obviously justifiable assumption for recreational discard mortality of pollock. In the absence of more information, the working group chose to assume 100% mortality of discarded recreational catch (B2). This assumption is also consistent with the 100% discard mortality assumed for commercial discards. Furthermore, because recreational catch is a minor component of the total catch, assuming 100% mortality was not expected to contribute undue influence on model results.

The WG decided that the length-frequency of discards would be best represented by samples of the recreational kept catch (A and B1). Recreational age samples are not available, so age compositions need to be borrowed from other data sources. The WG agreed that survey data would provide the most equivalent information to the recreational catch.

Estimates of recreational catch of pollock begin in 1981. The WG decided to assume negligible recreational catch prior to 1981, as there is no agreed method and scant data upon which to base hindcast estimates. Furthermore, the magnitude in recent years is a minor component of total catch, and it is assumed that any recreational catch prior to 1981 would not have exceeded the recent amounts.

Resource Surveys

Term of Reference #2: Survey Data

Characterize the survey data that are being used in the assessment (e.g., regional indices of abundance, recruitment, state surveys, age-length data, etc.). Describe the uncertainty in these sources of data, including consideration of stock definition.

Several surveys are available to provide indices of relative abundance. The properties of each survey were examined to determine whether it should be used for stock assessment of pollock. Table C5 provides a summary of survey attributes.

Given the stock definition described above, survey indices will be based on data from all strata that have been consistently sampled in US waters (NEFSC strata 13-30, 36-40; Figure C16). While several of these strata straddle the Hague Line, the working group decided that dropping those strata would create a larger discontinuity between the fishing area and the survey area, and would likely increase the estimated variance. Both the fall and spring surveys have large inter-annual variation (Figures C17 and C18). The NEFSC fall survey series generally corresponds with the exploitation history: the survey index declines from high biomass in the late 1970s to extremely low biomass in the mid 1990s, consistent with annual landings exceeding 20 000t during the same period; biomass increased in the late 1990s when landings were <6 000t; survey biomass decreased again as recent landings approached 10 000t. The spring survey does not correspond as well with the exploitation history.

Previous assessment models (VPA, AIM) dealt only with the annual index point estimate, with all points given the same weight in the objective function. In an attempt to avoid undue influence from some of the year effects, indices for those earlier models were derived from log-retransformed data (with a value of 1.0 added to observed zeros). For the present assessment, the new assessment model (ASAP) has the capability to apply index-specific weights as well as year-specific weights within each index. The working group decided to use the NEFSC spring and fall survey N/tow without transformation, and to use the annual estimates of coefficient of variation (CV) as annual weighting factors. No additional weights were applied to the indices.

Several changes to the fishing system occurred in the NEFSC spring and fall survey time series. In 1985, trawl doors were changed from ‘BMV oval’ doors to ‘Euronet Polyvalent’ doors. Calibration experiments for the two sets of survey doors included only nineteen paired tows that caught pollock. Conversion coefficients were significantly different than zero (p=0.03 for number, p=0.01 for weight), with a door coefficient of 2.21 (95% CI 1.11 - 4.30) for number per tow and 2.90 (95% CI 1.38 - 5.54) for weight per tow. Although most surveys were done by the R/V Albatross, the R/V Delaware was used intermittently. Vessel calibration experiments included 32 paired tows that caught pollock, and conversion coefficients were not significantly different than zero (P=0.92 for number, p=0.66 for weight). In 2009, the R/V Albatross was permanently replaced by the FSV Bigelow. Nineteen paired tows in the Albatross-Bigelow calibration experiment caught pollock (8 in spring, 11 in fall). A peer review panel offered general guidelines for calibration protocols:

- If there are less than 30 paired observations with positive catches, do not attempt any conversion.
- If there are less than 30 paired observations with positive catches in any one season, seasonal conversion are not appropriate.
- Pollock catches are too low to derive a reliable conversion factor, and the comparison is driven by one large value.

Given the low sample sizes and imprecise estimates from calibration, the WG decided that calibration coefficients will not be used to adjust survey data for changes to survey systems (e.g., doors, nets, vessels).

Several analyses were explored to investigate potential factors in survey catchability. In response to the observation that pollock distribution may have shifted to deeper habitats (Nye et al. 2009), survey trends from deep strata (24, 27, 28, 37-38, 29, 30, 36) were evaluated and found to be similar to the entire strata set (Figure C19). Diurnal/notcturnal comparisons showed no substantial differences between selected daytime and nighttime tows (Figure C20). No relationships were detected between survey catches and temperature (Figure C21).

The ASMFC-NEFSC summer shrimp survey samples shrimp habitat in the western Gulf of Maine (Figure C22). Data are available from this survey since 1985, and there have been no changes in vessel or gear. The summer shrimp survey catches pollock in a slightly greater proportion of tows than the NEFSC fall or spring surveys. Pollock lengths are measured on the summer survey, but age structures are not collected. The biomass trend from the summer survey is generally consistent with the fall survey in that biomass generally increased from the mid 1990s to 2004, but declined in recent years (Figure C23).

Pollock are also sampled by state surveys of inshore waters. The Maine-New Hampshire survey, in operation since about 2000, catches small pollock along the coast of Maine and New Hampshire in spring and fall. The Massachusetts survey, in operation since 1978, occasionally catches small pollock in spring, but few pollock are caught in the Massachusetts fall survey. State surveys may provide recruitment indices for the pollock assessment.

Relative abundance of pollock larvae from ichtyoplankton surveys may be considered as a proxy annual index of spawning stock biomass. An annual index of pollock larval abundance was derived using methods similar to those applied to herring by Richardson et al. (2010). Data from several sequential surveys were combined: 1971-1978 ICNAF, 1977-1988 MARMAP, 1989-1994 herring-sandlance survey, 1995-1999 GLOBEC, and 1999-2009 ECOMON. Each survey used a 61cm bongo net to sample to 200m deep, and up to 50 larvae were measured from each program. Mesh size was decreased from 505um to 330um in the GLOBEC survey. Pollock larvae were found from November to April, but primarily from December to March. The larval index suggests large spawning biomass in the mid 1980s, but much lower biomass since then (Figure C24). The WG noted the large difference in magnitude of the confidence intervals between the early and late period of the larval index time series. The difference in confidence intervals most likely results from different survey timing relative to the spawning season. The larval index was included in exploratory stock assessment models as an index of spawning biomass.

The WG decided that the MADMF inshore fall survey would not be considered as an index of abundance, because it catches too few pollock (e.g., pollock are not caught at all in many years). All other surveys (NEFSC spring, fall, summer and larval surveys; ME-NH inshore survey; MA spring inshore survey) would be evaluated as stock size indices in exploratory assessment analyses.

Age Structure –

Size and age structure from NEFSC spring and fall surveys suggest a relatively robust distribution of sizes and ages in the early 1970s, a truncation of large and old fish from the late 1970s to the turn of the century, with some rebuilding of size and age structure in the last decade (Figure C25, Tables C6a and C6b). With the exception of a relatively strong yearclass in the early 1970s, there is little correspondence among age-based survey indices to track yearclasses over time.

Stock Assessment

Term of Reference 3: Stock biomass, fishing mortality and recruitment

Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and characterize the uncertainty of those estimates.

Natural Mortality Assumption

Age data for pollock has been available since the early 1970s. The maximum age that has been seen in the NEFSC surveys since 1970 is 24 (Figure C26). There is no reason to believe that age structure was truncated before the mid-1970s, because removals during the 1970s and mid-1980s were three times the levels seen prior to 1970. The oldest age in the commercial age data is also 24, from a sample in 1984. An instantaneous annual natural mortality rate of 0.2 was used in previous assessments, and corresponds to approximately 1% survival to age 24.

Due to the lack of reliable data on natural mortality rate by age or year, it would be difficult to develop a time or age-varying mortality schedule. Although an age-specific mortality schedule could be developed using a functional response, the lack of data available to build such a model would make any gains from age-dependent mortality schedule negligible. The Working Group decided to assume M=0.2, because it is consistent with available data, and it was the value assumed in past assessments. The WG agreed that a sensitivity model run would consider M=0.15.

Size and Weight at Age

Data from surveys indicate that median age and mean length generally declined. Mean size at age plots showed some inter-annual variation for ages 1 to 10 (Figure C27a), with a slight decline suggested in recent years. Data for older fish are limited, and size at age estimates are more variable.

The WG decided that growth will be based on observed weight at age, and spawning weights will be based on January-1 weights using Rivard's interpolation method applied to the commercial catch weights. Weights at age show a consistent decline over the last decade (Figure C27b). Projections and reference points will be based on recent averages of weight at age.

Maturity

The 'hit or miss' nature of the pollock catches in surveys results in highly variable estimates of maturity at age resulting from low sample sizes in many years (Figure C28). When maturity data is pooled over all years, age 3 appears to be an inflection point in the maturity ogive, with most fish younger than 3 immature and most fish older than 3 mature (Figure C29). A time-averaged maturity leads to more reliable estimates of maturity at age. The WG decided that maturity at age will be assumed to be constant over time, and will be estimated using pooled-year data.

Update of Previous Assessment Method

Recent assessments of pollock applied an index-based method for "the portion of the unit stock of pollock primarily within the USA EEZ (NAFO Subareas 5 and 6) including a portion of eastern Georges Bank (Subdivision 5Zc) that is under Canadian management jurisdiction" (NEFSC 2002b). Overfishing was defined as the relative exploitation rate that allowed replacement, and B_{MSY} was approximated as the NEFSC fall survey biomass index from the 1980s (NEFSC 2002b). In 2006-2007, the fall survey index decreased (Figure C17), and the 2008 index-based assessment determined that the stock was overfished and overfishing was occurring (NEFSC 2008).

The most recent assessment used a centered three-year average for stock status determinations (NEFSC 2008). In order to provide catch advice for 2010 and 2011, the index-based assessment was updated with 2008 catch and survey data by the Multispecies Plan Development Team. The 2008 catch and 2007-2008 survey indices were used to 'project' the survey index value for 2009, however, this implied a negative survey index in 2009. As an alternative, the lowest observed fall survey index value was used to replace the implied negative 2009 value, and the 2007, 2008, estimated 2009 survey values were used to estimate the 2008 biomass proxy. While the pollock index from the fall survey is highly variable (even the log retransformed indices), projection results imply erratic fall survey indices and a pattern of a large increase in one year followed by two years of decline. When the lowest observed survey value is used for 2009, a two-year projection implies the survey value for 2010 will be near 0 and will increase by a factor of 37 in 2011. One reason that the projection gives unrealistic results is that it does not incorporate any stock dynamics—the method assumes that the stock will grow without interruption. The New England Scientific and Statistical Committee rejected the index-based assessment as a basis for catch advice in 2009.

To build a bridge between previous (AIM) and current (ASAP) assessment approaches, the AIM model was run with commercial landings through 2009 and the fall log-transformed index through 2009. The previous index biomass reference point (GARM III) was 2 kg/tow from the NEFSC Fall Bottom Trawl survey, and the previous overfishing reference point was 5.66. Using the data through 2009 for both landings and surveys the overfishing reference point estimate drops slightly to 5.41. The predicted MSY for the updated AIM assessment is 10,820 mt(ie.5.41(000mt/kg/tow)x2.0kg/tow).

The AIM model calculations of stock status and relative F were based on a 3-year centered average, so the most recent estimate with 3 observations corresponds to year 2008 (i.e., 2007-2009). The average survey abundance is 0.63 kg/tow. As this is lower than the previous biomass reference point of 2.0 kg/tow, the stock would be considered overfished. The average of the 2008 and 2009 survey estimates is 0.57 kg/tow and would also be considered overfished. The AIM model's relative replacement ratio estimate in 2008 of 0.6 indicates that the stock is declining at current values of relative F. The relative F estimated for 2008 is 16.3, which is about 3 times greater than the previous overfishing reference point 5.41. Theoretically the reference point relative F would keep the population at its current biomass. Therefore the AIM analyses would have concluded that overfishing was occurring.

There are numerous reasons why the two models (AIM and ASAP) reach different conclusions about stock status. First, the ASAP model includes age structure. This means that maturity, fecundity, and selectivity at age are incorporated in the ASAP framework. This is significant, because fishery selectivity has evolved from primarily selecting young immature fish to now selecting primarily large, mature fish. Additionally, while the fall index generally appeared to respond to trends induced by fishing, the last 10-15 years has seen a widening disparity between the selectivity of the fall index, which samples proportionately younger fish, and the fishery. The incorporation of the spring index, and the annual variances for both indices, allowed the model to properly smooth through trend without being driven by apparently large year effects. Finally, the ASAP assessment model takes a more complete accounting of total catch by including commercial discards, and recreational landings and discards.

Revised Assessment Method

Model Description

Pollock has been assessed using AIM (An Index Method, NEFSC 2002b) since 2000. Given the wide changes that have occurred in the fishery (gear, selectivity, targeting, and management), the change to a new survey vessel (for which a calibration cannot be estimated), the importance of age structure (maturity and growth), and the limited projection capability of AIM, alternative assessment methods were considered for this benchmark. The new assessment model is ASAP (Age Structured Assessment Program v2.0.20, Legault and Restrepo 1998), which can be obtained from the NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov/). As described at the NFT software website, ASAP is an age-structured model that uses forward computations assuming separability of fishing mortality into year and age components to estimate population sizes given observed catches, catch-at-age, and indices of abundance. Discards can be treated explicitly. The separability assumption is partially relaxed by allowing for fleet-specific computations and by allowing the selectivity at age to change in blocks of years. Weights are input for different components of the objective function which allows for configurations ranging from relatively simple age-structured production models to fully parameterized statistical catch at age models.

The objective function is the sum of the negative log-likelihood of the fit to various model components. Catch at age and survey age composition are modeled assuming a multinomial distribution, while most other model components are assumed to have lognormal error. Specifically, lognormal error is assumed for: total catch in weight by fleet, survey indices, stock recruit relationship, and annual deviations in fishing mortality. Recruitment deviations are also assumed to follow a lognormal distribution, with annual deviations estimated as a bounded vector to force them to sum to zero (this centers the predictions on the expected stock recruit relationship). For more technical details, the reader is referred to the technical manual (Legault 2008).

Model Inputs

Catch at age for years 1970-2009 are used for two distinct fleets: a composite commercial fleet, and a recreational fleet (Table C7a and C7b). The commercial fleet includes US catch by otter trawl and gillnet (with minor contributions from hook and line gear), as well as landings by distant water fleets (1970-1976) and Canadian fleets (1970-1985). Total discards for the commercial fleet are estimated for years 1989-2008 from observer data. Discards at age were estimated from discard length frequencies, raised by estimated total discards by area and gear (otter trawl, gillnet). Age length keys from combined survey and commercial data were used to obtain number at age from number at length. Data were not available to estimate discards for 2009, so it was assumed that total mt of discards in 2009 were the same as in 2008, and no age composition was included in the objective function for 2009.

Catch for the recreational fleet begins in 1981 when a standard method of data collection and statistical estimation was initiated (*Marine Recreational Fisheries Statistics Survey, MRFSS*). Landings and discards are assumed to have the same length frequency, and discard mortality is assumed to be 100%. Expanded length frequencies were converted to catch at age by multiplying by age length keys from survey data.

Several model runs were performed with a sensitivity assessment model (SCAA by Butterworth and Rademeyer, see below) including one or more of the sensitivity indices (NEFSC summer, NEFSC larval, ME-NH spring and fall, MA spring). Examination of these runs suggested that the sensitivity indices were not adding information or signal to the model estimated trends. Furthermore, the WG felt that the assumed selectivities for these indices, which required an assumption about size at age by season for young fish, needed a more detailed analysis due to the rapid growth realized by fish aged 1 to 3. The WG decided that these indices should be considered in future assessments if the lengths could be treated suitably. Consequently, only the NEFSC Spring and Fall surveys were used in the model. Annual number/tow and the estimated CV were used along with annual estimated age composition for years 1970-2009.

Age-specific but time invariant maturity was used in the model. An age and time invariant natural mortality (M) of 0.2 was assumed.

Base Model Configuration (ASAP)

Model estimates of selectivity at age were freely estimated for fisheries and surveys, with no restriction for flat-topped or dome-shaped results. Although it is difficult to directly observe relative selectivity of old ages, domed selectivity for pollock can be justified from information on fishing gears and pollock behavior. Gillnets, which contribute approximately 40% of the recent commercial landings, typically have dome-shaped selectivity (Hamley 1975), and gillnet selectivity of pollock was estimated to be dome shaped in the Gulf of Maine (Marciano et al. 2005). Pollock also have greater swimming speed and endurance than other groundfish, and swimming speed increases as a function of size (He and Wardle 1988). Therefore, selectivities that have a dome-shape (i.e., selectivity at older ages is <100%) would not be an unexpected result. Furthermore, it is worth noting that the selectivity estimated for the 9+ group reflects the catchability for all ages 9 and older.

Beginning with a single selectivity function for each fleet, model diagnostics were examined for trends in age composition residuals. With only one selectivity vector per fleet, there were strong trends in residuals with long runs of positives and negatives (Figure C30).

Additional selectivity blocks were added one at a time, with each fleet being addressed separately, until residual patterns were acceptable. The addition of selectivity blocks was balanced against the reduction in the objective function value (given the added parameters) to avoid overparameterization. To determine the best year for introducing new selectivity blocks, a split was introduced for several consecutive years and the model with the lowest objective function value determined the year when the new block would begin. Somewhat concurrent with this process, changes in fleet composition (e.g., following the establishment of the EEZ in 1976, establishment of The Hague Line in 1985) and major management changes (such as introduction of minimum sizes, changes in mesh size and introduction of closed areas), were considered as potential years where a new selectivity block might be anticipated.

The base model contains four selectivity blocks for the commercial fleet with breaks between the following years: 1985/1986, 1993/1994, 2003/2004. The 1985/1986 split can be related to the international boundary decision, with recent commercial catch at age coming exclusively from the US fleets rather than including foreign fleets. Furthermore, a 17 inch minimum size was introduced (previously there had been no minimum size), and a minimum mesh size of 5 ½ inches was introduced for sink gillnet fishing in the mid 1980s. The 1993/1994 block can be related to an increase in trawl mesh size from 5 ½ to 6 inches, and the year round closure of Closed Areas I and II. There were numerous management actions between 2001-2004, including increasing trawl mesh and sink gillnet mesh sizes to 6 ½ inches, and differential days at sea counting. Each consecutive selectivity vector shows a trend towards selecting older fish, which appears to be consistent with management regulations (Figure C31).

For the commercial fleet, selectivity at age is estimated within each block for 8 out of 9 ages, with one age class fixed at full selectivity in each block. In the interval 1970-1985, selectivity at age 6 is assumed fully selected, while in the remaining blocks age 7 is assumed fully selected. The estimated selectivities are dome shaped, and while a double-logistic form would have been more parsimonious, freely estimating selectivity at age was chosen over estimating selectivity with a double logistic due to convergence problems. Estimates for the parameter defining the age of 50% selectivity for the descending limb were tending towards the plus group (age 9), leading to boundary solutions or simply lack of convergence. Expanding the catch at age so that the plus group occurred at age 12 resolved the boundary problem (unless the descending a50 was fixed at 12), but the working group felt that the data at that age were too sparse and the model would more likely be fitting noise rather than signal.

Three selectivity blocks are estimated for the recreational fleet with breaks occurring between the following years: 1993/1994, 2001/2002. Selectivity in each period was estimated with a double logistic function and there were no problems with parameters being estimated at boundaries. No specific management or fleet change occurred in 1993-1994, although a federal minimum size of 19 inches was introduced for recreational fishing in 1989. As fish continued to be landed below the federal minimum size, this regulation is not believed to have had a significant effect on landing patterns, partly from the lack of minimum size regulations in state waters. The selectivity block in 2001/2002 reflects a shift in the mode of fishing that accounted for the greatest proportion of catch. Previously, the shore mode had contributed on average about 20% of the catch, although in any given year it ranged from 5% to 65%. After 2001, the shore mode of fishing contributed 5% or less, while the rest of the catch was contributed by private/rental boats or by party/charter boats. As the shore mode includes fishing from the beach, piers, bridges, and other fixed structures, this mode primarily catches what are referred to as 'harbor pollock'—principally fish aged 1-3 (Figure C32). The selectivity estimated for the final block is shifted towards older ages, which seems consistent with the change in mode of fishing, and may reflect greater adherence to the federal minimum size.

One time invariant selectivity vector was estimated for each of the two surveys (NEFSC Spring and Fall). Selectivity was estimated freely for 6 out of 9 ages for both the spring and the fall survey, with the remaining three ages fixed: ages 6 and 7 were assumed to be fully selected, and age 9 was fixed at a value of 0.5 (Figure C33). When selectivity at age 9+ was freely estimated, the model estimated a value of 0.25 for the spring and 0.22 for the fall index. However, such a sharp dome implied that starting spawning stock biomass in 1970 was nearly 3 times greater than the deterministic estimate of unexploited spawning biomass, which was not believed to be realistic. A fixed value of 0.5 was accepted by the working group after trying values from 0.1 to 1.0 (in increments of 0.1) and examining model diagnostics (residual patterns in age composition for both surveys and catch), objective function value, and the reasonableness of estimated abundance levels. The abundance levels were evaluated by examining the model estimate of the ratio of initial spawning biomass to unexploited spawning biomass (SSB1970/SSB0), and inspecting the time series of estimated SSB relative to a heuristic 'envelope' of realistic biomass levels (described more fully below). The model estimate of steepness was another diagnostic, and runs that estimated steepness near its upper bound of 1.0 were dropped from further consideration. This series of diagnostics reduced the set of values considered for selectivity at ages 9+ to 0.3, 0.5, and 0.6, although the initial spawning biomass with 9+ selectivity of 0.3 was somewhat high at double the unexploited SSB. Retrospective analysis for the 7 preceding years (2002-2008) was then performed for models using each selectivity value. The model with index selectivity fixed at 0.5 or 0.6 achieved convergence for 6 out of 7 runs, with logical retrospective patterns (Figure C34). Only 5 out of 7 runs with selectivity fixed at 0.3 converged. Needing to proceed with an approach which readily provided convergence across other retrospective runs, the working group adopted the model with selectivity fixed at 0.5 as the base formulation.

The effective sample size estimated for the catch at age data (which are treated as multinomial) was compared to the input effective sample size in an iterative fashion until the effective sample size specified more or less matched the model estimated value, or until no further improvement in trying to match the estimated value could be made. The final input effective sample sizes were 50 and 35 for the commercial and recreational fleets, respectively. An annual CV of 0.05 and 0.25 were assumed for the commercial and recreational landings, respectively. Commercial discard CVs for 1989 to 2008 were estimated as part of the standardized bycatch methodology. These values ranged from 0.12 to 1.04, with an average of 0.33. The estimated annual CV for recreational discards ranged from 0.47 to 0.91, with an average of 0.67.

In a similar fashion, the input effective sample size for the survey catch at age was manually tuned until the model estimate was reasonably close to the input value. For both surveys, the final input effective sample size was 30. The annual CV for each survey was the design based estimate (the surveys follow a stratified random design). For the spring survey, the average CV for the time series is 0.37, although it ranges from 0.18 to 0.85. For the fall survey, the average CV for the time series is 0.42, with a range of 0.19 to 0.74. These CVs reflect the strong year effects present in the survey.

Recruitment was assumed to follow a Beverton-Holt functional form, with an assumed CV=0.5 for annual recruitment deviations (i.e. on log-space the standard deviation of the residuals about the stock-recruitment relationship was 0.5).

Spawning was assumed to occur January 1. This is consistent with observations that the peak spawning period occurs December-January. Initially, observed lengths at age in the spring survey were used to calculate spring weight at age, and spring weights were used to estimate January 1 weights at age by the Rivard method. However, there was considerable variability between and within cohorts, and in many cases cohorts appeared to lose weight with age. The working group decided to use the observed catch weights at age, treat them as mid-year weights, and use the Rivard method to obtain January 1 weights at age. These new 'Rivard-ed' catch weights were then used as the spawning weights at age.

Base Model Results
Biomass –

The base model estimates a starting spawning stock biomass (SSB) in 1970 of about 297,000 mt, which is approximately 9% above the deterministic, point estimate of unexploited spawning biomass (~273,000 mt). Spawning biomass decreased to the time series low (68,600 mt) in 1990 (Table C8, Figure C35). Since the 1990 low, spawning biomass increased steadily through 2006, with a slight decline the last 3 years. The current estimate of spawning biomass is about 196,000 mt.

Two additional biomass measures were calculated from the estimated numbers at age (Table C9). Total population biomass was calculated with January 1 weights at age while exploitable biomass was calculated with mid-year catch weights at age and annual selectivity at age (Tables C10a,b). Total population biomass follows the same trend as SSB (Table C11, Figure C35). Exploitable biomass ranges from 35% to 70% of spawning biomass over the time series (Table C12). Due to the estimated dome-shaped fishery selectivities, exploitable biomass will always be less than spawning biomass.

Fishing Mortality –

In any given year, the fishing mortality experienced by an age class depends on the selectivity and amount of catch of each fleet. To provide a consistent metric for expressing F over the whole time series, the unweighted average F for ages 5-7 ($F_{5\text{-}7}$) is reported (Table C13). In 1970, $F_{5\text{-}7}$ is estimated at 0.11, and mostly increased to its peak of 0.49 in 1986. Since then, $F_{5\text{-}7}$ steadily decreased to 2006, when it reached the time series low of 0.03. In the last three years, $F_{5\text{-}7}$ was 0.05, 0.08, and 0.07, respectively.

Recruitment –

Mean recruitment was around 21 million age 1 recruits. Several abundant year classes were produced in 1971, 1979, 1997, 1998, 1999, and 2001, with the estimated number at age ranging from 34 to 58 million (Figure C36). The model estimated steepness at 0.66 with a CV of 0.24 (Figure C37).

Catch –

As a result of the small CVs assigned to the commercial landings, they were well fit (Figure C38). Commercial discards, which used CVs estimated from the data, had larger residuals compared to the landings (Figure C39). Increasing the number of selectivity blocks from one to four vastly improved the residuals in the commercial age composition (Figure C40). The final input effective sample size approximately matches most of the model estimated effective sample sizes (Figure C41).

The CV assigned to the recreational landings was five times greater than the commercial landings CV (0.25 versus 0.05), but they were still fit well (Figure C42). Recreational discards, which used CVs derived from the recreational landings data, had larger residuals compared to the landings (Figure C43). Increasing the number of selectivity blocks from one to three improved the residuals in the recreational age composition (Figure C44). The final input effective sample size does a reasonable job of matching most of the model estimated effective sample sizes (Figure C45).

Indices –

As noted above, the indices show apparently strong year effects, but these years tended to have the largest CVs. Thus, in fitting the indices, the influence of these effects was not strong. The predicted spring index smoothes through the early and late part of the time series, but there is a stretch of positive residuals in the 1980s and 1990s (Figure C46). The residuals in the spring age composition show some persistent trends at age for several year blocks, although the year-age blocks with the trends do not appear to be related (Figure C47). The age composition of the indices was downweighted relative to the landings by having a lower effective sample size (30, versus 50 and 35 for the commercial and recreational fleets, respectively). Although Figure C48 suggests that the indices could be downweighted further, this was not pursued.

The predicted fall index smoothes through the time series until about 1990, when there is a run of positive residuals through 2006 (Figure C49). The residuals in the fall age composition show some persistent trends at age for several year blocks (Figure C50). Unlike for the spring, however, these residual blocks somewhat trace diagonals through the plot and may reflect cohort effects. As was the case for the spring index, Figure C51 suggests that the fall index could be downweighted further but not to the extent that was seen for the spring index. Further downweighting was not pursued.

Envelope Analysis

An 'envelope analysis' was presented at the model meeting as a simple method to bound reasonable abundance estimates. The time series of total catch (mt), spring index (kg/tow), and fall index (kg/tow) were converted to total population biomass as follows:

$$Biomass(Catch) = Catch(y) / F$$
$$Biomass(SpringIndex) = SpringIndex(y) \times q_{Spring} \times A_{swept} / A_{tow} / 1000 .$$
$$Biomass(FallIndex) = FallIndex(y) \times q_{Fall} \times A_{swept} / A_{tow} / 1000$$

In the above, A_{swept} is the total area in the survey stratum (33,192 nm) and A_{tow} is the area swept by a tow (0.01 nm); these are divided by 1000 to maintain biomass units in mt. Index specific catchabilities are denoted q_{Spring} and q_{Fall}. Note that these equations tacitly assume full selectivity at all ages in the catch and the surveys.

For each biomass time series, a low and a high bound was calculated by assuming 2 values for F or q. In this particular analysis, the values considered were F={0.05, 1.0}, q={0.05, 0.50}. While these values weren't necessarily data-driven, assuming an F of 0.05 for all years would likely overestimate maximum abundance in some years and underestimate maximum abundance in other years. Similarly, assuming a q of 0.05 assumes fairly low catchability for the surveys. If catchability were actually lower, then the biomass calculated from q=0.05 would underestimate the maximum annual abundance. With these caveats in mind, the minimum and maximum biomass over the set of 3 biomass time series were plotted for each year to suggest reasonable bounds against which model estimated biomass could be compared. Figure C52 shows the envelope with 3 different biomass measures calculated from the new base model:

Total Biomass = $\sum_{age=1}^{9+} N_{age} W_{age,Jan1}$

Spawning Stock Biomass = $\sum_{age=1}^{9+} N_{age} W_{age,Jan1} p_{age}$

Exploitable Biomass = $\sum_{age=1}^{9+} N_{age} W_{age,Mid-yr} sel_{age}$

In the above, p_{age} is the proportion mature at age, and sel_{age} is the age-specific selectivity across both fleets. Note that both total biomass and spawning stock biomass used January 1 weight at age, while the exploitable biomass used mid-year weight at age.
This heuristic exercise provides further support that the ASAP base model abundance estimates are not unreasonable.

Retrospective analysis

Retrospective analysis was performed for years 2002-2007 (7 years). Before all selectivity blocks had been added to the model, the working group discussed whether retrospective analyses should be considered if selectivity changed in the most recent 7 years. The base model has recreational selectivity changing between 2001/2002, and the commercial fleet selectivity changes between 2003/2004. The working group suspected that changing selectivity during the years analyzed for retrospective analysis might tend to inflate the pattern as the model attempted to estimate selectivity parameters with fewer and fewer years of data. The pattern in Figure C34 shows two distinct clusters in the retrospective pattern for $F_{5\text{-}7}$ and SSB. The earliest years, which encompasses the change in recreational selectivity (2002-2003), is clustered furthest away from the origin (i.e., those years have higher relative retrospective bias). The years following the change in commercial selectivity are clustered (2004-2005), while the most recent three years (2006-2008) are much closer to the origin (lower relative retrospective bias). The working group interpreted this pattern as the model needing enough years beyond the last selectivity changes in order to reliably estimate those selectivity parameters. If all seven years are used to calculate Mohn’s rho (the 7 year average of relative retrospective bias), then the values are -0.17 for $F_{5\text{-}7}$ and 0.27 for SSB; using only 2006-2008 retrospective values, the average bias is -0.08 for $F_{5\text{-}7}$ and 0.13 for SSB. The average retrospective bias for 2006-2008 is small relative to other groundfish assessments in the Northeast.

MCMC simulation

MCMC simulation was performed to obtain posterior distributions of spawning stock biomass and $F_{5\text{-}7}$ time series. Two options in ADMB were invoked to reduce high autocorrelation. The variance-covariance was rescaled (with mcrb 2), and the tails of the sampled distribution were “fattened” (with mcgrope 0.07) (ADMB 2008). Initial trials without rescaling or without fattening the tails produced traces that resembled random walks rather than random sampling, i.e. there was high autocorrelation and strong evidence that the chains were

not well mixed. Two chains of initial length 10 million were simulated. The first half of each chain was dropped, and from the second half of the chain every 5,000th value saved, producing two chains of length 1,000. The traces of each chain's saved draws were plotted, and both indicated good mixing (Figure C53). Autocorrelations for F_{5-7} ranged from 0.26 in 1970 to 0.37 in 2009 with a lag of 1, and were less than 0.22 with a lag of 2 or greater. Autocorrelation for SSB ranged from 0.27 to 0.54 with a lag of 1, and were <0.4 with a lag of 2, <0.3 with a lag of 3, and < 0.24 with a lag of 4. The decreasing autocorrelation with increasing lag is another good indicator that the MCMC chains have converged. Finally, the Gelman-Rubin potential scale reduction factor (psrf) was calculated for the time series of F_{5-7} and SSB. All psrf were between 1.0 and 1.01, which again suggests convergence of the chains.
As the MCMC simulations appear to have converged, 90% Probability Intervals were calculated to provide a measure of uncertainty for the model point estimates (Figures C54, C55). Plots of the posterior for SSB_{1970}, SSB_{2009} and $F_{5-7(2009)}$ are shown for both chains in order to characterize the density of each distribution (Figures C56a-b, C57).

Sensitivity analysis of ASAP base model

A sensitivity model was examined where selectivity in both the spring and fall NEFSC surveys was fixed at 1.0 for ages 6-9+. The effect of this was predictable, in that abundances were scaled lower. Specifically, SSB in 1970 was 94,000 mt instead of 297,000 mt. Also, current biomass with flat survey selectivity dropped to 77,000 mt from 196,000 mt in the base model. Model estimates and likelihood components are compared in Table C14 for the ASAP base model, for this sensitivity model with index selectivity fixed at 1.0 for ages 6-9, and for the converged models where the index selectivity for the 9+ group was varied between 0.1-1.0. Compared to the base model, the age composition residuals for both the indices and the fleets barely changed. However, the fits to the indices were worse, with the indices dropping even further below the observed values from the 1990s and later. A retrospective run of the model with flat survey selectivities led to one year where the model couldn't run to completion (2003). For the remaining 6 years, the retrospective pattern had relative biases that were more than twice as poor as the base case (Figure C58). The 6 year average Mohn's rho for F was -0.41, and the 3 year average was -0.26. For SSB, the 6 year average Mohn's rho was 1.06, and the 3 year average was 0.54.

A sensitivity model was examined where natural mortality (M) was fixed at 0.15 instead of 0.2 for all ages and all years. The result of a lower M was to increase the estimated depletion through time, such that in 2009, spawning biomass was 45% of unexploited SSB instead of 72% under the base model. Lowering M to 0.15 increased the objective function value by 9 points over the base model.

As a simple exploration of the impact of using only the catch in US waters of NAFO areas 5 and 6, Canadian landings on the northeast corner of Georges Bank (5Zc, Figure C1) were included in the time series of total commercial landings (Table C15). No landings were reported by Canada in this area before 1982. The fraction of landings by Canada in 5Zc were generally less than 20% of total commercial landings with the exception of a period from 1992-2005, when Canadian landings ranged from 22% to 47% of the total. In the most recent 3 years, Canadian landings in 5Zc have been minor. It was assumed that these landings would have the same size/age structure, so catch at age was simply scaled to reflect the increase in total landings. No discarding was assumed for Canada in 5Zc. The effect on model results was minor. Estimates of initial conditions in 1970 were generally 4% less than the base model, while estimates for 2009 were 9% less (Table C14).

Sensitivity analysis to assessment model (Butterworth & Rademeyer SCAA)

An additional statistical catch at age (SCAA) assessment model was considered during the working group model meeting (29 March – 2 April, 2010). This model, the mathematical details of which are given in Appendix C2, differs from ASAP in several ways.

- The initial numbers-at-age vector was not estimated for all ages, but instead represented more parsimoniously in terms of two estimable parameters: • – the starting spawning biomass as a proportion of the corresponding deterministic pre-exploitation level, and ϕ reflecting an average fishing mortality (see equations B8 to B12 in Appendix C2). In implementation, the starting year chosen was 1960 rather than the 1970 for ASAP, so that a few more years of the early survey data were fitted. Furthermore the priors for • and ϕ for computing posterior distributions by means of MCMC were chosen as U[0.2;1.2] and U[0;0.3] respectively.
- Pope's approximation rather than the Baranov equation was used for the dynamics to speed computations, though the consequent differences would be rather small.
- In fitting to the survey indices of abundance, the inverse variance weighting approach used in computing the likelihood took account of an estimable additional variance as well as the sampling variance estimates that accompanied the survey data (see equations B18 and B19 with associated text in Appendix C2).
- Rather than a multinomial distributional form assumed for commercial or survey proportions-at-age data when computing the likelihood in ASAP, a modified log-normal was used with the intent of capturing both process and sampling error effects in a parsimonious way (see equations B20 to B24 in Appendix C2). The associated variance parameter was estimated directly from the residuals in the fitting procedure. Customarily such contributions to the negative log-likelihood are downweighted to allow for non-independence amongst such data inputs; here a multiplicative downweighting factor (w_{CAA}) of 0.1 was used, though runs without this downweighting were also conducted.
- A greater differentiation among fleets was effected with six distinct "fleets" being distinguished: US, distant water, and Canadian commercial fleets, as well as commercial discards, recreational landings and recreational discards.
- The selectivity functions (from models with a plus group at age 9+) were differently specified compared to ASAP. Selectivities were invariant over time unless selectivity "blocks" (see below) were specified for a particular "fleet". For each (block for each) "fleet", selectivity was estimated directly for each age from age '*data-minus*' to age '*data-plus*', where data were grouped below and above such ages when fitting to the model because of sample size considerations. The estimated decreases from ages *data-minus*+1 to *data-minus* and from ages *data-plus*-1 to *data-plus* were assumed to continue exponentially to ages 1 and 9 (the model plus group considered) respectively. For the commercial fisheries *data-minus* was taken to be 3, and 1 for the other "fleets", while *data-plus* was set at 9 for the US commercial, 8 for the other commercial and the recreational, and 6 for both discard "fleets". For the NEFSC spring and fall surveys, the fishing selectivity was estimated directly for each age from age 1 to age 8 and to age 7 for

the spring and fall surveys respectively, and was assumed to remain constant at those age 8 and age 7 values for higher ages.

During the model meeting, extensive testing of both models occurred. At the close of the model meeting, the working group felt comfortable that despite the structural differences between the two models, they were capable of producing similar results when configured similarly. Thus, the SCAA model provided valuable feedback regarding model sensitivity to assumed error distributions, estimation of starting conditions, and selectivity fitting.

As not all model inputs were complete by the model meeting, subsequent runs of this *SCAA* were conducted with the full data set (the same as used in the ASAP base model, as described above). To the extent possible, the SCAA was configured to match the ASAP base model to cross-check results. There were nevertheless some differences because of time limitations, though indications are that the impact of those differences on results would be small:

- The choice of periods (blocking) during which selectivity for a "fleet" remained the same differed from the ASAP implementation by including one extra selectivity block for the US commercial fleet, with the first block used for the ASAP model being split in 1976/1977. For the recreational "fleet", the first block was split in 1989/1990 instead of 1993/1994 as for ASAP.
- The Beverton-Holt stock-recruitment function steepness estimate was bounded above by 0.9.
- All catches (commercial, discard and recreational) were fixed on input without allowing the model fitting process to select possible relatively small errors in each year.

Table C16 compares results for some key outputs from the SCAA approach to those from the base case ASAP run. The SCAA runs shown converged reasonably, both in respect of point estimate and Bayes posterior computations achieved using MCMC. The runs commenced in 1960, and did not typically reflect values of SSB in 1970 greater than SSB0. Results are shown for three SCAA implementations, with the specifications detailed above, and compared with those for the ASAP base case in Table 16:

- SCAA1 downweights the CAA data (w_{CAA} = 0.1).
- SCAA2 gives full weight to the CAA data (w_{CAA} = 1).
- SCAA3 duplicates SCAA2, except that in the MCMC the selectivity of 9+ fish in the surveys is fixed at the point estimate for SCAA2.

SCAA2 is likely the closer analog of the ASAP base case in terms of the relative weight given to CAA data in the model fitting process, and associated point of MCMC estimates for SSB for this run are shown in Figure C59. SCAA3 is closer to the ASAP base case prescription in terms of variance computation, as it fixes the 9+ survey selectivity as in the ASAP case.

The SSBMSY and MSY estimates shown in Table C16 are not evaluated using the Beverton-Holt stock-recruitment curves estimated in these model fits, but instead are proxies based on $F_{40\%}$. They differ slightly in methodological terms from corresponding values calculated for the ASAP runs in that they reflect the multiplication of estimates of SSB/R and Y/R at $F_{40\%}$ by the average recruitment (which here is as estimated for the 1970-2005 period). Any changes in estimates of these proxies as a result of this difference should however be small.

In broad terms, these SCAA runs show very similar historic trends in spawning biomass to those from the base case ASAP. Both the scale (average magnitude over time) and the variance associated with the spawning biomass estimates are however larger for the SCAA runs than for the base case ASAP. Much of this difference relates to the weighting given to the CAA data in the model fit. As this weight is increased, both posterior medians and 95%-iles decrease to become closer to the ASAP estimates. However, even if the 9+ survey selectivity is fixed at its value in SCAA2 when estimating variance, results for spawning biomass still reflect less precision than do those for the ASAP base case. Nonetheless this scale difference translates only slightly (if at all) into estimates of sustainable yield, with MSY proxy estimates and their precision for SCAA2 and SCAA3 broadly similar to the results obtained from the ASAP base case.

Management Reference Points

Term of Reference 4: Update or redefine biological reference points
(BRPs; estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, and F_{MSY}; and estimates of their uncertainty). Comment on the scientific adequacy of existing and redefined BRPs.

The working group decided to adopt F40% as a proxy for F_{MSY}. The NOAA Toolbox program YPR was used to calculate a deterministic value for F40% given average vectors for the most recent 5 years (2005-2009) for SSB weights at age, catch weights at age, maturity at age (which is time invariant), and selectivity at age. Expressed as the average F experienced at ages 5-7, the estimate is $F40\%_{5\text{-}7}$ = 0.25, which corresponds to a fully selected F of 0.41.

The population numbers at age for year 2010 corresponding to each saved draw from one of the MCMC chains were used to make stochastic projections to determine the SSB and yield corresponding to F40%. In the stochastic projections, recruitment was resampled from the empirical distribution as estimated by the ASAP base model for years (1970-2007). The stochastic projections were made using the NOAA Toolbox program AGEPRO, and each projection was made for 100 years to allow the projection to reach equilibrium.

From the projected distributions of SSB and yield, the median value was taken as the proxy for SSB_{MSY} and MSY. The proxy for SSB_{MSY} is 91,000 metric tons, with 5^{th} and 95^{th} percentiles spanning 71,000 to 118,000 mt. One half of SSB_{MSY} is the $B_{THRESHOLD}$ (45,500 mt). The proxy for MSY is 16,200 mt, with 5^{th} and 95^{th} percentiles spanning 11,800 to 23,200 mt. It should be noted that the MSY estimate includes both commercial and recreational landings and discards. The median recruitment was 19.3 million age 1 fish, with 5^{th} and 95^{th} percentiles ranging from 8.4 to 42 million fish. Distributions for SSB_{MSY} and MSY are given in Figure C60.

A second stochastic projection was done for 0.75* $F40\%_{5\text{-}7}$ = 0.19, which corresponds to a fully selected F of 0.31. Spawning biomass under a harvest at 0.75* $F40\%_{5\text{-}7}$ has a median of 109,000 mt, with 5^{th} and 95^{th} percentiles ranging from 86,000 to 140,000 mt. The corresponding median yield is 14,500 mt, with 5^{th} and 95^{th} percentiles ranging from 10,700 mt to 20,600 mt. The distribution of recruitment is independent of the harvest scenario, as it is merely sampling from the cdf of estimated values from the base model. Thus, the median recruitment was still 19.2 million age 1 fish, with 5^{th} and 95^{th} percentiles ranging from 8.4 to 42 million fish.

To evaluate the sensitivity of reference points to the model estimated dome-shaped selectivities, results from the flat-topped sensitivity model run were also used to estimate reference points. Following the same methodology, the average F40% on ages 5 to 7 was 0.22, the proxy for SSB_{MSY} was 58,000 mt, and the proxy MSY was 11,200 mt. Thus, if the survey selectivity at ages 6-9 is fixed at 1.0, rather than having a dome shape, then the biomass reference points would be 30-35% lower.

Stock Status

Term of Reference 5: Evaluate stock status with respect to the existing BRPs. *as well as with respect to updated or redefined BRPs (from TOR 4).*

The estimate of $F_{5\text{-}7}$ in 2009 from the ASAP base model (0.07) is 28% of the F_{MSY} proxy for ages 5 to 7 (0.25). Therefore, overfishing is not occurring. To provide a historical perspective on overfishing, a time series of $F_{40\%}$ corresponding to a fully selected F is plotted in Figure C61. This year-specific $F_{40\%}$ was calculated for years 1974-2009 with a 5 year moving average of weights at age, selectivity at age, and maturity at age. The $F_{40\%}$ in 1974 used years (1970-1974) while the final $F_{40\%}$ used years (2005-2009). The reason for doing this is that selectivity at age has changed substantially through time (Figure C62), and an $F_{40\%}$ in recent years when fishing occurs on mature fish would not be an appropriate reference point earlier in the time series when fishing occurred on immature fish. The calculated $F_{40\%}$ on ages 5-7 ranges from a low of 0.20 in 1976 to a high of 0.28 for 2000-2003. Considering the year-specific $F_{40\%}$ estimates, the base model estimates of F indicates that overfishing was occurring during the period 1973-1990.

The estimate of SSB in 2009 from the ASAP base model (196 000 t) is more than twice the SSBmsy proxy (91 000 t). One half of SSB_{MSY} is the $B_{THRESHOLD}$ (45,500 mt). Therefore the stock is not overfished. Similar to the reasoning above for F40%, the SSB_{MSY} proxy calculated using recent selectivity and weight patterns is not appropriate to compare to historic estimates of SSB. The year-specific $F_{40\%}$ values were used to make stochastic projections for determining the median equilibrium SSB_{MSY}. The full time series of model estimated recruitments was used in all projections, even for the 1974 estimate of SSB_{MSY} when the model would theoretically have only had 5 years of observations. The estimated year specific SSB_{MSY} proxies range from 91,000 mt to 122,000 mt, and indicate that the base model estimates of $SSB < SSB_{MSY}$ during the period 1987-1998 (Figure C63).

This revised assessment provides a different perception of stock status when compared to the stock status results from the AIM model. The most recent update of the AIM model indicated that the stock was overfished and overfishing was occurring in 2008. As Figure C64 indicates, the divergence between the NEFSC fall index selectivity and the fishery selectivity is especially pronounced towards the end of the time series. This divergence is important, as the AIM model assumes that the selectivity is the same in the fishery and the index.

The sensitivity of stock status to the model estimated dome-shaped selectivities was evaluated by comparing current F and SSB estimates from the sensitivity model with flat survey selectivity for ages 6-9 to their corresponding reference points. Assuming flat survey selectivity, the model estimate of SSB_{2009} was 77,000 mt, which is greater than the SSB_{MSY} proxy of 58,000 mt, so the stock would not be considered overfished. The model estimate of $F_{5\text{-}7}$ in 2009, assuming flat survey selectivity, is 0.13, which is less than the corresponding F40% on ages 5-7 of 0.22, so overfishing is not occurring. It was therefore concluded that stock status is not sensitive to the shape of survey selectivity at older ages.

Projections

Term of Reference 7: Develop and apply analytical approaches and data *that can be used for conducting single and multi-year stock projections and for computing candidate ABCs (Acceptable Biological Catch).*

a) Provide numerical short-term projections (through 2017). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. In carrying out projections, consider a range of assumptions to examine important sources of uncertainty in the assessment.
b) Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.
c) For a range of candidate ABC scenarios, compute probabilities of rebuilding the stock by 2017.
d) Describe this stock's vulnerability to becoming overfished, and how this could affect the choice of ABC.

The base ASAP model estimates that the stock is not overfished, so no rebuilding projections were conducted. However, for the purposes of providing advice for setting ABCs, the projections described above ($F=F_{40\%}$, and $F=0.75*F_{40\%}$) are summarized through 2017. In addition, a third projection, $F_{status\text{-}quo}$ was conducted with the same bootstrapped numbers at age and the same recruitments, but F was fixed at $F_{2009}=0.12$ (equivalent to $F_{5\text{-}7}=0.07$).

Projections are summarized for various percentiles of spawning stock biomass and catch under all 3 scenarios in Tables C17a, b. Under all three scenarios, spawning biomass declines from SSB_{2009}=196,000 mt until it reaches equilibrium at the projected F. Under $F_{status\text{-}quo}$, the median SSB equilibrates at 166,000 mt. Projecting at $0.75*F_{40\%}$, the median SSB equilibrates at 109,000 mt, while at $F_{40\%}$ the median SSB equilibrates at 91,000 mt (the proxy for SSB_{MSY}).

Projected catch includes both commercial and recreational landings and discards. Under $F_{status\text{-}quo}$, median projected catch decreases from 8,100 mt in 2010 to 7,200 mt in 2012, then gradually increases until equilibrating around 8,400 mt in 2017 (Table C17b). Projecting at $0.75*F_{40\%}$, the median catch fluctuates from 19,800 mt in 2010 to 15,400 mt in 2012, and continues to oscillate in this range until equilibrating at 14,500 mt. Projecting at $F_{40\%}$, median catch declines from 25,700 mt in 2010 to 17,500 mt in 2017 with minor fluctuations until equilibrating at 16,200 mt (the proxy for MSY). It should be noted that a projected 2010 catch of 25,700 mt would exceed MSY, be more than double recent catch, and has not been observed since the 1980s.

Trophic Ecology

Term of Reference 6: Evaluate pollock diet composition data *and its implications for population level consumption by pollock.*

Food habits were evaluated for pollock as a major predator in the ecosystem. The total amount of food eaten and the type of food eaten were the primary food habits data examined. From these basic food habits data, diet composition, per capita consumption, total consumption, and the amount of prey removed by pollock were calculated. Contrasts to total energy flows in the ecosystem and fishery removals of commercially targeted skate prey were conducted to fully address the Term of Reference.

To estimate mean stomach contents (S_i), pollock had the total amount of food eaten (as observed from food habits sampling) calculated for each size class, temporal and/or spatial scheme. The denominator in the mean stomach contents (i.e., the number of stomachs sampled) was inclusive of empty stomachs. These means were weighted by the number of tows in a temporal and spatial scheme as part of a two-stage cluster design. Further particulars of these estimators can be found in Link and Almeida (2000). Units for this estimate are in g.

Estimates were calculated on an annual basis for each pollock size class. These size classes corresponded to < and • 50 cm for Small (S) and Large (L) size classes, respectively. The food habits data collections started quantitatively in 1973. For more details on the food habits sampling protocols and approaches, see Link and Almeida (2000). This sampling program was a part of the NEFSC bottom trawl survey program; for background and context, further details of the survey program can be found in Azarovitz (1981) and NEFC (1988). Key diagnostics were the number of empty stomachs over time and mean length vs. mean stomach contents weight (with ± 95% CI), which were examined to identify any major outliers in the data and to ascertain any notable patterns in variance.

To estimate diet composition (D_{ij}), the amount of each prey item was summed across all pollock stomachs. These estimates were then divided by the total amount of food eaten in a size class, temporal and spatial scheme, totaling 100%. These estimates are proportions and were only presented for those major prey comprising >85% of the total for each size class, temporal and spatial scheme. Further particulars of these estimators can be found in Link and Almeida (2000).

The approach to calculate consumption followed previously established and described methods for estimating consumption, using an evacuation rate model methodology. For further details, see Durbin et al. (1983), Ursin et al. (1985), Pennington (1985), Overholtz et al. (1991, 1999, 2000, 2008), Tsou & Collie (2001a, 2001b), Link & Garrison (2002), Link et al. (2002, 2006, 2008, 2009), Methratta & Link (2006), Link & Sosebee (2008), Overholtz & Link (2007, 2009), Tyrrell et al. (2007, 2008), Link and Idoine (2009), Moustahfid et al. (2009a, 2009b), and NEFSC (2006, 2007a, 2007b, 2008). The main data inputs are mean stomach contents (S_i) for each pollock size-time-space scheme i, diet composition (D_{ij}) where j is the specific prey of interest, and T is the bottom temperature taken from the bottom trawl surveys (Taylor et al. 2005). Estimates of variance about all these variables (data inputs) were calculated. Further particulars of these estimators can be found in Link and Almeida (2000). Again, units for stomach estimates are in g.

More specifically, using the evacuation rate model to calculate consumption requires two variables and two parameters. The per capita consumption rate, C_i is calculated as:

$$C_i = 24 \cdot E_i \cdot \overline{S_i}^{\gamma} \quad ,$$

where 24 is the number of hours in a day and the evacuation rate E_i is:

$$E_i = \alpha e^{\beta T} \quad ;$$

and is formulated such that estimates of mean stomach contents (S_i) and ambient temperature (T; here used as bottom temperature from the NEFSC bottom trawl surveys (Taylor et al. 2005)) are the only data required. The parameters • and • are set as values chosen from the literature (Tsou and Collie 2001a, 2001b, Overholtz 1999, 2000). The parameter • is a shape function is almost always set to 1 (Gerking 1994). As noted, to estimate per capita consumption, the gastric evacuation rate method was used (Eggers 1977, Elliott and Persson 1978). There has been copious experience in this region using these models (see references listed above). The two main parameters, • and •, were set to 0.004 and 0.11 respectively based upon prior studies and sensitivity analyses (NEFSC 2007a, 2007b). From 1992 and forward (when individual weights were measured), a diagnostic of % daily ration was also calculated.

Once per capita consumption rates were estimated for each pollock size class, temporal and spatial scheme, those estimates were then scaled up to an annual and stock wide basis, *C*:

$$C = 365 \cdot C_i \cdot N_i$$

where N_i is the estimate of abundance (see stock assessment results) for each pollock size class, temporal and spatial scheme and 365 is the number of days in a year.

This total consumption was partitioned for the major prey items of pollock by multiplying it by the diet composition of each prey (D_{ij}) to provide an estimate of prey removals. Both the total consumption and the amount of prey removed by each pollock size class (and combined across sizes) are presented as metric tons year^{-1}.

To evaluate the consumptive demands of a pollock and the predatory removals of pollock in a broader ecosystem context, two contrasts were executed. First, comparisons of total consumption by pollock were compared to the amount of energy flows for the entire ecosystem. These total energy flows were calculated in a recent energy budget (Link et al. 2006, 2008, 2009). Pollock consumption is presented as a percentage of total energy flows in the ecosystem.

Second, the total amount of commercially targeted prey eaten by pollock was treated as a removal. These estimates were then compared to concurrently estimated fishery landings to provide an evaluation of potential competition between pollock and fisheries on some of their major prey.

Results and Observations:

- From recent energy budgets, the amount of food consumed by pollock is 0.001-0.007% of all energy flows in the system.
- From recent energy budgets, pollock comprise 0.5-5% of the total consumption by all finfish on GB & GoM.
- This has changed over time, mainly as a function of pollock abundance.
- All diagnostics were within the normal range.
- Pollock consumption has been more important at times, perhaps when other piscivore species were at lower abundances, but has never been the dominant piscivore.

Summary:

- Abundance, landings, consumption, energy flow, and relative importance to overall system peaked in late 1990s to early 2000s (Figure C65).
- Trends are similar to prior studies (Tyrrell et al. 2007).
- These estimates are 1-2 orders of magnitude lower than other, previous estimates: mainly due to a more conservative choice of the • parameter.

- Pollock remain an ecologically important piscivore and shrimpivore in the NEUS ecosystem.
- Pollock probably do not consume a significant amount of certain species (relative to those spp. B, P, F), except for pandalid shrimp and maybe herring.

Research Recommendations

Term of Reference 8: Research Recommendations
Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

The WG offers several research recommendations, prioritized below.

- Selectivity studies
  - Physical selectivity (e.g., multi-mesh gillnet)
  - Behavioral studies (e.g., swimming endurance, escape behavior)
  - Explore geographic and vertical distribution by size and age
  - Tag-recovery at size or age
  - Evaluate information on length-specific selectivity at older ages
- Stock definition – sensitive genetic markers
- Alternative pollock surveys (fixed gear, etc.)
- Examine how to incorporate Bigelow survey given that no calibration is available
- Explore inclusion of existing surveys (e.g., age composition of summer survey, inshore recruitment indices)
- Consider new survey approaches, because trawls surveys don't survey pollock well (off-bottom, hard-bottom, fast-swimmers, patchy, …)
- Further evaluate age determination of old fish
- Investigate magnitude of historical discards
- Discard mortality studies (by gear)
- This assessment uses relative estimates (stratified mean) for survey indices. Investigating area swept estimates could be a research recommendation for the future.
- Investigating the use of party charter logbooks for recreational catch-at-age could be considered as a research recommendation.

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