## D. OFFSHORE HAKE STOCK ASSESSMENT FOR 2010

**[SAW-51 Editor's Note: The SARC-51 Review Panel concluded that sufficient information is not available to determine offshore hake stock status with confidence, because fishery data are insufficient and one cannot assume that survey data reflect stock trends. The Panel concluded that it is not possible at this time to provide a reliable definition for overfished and overfishing for this stock. SEINE and AIM modeling is included in this report to show what the Working Group provided to the SARC-51 for peer review.]**

### Terms of Reference

1. Use models to estimate the commercial catch. Describe the uncertainty in these sources of data.
2. Characterize the survey data that are being used in the assessment (e.g., regional indices of abundance, recruitment, age-length data, etc.). Describe the uncertainty in these sources of data.
3. Estimate measures of annual fishing mortality, recruitment and stock biomass for the time series, and characterize the uncertainty of those estimates.
4. State the current definitions for overfished and overfishing. Then 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 Offshore hake TOR 4).
6. If a model can be developed, conduct single and multi-year stock projections and for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs).
    1. Provide numerical short-term projections (3 years). 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 about the most important uncertainties in the assessment.
    2. Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.
    3. Describe this stock's vulnerability to becoming overfished, and how this could affect the choice of ABC.
7. Propose new research recommendations.

### Executive Summary

Offshore hake (*Merluccius albidus*) is a data-poor stock and very little is known about its biology and life history. They are commonly distributed from southern Georges Bank through the Mid-Atlantic Bight, at depths of 160-550 meters and temperatures ranging between 11-13$^{o}$C.

They are known to co-occur with silver hake (*Merluccius bilineris*) in the outer continental slopes of the Atlantic Ocean and are easily confused with silver hake because of their strong morphological resemblances.

The primary sources of biological information for offshore hake are based on the annual fishery independent surveys conducted by the Northeast Fisheries Science Center (NEFSC). The NEFSC have conducted both spring and fall bottom trawl surveys off the US continental shelf annually since 1963. The surveys extend from the Gulf of Maine to Cape Hatteras, in offshore waters at depths 27-365 meters, and have been conducted in the fall since 1963 and in the spring since 1968. The winter bottom trawl survey began in 1992 and was specifically designed for flatfish, however, the deeper survey strata were not sampled until 1998. The winter trawl survey does not cover the Georges Bank area because the survey was designed specifically for flatfish in the southern region.

Survey catches are highly variable but the trends in the spring and fall are similar. The higher catchability in the winter survey can be explained by the net configuration (i.e smaller cookies) specifically designed to target flatfish.

Offshore hake are located primarily on the continental shelf and presumably beyond the NEFSC survey area. Offshore hake tend to be concentrated in the southern Georges Bank region in the fall, whereas in the spring, they are found further south in the Mid-Atlantic Bight. They also appear to be more abundant during the winter months at temperatures ranging between 11-13 °C and in deeper waters.

Offshore hake appear to be sexually dimorphic with females slightly larger than males. Females mature at a larger length than males, similar to other gadoid species (O'Brien et al 1993). Length at 50% maturity ($L_{50}$) also differed significantly between sexes with females maturing at larger sizes (28cm) relative to males (23cm). More fish are found in the developing stage in April than in the other months sampled. There is also more frequency in resting stage in the fall than in the spring, which would also indicate that spawning occurs in the late spring and summer months (Traver et al., in review). We do not have a summer survey to verify these results.

Offshore hake is a trawl based fishery and primarily a bycatch fishery for silver hake, with 95% being caught by otter trawl. They are being caught in deep waters, where they are potentially being mixed with and reported as silver hake. Landings data are a major source of uncertainty for this stock, due to mixed reported landings with silver hake and landings were not reported until 1991. Even those that are reported may not be correctly identified (Garcia-Vazquez et al., 2009), therefore fishing mortality rates remain unknown. Two models were used to estimate the proportion of offshore hake landed as silver hake, a length-based and a depth-based model. The two models give similar estimates that are both much higher than the nominal landings. The data used in the assessment include survey indices from the NEFSC fall survey, landings estimated using two models, and discards estimated using a single model. The length-based model used the catch-at-length for silver hake and used the proportion of offshore hake at length from the survey to apportion catch. The depth-based model used VMS data and depth-based logistic functions from the survey to apportion landings. Two assessment models were attempted, An Index Method (AIM) and Survival Estimation in Non-Equilibrium Situations Model (SEINE). Neither model was considered adequate for management.

The survey data may not be a good index of abundance, and the values may be driven more by environmental changes or fish migrations. The survey likely does not cover the entire stock area and therefore, the survey estimates could potentially be under-representing the population. It also appears that the fishery as estimated by either the length-based model or the depth-based model has not had an impact on the stock. The mortality estimates from the SEINE model are in direct contrast to the catch data. Developing ACLs will be challenging given that the landings are not separated to a great extent. Garcia-Vazquez et al (2009) found 12% of hake sold in Spain as silver hake were actually offshore hake. No alternative reference points are recommended and the existing BRPs should also not be accepted.

**Hake Working Group Meetings**
Three meetings were held in preparation of the 2010 silver hake assessment.

1. Hake fishermen's/stakeholder's meeting – August 6, 2010 – UMASS School of Marine Science and Technology (SMAST), Fairhaven, MA. Participants include fishermen Dan Farnham and Bill Phoel. Also in attendance were David Goethel (Oversight Committee chair), Andrew Applegate (staff) Steve Cadrin (SSC and WG chair, SMAST), Pingguo He, Klondike Jonas, Yuying Zhang, Tony Wood, and Daniel Goethel (SMAST), Loretta O'Brien, Michele Traver, Kathy Sosebee and Larry Alade (NEFSC), and Dick Allen (advisor at large).

2. Data Meeting – September 7-10, 2010, NEFSC Woods Hole MA. Participants included Steve Cadrin (WG Chair), Assessment leads (Larry Alade, Kathy Sosebee , Michele Traver), Rapporteurs (Jessica Blaylock and Julie Nieland), Mark Showell (DFO), Andy Applegate (NEFMC Staff), NEFSC (Loretta O'Brien, Mark Terceiro, Chris Legault, Tim Miller, Dave Richardson, Ayeisha Brinson, Jiashen Tang, Janet Nye, Mike Palmer, Paul Rago, Josef Idoine, Jon Hare), Moira Kelly (NERO), SMAST (Tony Wood, Yuying Zhang, Saang-Yoon Hyun).

3. Model Meeting – October 25-29, 2010, NEFSC, Woods Hole, MA. Participants included Steve Cadrin (WG chair), Assessment leads (Larry Alade, Kathy Sosebee , Michele Traver), Rapporteurs (Jessica Blaylock and Julie Nieland), Mark Showell (DFO), Andy Applegate (NEFMC Staff), Dan Farnham (Fisherman and Industry Advisor), (Loretta O'Brien, Paul Nitschke, Mark Terceiro, Jay Burnett, Chris Legault, Tim Miller, Jon Deroba, Rich McBride, Jim Weinberg, Paul Rago, Josef Idoine, Jon Hare, Janet Nye, Dave Richardson, Laurel Col, Jason Link), SMAST (Tony Wood, Yuying Zhang, Dan Goethel). The groups met by correspondence after the meetings, including a WebEx meeting on November 5, 2010 to report updates on silver hake analyses, provide guidance on reference points and discuss plans for report development.

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

**Fishery Regulations**
The following outlines the current small mesh multispecies regulations (based on the small mesh

exemption program) for the New England whiting fishery to provide context for interpreting the fishery and model results.

1. 1994 & 2000 - Exempted fisheries allows vessels to fish for specific species such as whiting or northern shrimp in designated areas using mesh sizes smaller than the minimum mesh size allowed (Gulf of Maine, Georges Bank, Southern New England, Mid-Atlantic : 6.5-inch square or diamond) under the Regulated Mesh Area (RMA) regulations .

2. Permits
a. Open access Category K Multispecies
b. Limited Access Category A-F (non Days-at-Sea fishing )

3. No Size Limits

4. 500 lbs at sea transfer limit.

5. 2003 - Possession limits vary by exemption area
a. 3,500 lbs if mesh < 2.5 inches (63.5mm)
b. 7,500 lbs if mesh <=3.0 inches (76.2mm)
c. 30,000 lbs if mesh > 3.0 inches (76.2mm)
d. No Red Hake possession limit

**Introduction**
Offshore hake, *Merluccius albidus* belongs to one of the twelve hake species of the genus *Merluccius*, inhabiting the northern and southern hemisphere of the world's oceans (Pitcher and Alheit 1995; Helser 1996). Like other species of the *Merluccius* genus, they are considered to be a 'true hake' species and are morphologically distinct from other gadoid-like hakes (e.g., red and white hake, Helser 1996). Offshore hake are known to be distributed off the continental slope of the northwest Atlantic to the Caribbean and the Gulf of Mexico (Chang et al 1999) (Figures D1-4). They are commonly located off southern Georges Bank through the Mid-Atlantic Bight at depths ranging from 160-550 meters (Bigelow and Schroeder 1953, Klein-MacPhee 2002). Offshore hake and silver hake (*M. bilinearis*) are sympatric species, and they co-exist over a considerable range of the continental slope, but are often separated by depth preferences (Helser 1996). The most distinguishing morphological characteristics between these species are the number of gill rakers and lateral line scales (Chang et al 1999). Due to the similar morphological features and spatial areas where they co-exist, they have been commonly misidentified for many years. The fishing industry did not separate the commercial landings of the two species until 1991, but the extent to which they are still landed as a single species is unknown (Helser 1996).

Offshore hake is currently included in the New England Fishery Management Council's (NEFMC) small mesh multi-species fishery management plan. Unfortunately, very little is known about the biology and population dynamics of offshore hake. They have never been formally assessed before.

**Biology**
Spawning usually occurs between April and July in the New England area, at depths ranging from 330-550 meters (Cohen et al. 1990). The maximum observed length from all areas is 40cm for males and 70cm for females (Chang et. al. 1999). Maximum observed size in samples from the Northwest Atlantic was approximately 43cm for males and 56cm for females, and fish greater 40cm consist mainly of females, suggesting that they are sexually dimorphic (Traver et al. in review). Length at 50% maturity ($L_{50}$) also differed significantly between sexes with females maturing at larger sizes (28cm) relative to males (23cm) (Traver et al. in review).

***TOR 1. Use models to estimate the commercial catch. Describe the uncertainty in these sources of data.***

Nominal commercial landings of offshore hake did not occur until 1991 (Figure D5, Table D1). Offshore hake commercial landings peaked at 120 mt in the early 1990s, then declined sharply to less than 5mt in 2001, the lowest in the time series (Figure D5). Landings have since increased slightly and average around 15 mt. Nominal landings of offshore hake occur in the silver hake northern area even though offshore hake are not found in these areas.

In the north, Massachusetts is the primary state that has nominal offshore hake landings while New Jersey and Rhode Island account for most of the southern area landings (Tables D2-D3). Otter trawl is the dominant fishing gear for offshore hake, accounting for 95% of the total nominal landings in both regions (Tables D4-D5). Other gears such as gillnet or hook and line were very minimal, contributing less than 1% in offshore hake catches.

Nominal landings of offshore hake occur sporadically in the north over time (Table D6). The landings are spread somewhat evenly among months in the south (Table D7-D8). Offshore hake are landed in an unclassified or dressed market category (has been combined in Table D9). King offshore hake are large component of the southern stock landings accounting for more than 50% of the total (Table D9).

There are currently no estimates of CPUE or effort for this species. Given the uncertainties given below with species identification and the major changes in management noted in the introduction, CPUE is not likely to be a good indicator of stock status.

It is thought that landings of offshore hake are likely under-reported or mis-reported and landed as silver hake as well as reported in areas that are not likely. There is no price differential so there is no real incentive to separate the two species when they are landed. Landings from the northern area are assumed to be silver hake. In order to estimate landings of offshore hake from the landings of silver hake from the southern region (Table D10-D13), two alternative methods were developed.

The first method used the port length samples of both species directly. Length samples of silver and offshore hake were combined by stock (Tables D14-D16). In examining the silver hake length samples by market category, it appeared that most of the market categories were similar in length composition to the round category (Figures D6-9). Therefore, only three market categories were used for stratification: round, king, and large. Even with the reduction of market categories, pooling over years was required to get an adequate number of fish (Table D17). The length-weight equations for silver hake by season from Wigley et al. 2003 were applied to the samples and used to estimate the landings numbers at length for each market category.

For the southern stock, length compositions for each species were estimated for the spring and fall surveys from 1968-2009. The species-specific length-weight equations were then applied to determine weight-at-length by species. The proportions at length by species for both number and weight were applied to the commercial landings-at-length to estimate landings-at-length by species. The lengths had to be grouped into intervals to avoid zero cells in the survey. To hind-cast the species proportions back to 1955, the average proportion of offshore hake for the time series was used and applied to the total silver hake landings.

The second method relates survey catch composition to Vessel Monitoring System (VMS) derived commercial landings from 2004-2009 using survey depth as an explanatory factor to develop a model that predicts the hake species landings composition. Offshore and silver hake composition ($R_{23}$) in the trawl survey tows were modeled as a two parameter logistic function of average depth. Only survey tows with silver hake, offshore hake or both were fitted and mean depth was the dependent variable.

$$R_{23} = \frac{e^{a+b*depth}}{1+e^{a+b*depth}}$$

For each stratum group, survey (winter, spring, and fall), and sets of time series, the catch and depth data were fitted by a non-linear least squares, weighted by the number of positive tows in a stratum, using the Marquardt method (Marquardt 1963) to aide convergence. Data were weighted by the number of positive tows in a stratum group. $R^2$ and Wald 95% confidence intervals (Cook and Weisberg 1990) were calculated for parameters a, b, D50, and the range to evaluate goodness of fit. Fitting the data with a two parameter logistic non-linear regression using maximum likelihood estimation and iteratively reweighted least squares approaches was attempted, but did not improve the results.

The parameter estimates for 1985-2009 were applied to the depth association with the VMS-derived commercial landings at depth (Applegate 2010). The model ratio of offshore to silver hake were assigned to landings from each group depth zone, survey season, and survey stratum group and summed for the calendar year (Applegate 2010). The final landings from this method were greater than 90% of the total landings reported by dealers in 2004-2009.

Estimates of offshore hake landings ranged between 290 – 893 mt and 5 – 12% of total hake landings (Table D18). These estimates are considerably higher than those reported by either dealers or by fishermen on Vessel Trip Reports (VTR).

Given that VMS data for 2004 – 2009 were deemed acceptable for direct estimation of silver and offshore hake landings composition, landings prior to 2004 (1955 – 2003) were hindcasted to generate longer time series of removal for assessments and for developing biological reference points. Although the hindcast procedure allowed the distribution of catch to vary between statistical areas, the distribution of catch within these intermediate depth statistical areas was assumed to be constant, equal to the average depth distribution observed by VMS during 2004-2009. Details of the hindcasting methodology can be found in Applegate (2010).

Hindcast and model based estimates of offshore hake landings were an order of magnitude greater than that reported by dealers. Landings rose from 951 mt in 1955 (7.0% of the total) to 24,189 mt in 1965 (8% of the total). Offshore hake as a proportion of total hake landings ranged from 2% in 1971, 1976, 1978-1980 to 13% in 1988 and 1996 (Tables D18a-b).

Relative to the length-based approach, the results from the depth-based method for allocating silver hake catches were very similar (<1 – 14% relative difference). Conversely, offshore hake estimates showed substantial differences between both methods. However, these differences are more noticeable on a relative scale because offshore hake consists of a small fraction of the total hake catches (Figure D10).

For assessment purposes, the Working group felt that the length-based estimator was more suitable because of the shorter period in hindcasting analyses. The group also felt that the small differences between the methods for silver hake estimates are likely not to influence assessment model results.

The resulting offshore hake landings for the two methods are given in Tables D18a-b and Figures D11-12. On average, the two methods gave slightly different results, with the length-based model averaging 7% silver hake while the depth-based method averaged 4% silver hake.

**Commercial Fishery Discards**

Discard estimates were calculated in this assessment. The ratio-estimator used in this assessment is based on the methodology described in Rago et al. (2005) and updated in Wigley et al. 2007. It relies on a d/k ratio where the kept component is defined as the total landings of all species within a "fishery". A fishery is defined as a homogeneous group of vessels with respect to gear type (longline, otter trawl, shrimp trawl, sink gill net, and scallop dredge), quarter, and area fished (GOM-NGBK, SGBK-MA), and for otter trawls, mesh size (<= 5.49", > = 5.5 "). All trips were included if they occurred within this stratification regardless of whether or not they caught hakes.

The discard ratio for hakes in stratum h is the sum of discard weight over all trips divided by sum of kept weights over all trips:

$$\hat{R}_h = \frac{\sum_{i=1}^{n_h} d_{ih}}{\sum_{i=1}^{n_h} k_{ih}} \qquad (1)$$

where $d_{ih}$ is the discards for hakes within trip i in stratum h and $k_{ih}$ is the kept component of the catch for all species. $R_h$ is the discard rate in stratum h. The stratum weighted discard to kept ratio is obtained by weighted sum of discard ratios over all strata:

$$\hat{R} = \sum_{h=1}^{H} \left( \frac{N_h}{\sum_{h=1}^{H} N_h} \right) \hat{R}_h \qquad (2)$$

The total discard within a strata is simply the product of the estimate discard ratio R and the total landings for the fishery defined as stratum h, i.e., $D_h = R_h K_h$. Cells with < three trips were imputed using annual averages by gear type and region. To hind-cast the discards to 1981 (the first year in which there was no industrial fishery), discards/total landings by half year for the first three years (1989-1991 for otter trawl, sink gill net, and shrimp trawl; 1992-1994 for longline and scallop dredge) were averaged and the rate applied to the total landings from the dealer database. For the otter trawl fisheries, the mesh sizes were combined for the hind-cast.

Discards from the longline and sink gill net fishery were minimal for silver and offshore hake in both stock areas (Table D19-D22). Discards from the otter trawl fisheries have been significant and variable for silver hake.

The same problem with species identification that exists in the landings is found in the FOP data. There are discards of offshore hake estimated for the north. The geographical distribution of offshore hake is limited to the southern stock of silver hake and therefore, any discards from the northern stock (Tables D19) are considered to be silver hake. In order to estimate discards of offshore hake from the southern region, only one of the alternative methods was employed.

The observer discard length samples of silver and offshore hake were combined by stock (Tables D23-D26). Enough length samples were available for large and small mesh otter trawls in both regions and sink gill net and shrimp trawl in the north. Pooling over years was still required to get an adequate number of fish (Table D27-D28). The length-weight equations by season from Wigley et al 2003 were applied to the samples and used to estimate the landings numbers at length for each market category. The discards-at-length were raised to the total discards including all the gear types to account for as much of the removals as possible.

For the southern stock, length compositions for each species were estimated for the spring and fall surveys from 1968-2009. The species length-weight equations were then applied to determine weight-at-length by species. The proportions at length by species for both number and weight were applied to the commercial discards-at-length to estimate discards-at-length by species. The lengths had to be grouped into intervals to avoid zero cells in the survey. To hind-cast the species proportions back to 1981, the average proportion of offshore hake for the time series was used and applied to the total silver hake discards (Table D29).

***TOR 2. Characterize the survey data being used in the assessment (e.g., regional indices of abundance, recruitment, age-length data, etc.). Describe uncertainty in these sources of data.***

**Data Source:** The primary sources of biological information for offshore hake are based on the annual fishery independent surveys conducted by the Northeast Fisheries Science Center (NEFSC). The surveys were conducted using a random stratified sampling design which allocates samples relative to the size of the strata, defined by depth. The NEFSC have conducted both spring and fall bottom trawl surveys off the US continental shelf annually since 1963. The surveys extend from the Gulf of Maine to Cape Hatteras, in offshore waters at depths 27-365 meters, and have been conducted in the fall since 1963 and in the spring since 1968. The winter bottom trawl survey began in 1992 and was specifically designed for flatfish, however, the deeper survey strata were not sampled until 1998 (Figure D1). The winter trawl survey does not cover the Georges Bank area because the survey was designed specifically for flatfish in the southern region. Details on the stratified random survey design and biological sampling methodology may be found in Grosslein (1969), Azarovitz (1981) and Sosebee and Cadrin (2006).

Survey analysis suggests that offshore hake are distributed within the narrow band of the outer continental shelf from southern Georges Bank to the Mid-Atlantic region (strata 3-4, 7-8, 11-12, 14-15, 17-18, 63-64, 67-68, 71-72, and 75-76). There are seasonal differences in the patterns of distribution with concentrations shifting south of Georges Bank in the winter months and extending to the southern flank of Georges Bank and further south in the spring (Figures D2-4).

**Transform:** Survey estimates were computed using both delta transformation and arithmetic means for numbers and weight. The Whiting Plan Development Team (PDT) has used the delta mean for assessing stock status. The delta transformation uses only the positive tows for log transformation:

$$\hat{M}_\delta = \begin{cases} \frac{m}{n} e^{\bar{y}} \psi_m\left(\frac{1}{2}s_y^2\right) & m > 1, \\ \frac{1}{n}x_1 & m = 1, \\ 0 & m = 0 \end{cases}$$

$$m = \text{number of non-zero tows}$$
$$n = \text{total number of tows}$$

$$\hat{V}_\delta = \begin{cases} \frac{m}{n} e^{2\bar{y}} \left[\psi(2s_y^2) - \frac{m-1}{n-1}\psi_m\left(\frac{m-2}{m-1}s_y^2\right)\right] & m > 1, \\ \frac{1}{n}x_1^2 & m = 1, \\ 0 & m = 0 \end{cases}$$

Examination of the differences between the delta and arithmetic means revealed that use of the delta transformation did not reduce the variability of the survey (Figure D13). If a survey has a high variance, the back-transformation may be biased high (see Silver Hake Assessment). The delta transformation was also more sensitive to the handling of missing weights. Prior to 2001, the data for weights were recorded to the nearest 0.1 kg and if a tow contained only a single small fish, the weight was entered into the data as zero. Since the delta transform uses the positive tow, how this is handled has an impact on the result. There are three options: taking out the zeros, leaving in the zeros, and filling in zeros using a length-weight equation. Since these options did not affect the arithmetic as much as the delta mean, the decision was made to use the arithmetic and length-weight options for any new analyses (Figure D14).

**Calibration:** In 2009 the *NOAA SHIP Henry B. Bigelow* replaced the *R/V Albatross IV* as the primary vessel for conducting spring and fall annual bottom trawl surveys for the Northeast Fisheries Science Center (NEFSC). There are many differences in the vessel operation, gear, and towing procedures between the new and old research platforms (NEFSC Vessel Calibration Working Group 2007). To merge survey information collected in 2009 onward with that collected previously, we need to be able to transform indices (perhaps at size and age) of abundance from the *Henry B. Bigelow* into those that would have been observed had the *Albatross IV* still been in service. The general method for merging information from these two time series is to calibrate the new information to that of the old (Pelletier 1998). Specifically we need to predict the relative abundance that would have been observed by the *Albatross IV* ($\hat{R}_A$) using the relative abundance from the *Henry B. Bigelow* ($R_B$) and a "calibration factor" ($\rho$),

$$\hat{R}_A = \rho R_B . \qquad (4)$$

To provide information from which to estimate calibration factors for a broad range of species, 636 paired tows were conducted with the two vessels during 2008. Paired tows occurred at many stations in both the spring and fall surveys. Paired tows were also conducted during the summer and fall at non-random stations to improve the number of non-zero observations for some species. Protocols for the paired tows are described in NEFSC Vessel Calibration Working Group (2007).

The methodology for estimating the calibration factors was proposed by the NEFSC and reviewed by a panel of independent scientists in 2009. The reviewers considered calibration factors that could potentially be specific to either the spring or fall survey (Miller et al. 2010). They recommended using a calibration factor estimator based on a beta-binomial model for the data collected at each station for most species, but also recommended using a ratio-type estimator under certain circumstances and not attempting to estimate calibration factors for species that were not well sampled. In the case of offshore hake, the Working Group decided that using silver hake calibration factors as a proxy was better than not using any calibration factors.

Since the review, it has become apparent that accounting for size of individuals can be necessary for many species. When there are different selectivity patterns for the two vessels, the fraction of available fish of a given size taken by the two gears is different. Therefore, the ratio of the mean catches by the two vessels will change with size. Under these circumstances, the estimated calibration factor that ignores size reflects an average ratio weighted across sizes where the weights of each size class are at least in part related to the number of individuals at that size and the number of stations where individuals at that size were caught. Applying calibration factors that ignore size effects to surveys conducted in subsequent years when the size composition is unchanged should not produce biased predictions (eq. 1). However, when the size composition changes, the frequency of individuals and number of stations where individuals are observed at each size changes and the implicit weighting across size classes used to obtain the estimated calibration factor will not apply to the new data. Consequently, the predicted numbers per tow that would have been caught by the *Albatross IV* will be biased.

Calibration coefficients for silver hake were used because an insufficient number of offshore hake were captured during calibration studies to derive a coefficient for offshore hake. For silver hake, a suite of beta-binomial models were fit that made different assumptions on the relationship of the calibration factor to length. The models ranged from those that were constant with respect to length to logistic and double-logistic functions of length. A season-specific model was chosen based on $AIC_c$ for silver hake by the working group where a logistic functional form for the spring and a double-logistic form for the fall provided the best fit (Table D30, Figure D15). Refer to the silver hake chapter of this NEFSC CRD for more details.

**Survey Data Results:** Swept Area abundance and biomass were calculated by using swept area conversions of 0.0112 for the NEFSC fall and spring surveys and 0.0131 for the NEFSC winter survey. A three-year moving average was calculated for the arithmetic means and swept area abundance and biomass for the fall and spring surveys in order to smooth out the variability of the surveys (Tables 31-32).

The fall survey stayed rather stable with similar trends to the spring survey in the late 1970s and early 1980s. The highest swept area biomass was in 1981, with 577 metric tons. It sharply declined to 17 metric tons in 1982. It stayed fairly low until 2001 and 2003, where the biomass was over 100 metric tons. 2009 has a 28% increase over 2008, with 56 metric tons (Table D34, Figure D17).

The spring survey was low in the early part of the time series and increased steadily to a record high in 1980 at 1,886 metric tons. Like the fall survey, the spring survey then had a sharp decline to 336 metric tons. It has continued to decline, with its lowest value in 2006 at 10 metric tons. It has since increased from 2006 to 30 metric tons (Table D36, Figure D19).

The winter survey abundance and biomass have varied substantially over the entire time series (1998-2007) with no trend (Table D38, Figure D21). Survey catches are highly variable but the trends in the spring and fall are similar. The higher catchability in the winter survey can be explained by the net configuration (i.e. smaller cookies) specifically designed to target flatfish.

**Age Data:** Growth parameters were calculated from the survey data using the Von Bertalanffy growth equation:

$$L(t) = L\infty * (1 - exp(-k * t - t0))$$

There are 55 ages that were aged by the NEFSC that were used in this analysis. The lengths range from 13cm to 45cm, with ages 1-5. The ages are considered preliminary since there is no published ageing study in the Northwest Atlantic and were based on the same ageing criteria for silver hake. The growth equation with an $L_\infty$ value set to 70cm resulted in a k value of 0.174.

**Length Data:** Survey length distributions for offshore hake in the spring and the fall do not show any clear modes and were difficult to interpret due to very low sample sizes. However, the general trend indicates that majority of the catches range between 20-40 cm in the fall and spring with very few fish greater than 40 cm. Despite, the higher sampling in the winter survey, the trends in the length distribution remain similar to the fall and spring (Table D39, Figures D22-24). To improve sampling intensity and trends in the length distribution, a three year moving average was calculated for the fall and the spring surveys and there were still no clear trends in the length distributions (Figures D25-26).

***TOR 3. Estimate measures of annual fishing mortality, recruitment and stock biomass for the time series, and characterize the uncertainty of those estimates.***

Application of Survival Estimation in Non-Equilibrium Situations (SEINE) to Offshore hake

***SEINE Method***

Gedamke and Hoenig (2006) developed a method to estimate mortality from mean length data in nonequilibrium situations, now called Survival Estimation in Non-Equilibrium Situations Model (SEINE, available at http://nft.nefsc.noaa.gov/). It is an extension of the Beverton-Holt length-based mortality estimator that assumes constant recruitment throughout the time series and mortality at fixed levels for certain periods within the time series. The approach allows for the transitory changes in mean length to be modeled as a function of mortality rate changes. After an increase in mortality, mean length will gradually decrease due to larger animals being less prevalent in the population. After a decrease in mortality, mean length will increase slowly due to growth of the fish in the population. The rates of change in both cases depend on the von Bertalanffy growth parameters and the magnitude of change in the mortality rates. Since the method requires only a series of mean length above a user defined minimum size and the von Bertalanffy growth parameters, it can be applied in many data poor situations. Gedamke and Hoenig (2006) demonstrated the utility of this approach using both simulated data and an application to data for goosefish caught in the NEFSC fall groundfish survey.

The SEINE model requires the growth parameters, $L_\infty$ and k. It also requires mean lengths and sample size (Table D40). Since there are no accepted growth parameters for offshore hake, we used an average of Southern Georges Bank and Southern New England silver hake growth parameters ($L_\infty = 43.91$ and $k = 0.33$) for Lcritical values of 20cm as a base model. We varied the Lcritical values to 17cm and 23cm. The three mortality cut points (17cm, 20cm, and 23cm) were chosen because it is synonymous with fishable biomass.

Sensitivity analyses were run for the fall survey only, as the working group thought one season would be sufficient and it had the best likelihood value compared to the spring. Winter has too short of a time series. The model was run with higher and lower growth parameters at the different cut points. Silver hake growth parameters for the Southern Georges Bank ($L_\infty$ = 43.78 and k = 0.28) and Southern New England ($L_\infty$ = 44.04 and k = 0.37) alone were used. Using the preliminary offshore hake ages, von Bertalanffy growth parameters ($L_\infty$ = 70 and k = 0.174) were estimated, and used in the SEINE model as part of the sensitivity analyses (Tables D41-42, Figure D27).

We set $L_\infty$ to 70cm, as it corresponded with the largest offshore hake seen in both the NEFSC and Canadian DFO surveys. When it wasn't set, Solver gave an $L_\infty$ result of 274cm, which is completely infeasible. The model results showed that using the offshore hake estimated growth parameters at 20cm were the best fit. They had the lowest AIC and likelihood values and realistic z values of all the runs completed.

The model includes an assumption of flat-topped selectivity. The working group felt that there is no correspondence between the mortality rate and the catch (Figures D28-34). For example, in the 1970s, when landings increased substantially, total mortality apparently decreased. Subsequently, when catch declined, mortality increased. Therefore, the results from SEINE are not a reliable basis for management.

Application of An Index Method (AIM) Model to Offshore Hake

***AIM Method***

The AIM model is a simple approach for examining the relationship between survey data and catch in data poor stock assessments. AIM is designed to address the question of whether a given rate of fishing mortality is likely to increase or decrease the population size. Survey data are used to define a relative rate of increase and the ratio of catch to survey indices provides a measure of relative fishing mortality. Theoretically the model can identify a stable point about which the stock will neither increase nor decrease in response to a fixed harvest rate. The model assumes that the resource dynamics are approximately linear with relatively minor influence of density dependent effects or variable environmental or ecological factors. Such conditions often typify stocks that have been historically harvested at high fishing rates and are therefore at low population sizes. AIM is both an analytic and graphing approach. The analytical methods can be used to define relative Fs for replacement and the graphical methods can be used to identify transient conditions that are relevant to implementation of any model. The details of the methodology are described below.

- ✓ Population biomass at time t can be written as a linear combination of historical population biomasses
- ✓ Recruitment is proportional to population biomass
- ✓ Fishing mortality is proportional to catch divided by an index of population size (relative F).
- ✓ The rate of change in population biomass is a monotonically decreasing function of relative F.
- ✓ Smoothing methods can be used to identify underlying trends.
- ✓ Randomization methods can be used to develop sampling distributions of test statistics
- ✓ Graphical methods can help identify linkages among variables

Relative F is defined as the ratio of catch to an index of population abundance. A three-year centered average of the abundance index is chosen as the measure of average stock size.

$$relF_{j,s,t} = \left( \frac{C_{s,t}}{\frac{I_{j,s,t-1} + I_{j,s,t} + I_{j,s,t+1}}{3}} \right) \quad (1)$$

Where $relF_{j,s,t}$ = relative F for relative index j for stock s at time t
$C_{s,t}$ = catch or landings of stock s at time t (in units of weight)
$I_{j,s,t}$= Index of abundance j for stock s at time t expressed in terms of average weight per tow

The population size at any given time can be viewed as a weighted sum of previous recruitment events. For a population with a maximum age of A years, the population in year t consists of the recruits from year t-1, t-2, …t-A. At high levels of total mortality, the contributions from the earliest recruitments, say t-k-1 to t-A will diminish in importance such that the population can be viewed as the sum of recruitments from t-1 to t-k years.

Using the linearity assumption defined above, we can employ basic life history theory to write abundance at time t as a function of the biomasses in previous time periods. The number of recruits at time t ($R_t$) is assumed to be proportional to the biomass at time t ($B_t$). More formally,

$$R_t = S_o \, Egg \, B_t \quad (2)$$

where **Egg** is the number of eggs produced per unit of biomass, and $\mathbf{S_o}$ is the survival rate between the egg and recruit stages. Survival for recruited age groups at age a and time t ($S_{a,t}$) is defined as

$$S_{a,t} = e^{-F_{a,t} - M_{a,t}} \quad (3)$$

where F and M refer to the instantaneous rates of fishing and natural mortality, respectively. We also need to consider the weight at age a and time t ($W_{a,t}$) and the average longevity (A) of the species

Using these standard concepts we now write the biomass at time t as a linear combination of the A previous years. Without loss of generality, we can drop the subscripts on the survival terms and assume that average weight at age is invariant with respect to time. Further, set the product $S_o$ Egg equal to the coefficient α. The biomass at time t can now be written as

$$B_t = R_{t-1} S^1 W_1 + R_{t-2} S^2 W_2 + R_{t-3} S^3 W_3 + .. + . R_{t-(A-1)} S^{A-1} W_{A-1} + R_{t-A} S^A W_A \quad (4)$$

Substituting Eq. (2) into Eq. (4 ) leads to

$$B_t = \alpha B_{t-1} S^1 W_1 + \alpha B_{t-2} S^2 W_2 + \alpha B_{t-3} S^3 W_3 + .. + .\alpha B_{t-(A-1)} S^{A-1} W_{A-1} + \alpha B_{t-A} S^A W_A \quad (5)$$

If the population is replacing itself, then the left hand side of Eq. 5 will equal the right hand side. The replacement ratio can then be defined as

$$\Psi_t = \frac{B_t}{\alpha B_{t-1} S^1 W_1 + \alpha B_{t-2} S^2 W_2 + \alpha B_{t-3} S^3 W_3 + .. + .alphaB_{t-(A-1)} S^{A-1} W_{A-1} + \alpha B_{t-A} S^A W_A} \quad (6)$$

Substituting observed values of abundance indices into Eq 6 leads to

$$\Psi_t = \frac{\frac{I_t}{q}}{\alpha \frac{I_{t-1}}{q} S^1 W_1 + \alpha \frac{I_{t-2}}{q} S^2 W_2 + \alpha \frac{I_{t-3}}{q} S^3 W_3 + .. + \alpha \frac{I_{t-(A-1)}}{q} S^{A-1} W_{A-1} + \alpha \frac{I_{t-A}}{q} S^A W_A} \quad (7)$$

By noting that the q's cancel out, and letting $\varphi_j = \alpha S^j W_j$ , Eq. 6 simplifies to

$$\Psi_t = \frac{I_t}{\sum_{j=1}^{A} \phi_j \quad I_{t-j}} \qquad (8)$$

All of the $I_t$ and $\varphi_j$ are positive, and at equilibrium $I_t = I_{t+1}$ and $I_t = \sum \varphi_j I_{t-j}$ both hold . Therefore $\sum \varphi_j = 1$. When the population is not at equilibrium the parameter $\Psi$ becomes a measure of the non equilibrium state of the population and a measure of whether the population is increasing or decreasing relative to prevailing fishery and ecosystem conditions.

It would be desirable to express the parameters of $\varphi_j$ weighting terms as function of the underlying parameters. Analyses of other stocks with more detailed information, such as Georges Bank haddock, has suggested that setting the $\varphi_j$ to 1/A is a reasonable approximation. Equations 2 to 8 are a long way of justifying that the ratio of current stock size to a moving average of the previous A years of stock size can be used as a measure of population growth rate. This ratio embeds some life history theory into the basis for the ratio and simultaneously provides a way of damping the variations in abundance owing to measurement error. A ratio defined as $I_t/I_{t-1}$ has been found, as expected to be much more noisy measure of population change.

Further details on the AIM methodology may be found in Working Group (2002) and the NOAA

Fisheries Toolbox (NFT) 3.1 (2010a) software package http://nft.nefsc.noaa.gov/AIM.html. The relationship between $\mathbf{\Psi_t}$ and $\mathbf{relF_t}$ can be expressed as

$$\ln(\Psi_t) = a + b\ln(relF_t) \quad (9)$$

The usual tests of statistical significance do not apply for the model described in Eq. 9. The relation between $\mathbf{\Psi_t}$ and $\mathbf{relF_t}$ is of the general form of Y/X vs X where X and Y are random variables. The expected correlation between Y/X and X is less than zero and is the basis for the oft stated criticism of spurious correlation. To test for spurious correlation we developed a sampling distribution of the correlation statistic using a randomization test. The randomization test is based on the null hypothesis that the catch and survey time series represent a random ordering of observations with no underlying association. The randomization test was developed as follows:

1. Create a random time series of length $\mathbf{T}$ of $\mathbf{C_{r,t}}$ from the set $\{\mathbf{C_t}\}$ and $\mathbf{I_{r,t}}$ from the set $\{\mathbf{I_t}\}$ by sampling with replacement.

2. Compute a random time series of relative F ($\mathbf{relF_{r,t}}$) and replacement ratios ( $\mathbf{\Psi_{r,t}}$ )
3. Compute the r-th correlation coefficient, say $\boldsymbol{\rho_r}$ between ln($\mathbf{relF_{r,t}}$) and ln( $\mathbf{\Psi_{r,t}}$ ).
4. Repeat steps 1 to 3 K times.
5. Compare the observed correlation coefficient $\mathbf{r_{obs}}$ with the sorted set of $\boldsymbol{\rho_r}$
6. The approximate significance level of the observed correlation coefficient $\mathbf{r_{obs}}$ is the fraction of values of $\boldsymbol{\rho_r}$ less than $\mathbf{r_{obs}}$

It should be emphasized that relF is not necessarily an adequate proxy for Fmsy, since this parameter only estimates the average mortality rate at which the stock was capable of replacing itself. Thus, while relF defined as average replacement fishing mortality is a necessary condition for an $F_{msy}$ proxy, it is not sufficient, since the stock could theoretically be brought to the stable point under an infinite array of biomass states. The relF at replacement does however provide some guidance on the contemporary rate of harvesting and its potential impact on future stock abundance.

***Application of AIM to Offshore Hake***

AIM was applied to offshore hake using catches derived from the method of Sosebee, and the NEFSC fall and spring bottom trawl survey indices (Table D43). Relative F was defined as the ratio of catch to a centered 3-year average of survey abundance (Eq. 1) and the replacement ratio was defined as a 5-year moving average of previous stock sizes (Eq. 8). The relationship between catch, survey, relative F and the replacement ratio for the fall and spring survey indices are depicted in Figs. D35 and D36, respectively. Neither of the randomization tests resulted in significant statistical relationship between the replacement ratio and relative F (Table D44).

Bootstrap estimation of the relative F at replacement were imprecise (Table D44, Figure D37) and may not be appropriate measures of Fmsy proxies. Graphical results suggest some underlying causes for the absence of a strong statistical relationship. Relative F has been declining continuously for the fall index (Figure D35). For the spring (Figure D36) survey indices relative F declined through the mid 1980 rebounded for a decade and then declined again from the late 1990s onward. Fall and spring survey trends suggest high abundance before 1980 but much lower values (about one order of magnitude) since then. Replacement ratios for offshore hake in the fall survey have been generally below one since 1980 (Figure D35). The spring survey is slightly different with a brief excursion above 1.0 in the late 1990s followed by a general decline since 2001. Catch rates for offshore hake in both surveys is generally low, perhaps reflecting low abundance, low gear efficiency or both factors. Low gear efficiency can make the detection of trends difficult.

The relationship between survey abundance and relative F suggest a temporal trend wherein reductions in relative F do not necessarily induce similar increases in relative abundance (Figure D35 and D36--left middle panel). At a minimum these stanzas suggest major changes in the population abundance indices and exploitation rates. It is not possible from these data alone to identify causal factors but it does suggest that more advanced modeling if possible, will need to account for these changes in apparent productivity and/or natural mortality.

Survey exploitation indices were calculated using the swept area biomass for the fall, spring, and winter surveys, using the length-based total catch (Table D45, Figures 38-40). It was also calculated using the length-based landings, but the Working group decided that the catch was more accurate due to it being total removals (Table D45, Figures 41-43).

***TOR 4. State the existing definitions for overfished and overfishing. Then 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.***

**Existing BRPs**

The current overfishing definition is that:

> offshore hake is in an overfished condition when the three year moving average weight per individual in the fall survey falls below the 25th percentile of the average weight per individual from the fall survey time series 1963-1997 (0.236) **AND** when the three year moving average of the abundance of immature fish less than 30 cm falls below the median value of the 1963-1997 fall survey abundance of fish less than 30 cm (0.33) (NEFMC 2003).

In previous SAFE Reports, the WMC noted problems associated with this overfishing definition. Although the current definition is intended to identify overfished (i.e. low biomass) stock conditions, it is a better indication of overfishing (high exploitation rate). The WMC recommended that the overfishing definition for offshore hake be revisited.

The Hake Working Group noted that the survey data may not be a good index of abundance but may be driven more by the environment. Therefore, the existing BRPs should not be accepted, and no alternative reference points are recommended by SAW/SARC51.

***TOR 5. Evaluate stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from Offshore hake TOR 4).***

Based on current biological reference points, offshore hake (Figure D44,Table 46) is not overfished and overfishing is unknown. The three year delta individual mean weight index (Figure D44, Table 46), based on NEFSC fall bottom trawl survey data for 2007-2009 (0.16 kg/individual), is below the management threshold (0.24 kg/individual) but the three year average recruitment index (0.89 num/tow) is above the threshold value (0.33 num/tow).

Based on the SAW/SARC51 review, stock status is unknown.

***TOR 6. If a model can be developed, conduct single and multi-year stock projections and for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs).***

- ***a. Provide numerical short-term projections (3 years). 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 about the most important uncertainties in the assessment***
- ***b. Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.***
- ***c. Describe this stock's vulnerability to becoming overfished, and how this could affect the choice of ABC.***

No model could be developed. Therefore, this term of reference could not be completed.

***TOR 7. Propose new research recommendations.***

- Studies to estimate discard mortality should be conducted.
- As an alternative to using silver hake calibration coefficients, it may be better to explore depth-based survey calibration coefficients.
- Develop explicit process and criteria for the application of length-based (vs. constant) calibration coefficients (other than purely statistical criteria such as AIC, etc.). It may be useful, if enough data exist, to attempt a cross validation with a subset of data.
- Investigate silver and offshore hake data in deepwater surveys (e.g., monkfish survey).
- Information on consumption by more predators (including mammals, highly migratory species (HMS)) needs to be included.
- Examine diel (day/night) variation in consumption of hakes.
- Identify offshore hake otoliths found in predators' stomachs.
- Validation of the ageing method for offshore hake via tagging, radiocarbon, or tetracyclin research needs to be conducted.
- The extent of the stock covered by the NEFSC needs to be examined.
- Perform a stock reduction analysis.

**Sources of Uncertainty**

- It appears that the fishery as estimated by either the length-based model or the depth-based model has not had an impact on the stock. The mortality estimates from the SEINE model are in direct contrast to the catch data. Developing ACLs will also be challenging given that the landings are not separated to a great extent. Garcia-Vazquez et al (2009) found 12% of hake sold in Spain as silver hake were actually offshore hake.
- Given that the distribution of offshore hake in the NEFSC survey is very close to the edge of the survey range, the survey index may be more driven by environmental factors than abundance. The survey likely does not cover the entire stock area and therefore, the survey estimates could potentially be under-representing the dynamics of the population.

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