A. ASSESSMENT OF SILVER HAKE

EXECUTIVE SUMMARY

1) Overfishing definitions and biological reference points used in this assessment for the northern and southern stocks of silver hake are based on trends in three-year moving averages of fall survey biomass indices (delta mean kg/tow) and three-year averages of exploitation indices (landings / fall survey biomass index).

2) The biological reference points based on exploitation indices are new since the last assessment. They were developed during the interim by the New England Council's Whiting Monitoring Committee because fishing mortality estimates were not estimated for whiting in the last assessment and because it was not possible to use the original fishing mortality based reference points ($F_{0.1}$) in Amendment 12. The Whiting Monitoring Committee's proposal is a typical approach that was based on the original reference points to the extent possible. The new biological reference points were reviewed for this assessment and used because fishing mortality rates could not be estimated in this assessment either.

3) The northern stock of silver hake is not overfished and overfishing is not occurring. In particular, the three year average biomass index for 2002-2004 (6.72 kg/tow) was above the management threshold level (3.31 kg/tow) and near the target level (6.63 kg/tow). The three year average exploitation index for 2002-2004 (0.24) was below the management threshold and target level (2.57). The target and threshold reference points for defining overfishing in the northern stock are identical. The northern stock of silver hake was not overfished based on results from the last assessment (NEFSC 2001). Overfishing was not evaluated in the last assessment because fishing mortality rates were not estimated.

4) Based on current reference points, the southern stock of silver hake is not overfished and overfishing is not occurring. In particular, the three year average biomass index for 2002-2004 (1.37 kg/tow) was above the management threshold level (0.89 kg/tow) but below the target level (1.78 kg/tow). The three year average exploitation index for 2002-2004 (4.85) was below the management threshold level (34.39) and below the management target level (20.63). The southern stock of silver hake was overfished based on results from the last assessment (NEFSC 2001). Overfishing was not evaluated in the last assessment because fishing mortality rates were not estimated. The change in status is due to increases in stock biomass indices for the southern stock of silver hake.

5) The southern stock of silver hake was overfished based on results from the last assessment (NEFSC 2001). The change in status is due to increases in stock biomass indices for the southern stock of silver hake.

6) (EDITOR'S NOTE: THIS PART OF THE WORKING GROUP REPORT HAS BEEN OMITTED. IT WAS NOT ACCEPTED BY THE REVIEW PANEL.)

7) Fall survey recruitment indices show variable but generally increasing trends in the northern stock area since 1967. In the southern stock area, recruit and fishable biomass during fall surveys varied without trend.

8) Coast wide silver hake landings were less than 10 thousand mt per annually after 2002. During 2001-2004, coast wide silver hake discards averaged about 4000 mt y^{-1} (CV 17%) with at least 1,600 mt y^{-1} in the north and 2000 mt y^{-1} in the south on average during 2001-2004.

9) The most important uncertainties in management stem from clearly decreasing trends in abundance of relatively old and large individuals, despite low fishing mortality rates and relatively high biomass levels during recent years. Declines in abundance and occurrence of relatively old silver hake appear real and not due entirely to age reader errors, misidentification of offshore hake in surveys, or slower somatic growth. There is evidence of northward and offshore shifts in average location that may make relatively old and large silver hake less available to bottom trawl surveys. The possibility of increased natural mortality rates due to predation is a key area for future research.

10) Total allowable landings (TAL) for 2005 were calculated based on fall survey data through 2004 and exploitation index reference points. For the northern stock area during 2005, where the target and threshold reference points are the same, TAL < 17.3 mt. For the southern stock area during 2005 and based on the target reference point, TAL=28.3 mt. For comparison, annual landings averaged 1.71 thousand mt in the north and 6.65 thousand mt in the south during 2002-2004.

11) Stock projections were not carried out but stock biomass levels are relatively high. Fishing mortality rates are very low in the north and probably low in the south also. Recent recruitments have been roughly average. Significant declines in stock biomass due to fishing are unlikely in the short term.

1.0 TERMS OF REFERENCE:

1. Characterize the commercial and recreational catch including landings and discards.

Recreational landings of silver hake were not estimated in this assessment but are minor based on estimates in the last assessment (Brodziak et al. 2001).

Discards were estimated in this assessment.

2. Estimate fishing mortality, spawning stock biomass, and total stock biomass for the current year and characterize the uncertainty of those estimates. If possible, also include estimates for earlier years.

(EDITOR'S NOTE: THIS PART OF THE WORKING GROUP REPORT HAS BEEN OMITTED. IT WAS NOT ACCEPTED BY THE REVIEW PANEL.)

3. Evaluate and either update or re-estimate biological reference points, as appropriate.

Reference points proposed by the New England Fishery Management Council's Whiting Monitoring Committee and used in overfishing definitions for silver hake during recent years were reviewed and used in this assessment.

4. As needed by management, estimate a single-year or multi-year TAC and/or TAL by calendar year or fishing year, based on stock biomass and target mortality rate.

TAL levels were calculated based on fall survey data through 2004 and exploitation index reference points.

5. If possible,

a. provide short term projections (2-3 years) of biomass and fishing mortality rate, and characterize their uncertainty, under various TAC/F strategies and
b. evaluate current and projected stock status against existing rebuilding or recovery schedules, as appropriate.

Based on a qualitative analysis, significant declines in stock biomass due to fishing are unlikely in the short term. It was not possible to carry out quantitative projection analyses.

6. Review, evaluate and report on the status of the SARC/Working Group Research Recommendations offered in previous SARC-reviewed assessments.

This information is provided at the end of the stock assessment report.

2.0 INTRODUCTION

Silver hake (*Merluccius bilinearis* or "whiting") range from Newfoundland to South Carolina and are most abundant between Nova Scotia to New Jersey (Figure A1; Collette and Klein-MacPhee 2002). Silver hake are found over a broad range of depths ranging from shallow coastal areas to the continental slope. The offshore limit of habitat of silver hake habitat on the continental slope is uncertain but the species ranges to at least 400 m depth (Collette and Klein-MacPhee 2002). Silver hake are found in midwater as well as on the bottom but the extent to which they use the water column as habitat is unknown because most of the available information comes from bottom trawl gear.

As shown below, adult silver hake (age ≥ 2 y and TL ≥ 20 cm TL) tend to be distributed further offshore and further north than younger, smaller individuals. The size and age at which the offshore and northern shift in distribution occurs are approximately the same as the size and age at sexual maturity. Distribution patterns change seasonally as the adult population moves inshore with warmer water temperatures during the spring and summer to spawn near coastal juvenile habitat areas. Depth appears more important than temperature or season in determining distribution patterns because small individuals remain in shallow coastal areas despite substantial seasonal changes in water temperatures (warm during summer-fall and cool during winter-spring). Similarly, larger individuals remain primarily in deeper water that is relatively warm during winter-spring and cool during summer-fall.

Silver hake are important as predators and prey in the food web of the northeast continental shelf ecosystem (Sissenwine and Cohen 1991). They feed mainly at night (Collette and Klein-MacPhee 2002). Small silver hake (< 20 cm TL) eat euphausids, shrimp, amphipods and decapods. Larger silver hake eat fish (including other silver hake), crustaceans and squid. The shift in diet coincides with the onset of sexual maturity and offshore/north shift in distribution and cannibalism is common.

Two stocks of silver hake are currently assumed in managing the fishery and in stock assessments for silver hake in US waters (Figure A1). The northern stock area includes northern Georges Bank and the Gulf of Maine. The southern stock area includes southern Georges Bank, southern New England, and the Mid-Atlantic Bight. The two stock areas are based on differences in morphology (Almeida 1987), otolith shape (Bolles and Begg 2000), abundance trends, fishery patterns and the apparent break in silver hake habitat at Georges Bank.

Although management and stock assessments have been based on two stocks, silver hake along the northeast coast are likely one population with incomplete mixing between northern and southern areas (Brodziak et al. 2001). Larvae are pelagic and remain in the water column where they circulate freely for 1-5 months before metamorphosing to juvenile form and presumably settling to the bottom at about 1.7-2.0 cm TL (Lock and Packer 2004). North-south movement patterns are not well understood but it is likely, based on results from this assessment, that adults move around Georges Bank seasonally and depending on environmental conditions. The northern and southern stocks of silver hake are probably best viewed as management units.

Silver hake in Canadian waters are abundant enough to support a fishery.[1] The US and Canadian stocks of silver hake are probably linked to some degree and this is an important topic for future research.

The proportion of silver hake minimum swept area biomass in the northern area has varied substantially over time from less than 40% to more than 90% with proportions in the north generally increasing until recently (Figure A2). One of the key questions regarding silver hake is whether the shifts in distribution between the northern and southern areas are due to environmental effects on distribution or relatively high mortality in the southern area (Brodziak et al. 2001).

Silver hake grow rapidly (Figure A3). Growth rates vary over time and among areas but in an inconsistent fashion (Helser 1996; Brodziak et al. 2001). Based on Brodziak et al. (2001), growth has been rapid and almost linear in silver hake during recent years based on Brodziak et al. (2001). However, scarcity of older fish makes growth curves estimated from recent data difficult to compare to growth curves estimated from historic data (Brodziak et al. 2001). Growth and maturity rates may depend on stock biomass (Helser and Brodziak 1998).

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[1] http://www.frcc.ca/2004/SF2004.pdf

Based on data from Canadian waters, growth of males and females is similar up to about 22 cm TL (Collette and Klein-MacPhee 2002), which coincides with the onset of sexual maturity (Figure A4). After sexual maturity, females grow more rapidly and to larger maximum sizes.

Survey age data for silver hake collected during 1973-2005 are from thin sectioned otoliths. Age data for earlier years are from whole otoliths and less reliable. Age reader experiments described in this assessment show that criteria used to age silver age changed during 1973-2005. Historical age estimates are one or two years higher than estimates made recently from the same otoliths. The precision of age estimates decreases for older silver hake. Age data for silver hake are currently being re-audited to remove duplicate records discovered during this assessment.

There is considerable uncertainty about the potential longevity and underlying natural mortality rates silver hake. Brodziak et al. (2001) report that maximum ages observed in NEFSC fall and spring surveys declined from 14 y (corresponding to a natural mortality rate M of about 0.3 y^{-1}, Hoenig 1983) during the mid-1970's to 6 y recently (corresponding to a natural mortality rate of about 0.8 y^{-1}, Figure A5). One of the key questions regarding the stock is whether changes in maximum ages are due to environmental effects on availability of older fish to surveys, increased mortality, age estimation errors, or mis-identification of offshore hake (*M. albidus*).

3.0 THE FISHERY

Silver hake landings (Table 1) increased substantially during the 1960s due to directed fishing for silver hake by distant water fleets operating in US waters (Figure A6). During the 1990s, total silver hake landings were relatively low in comparison to historic values. Silver hake landings declined further to less than 10 thousand mt per year after 2002 (Figure A7).

Landings were almost entirely from the northern area prior to 1964 (Table A1 and Figures A8). After 1964, silver hake landings were mostly from the southern stock area.

Recreational Fishery

Silver hake once supported a recreational fishery in the Mid-Atlantic Bight (Fritz 1960) with annual landings of around 1,000 mt (2.2 million pounds) in the southern stock area. Recreational fishery landings decreased substantially in the 1970s and 1980s and are currently very low. Recreational landings of silver hake averaged only 18,000 fish per year during 1995-1999 (Brodziak et al. 2001).

Commercial Fishery

Directed commercial fishing for silver hake began in the 1920s. The fishery evolved over time from an inshore fishery using pound and trap nets to the modern otter trawl fishery (Fritz 1960; Table A2). The bulk of silver hake landings during recent years were from the southern stock area. In the northern stock area, landings are mostly from the Cultivator shoals, Gulf of Maine and the rest of Georges Bank (Table A2 and Figure A9). In the southern stock area landings are mostly from Southern New England and the Mid-Atlantic Bight (Table A2 and Figure A9). Landings data for years after 1994 are prorated to area of catch based on Vessel Trip Report (VTR) logbook data. Area of catch is identified in records for earlier years based on interviews by port samplers.

Silver hake were landed in six commercial market categories during 1995-2004 including the category "5095 (Large round)" that was new in 2004 (Table A2). Intensity of sampling was measured as number of length measurements divided by metric tons landed (Table A3). Sampling was highest (intensity > 1.5) for the hook & line gear group, gillnet gear group, and for the 5091 (King round) market category.
Length composition data for commercial landings indicate that the fishery has taken smaller silver hake since 1997 and that recruitment to the fishery begins to occur at about 20 cm TL (Figure A10). The shift in commercial length frequencies may be due to management measures, other changes in the fishery, or a change in the silver hake population.

Age composition data for commercial landings from Brodziak et al. (2001) show declines in proportions of older silver hake. Age data are not collected from the commercial fishery but commercial age composition can be inferred based on survey age data and commercial length composition data. Commercial and survey age composition data were not updated for silver hake in this assessment. Survey age data for silver hake used to construct age-length keys are currently being audited and should be ready for use in the next assessment.

Bycatch and Discards

Sea sampling data for 1989-1999 collected by observers on fishing vessels and reviewed by Brodziak et al. (2001) showed that discarding of silver hake captured by otter trawls occurred throughout the northern and southern stock areas. Discarding of silver hake by scallop dredges occurred in both northern and southern stock areas but discarding by sink gill nets occurred primarily in the northern stock area. Discard to kept (DK) ratios by weight (weight of silver hake discarded / weight of species landed) varied through time, ranging from 0% to over 100% for the directed silver hake fishery (small mesh otter trawl, cod end mesh 3" or less) and for the non-directed fisheries (large mesh otter trawl, shrimp trawl, sink gill net, and scallop dredge). Variability in discard ratios may have been due to non-random coverage of the fleet, small sample sizes, or inherent variation in discard rates and practices.

New discard estimates for recent years (2001-2004) in this assessment were based on observer data and a ratio estimator first used for spiny dogfish (*Squalus acanthias*, NEFSC 2003). Estimates in this assessment were for recent years only because observer data coverage has increased in recent years and because recent discards were most important in evaluating the status of the silver hake resource.

The ratio estimator approach has several potential advantages including well defined statistical properties, relative simplicity and objective stratification based on landings data (i.e. it is not necessary to determine target species for tows or trips based criteria that are possibly arbitrary). However, ratio estimators are biased (see below) and the relative merits of discard estimators used in the Northeast (Rago et al. 2005) have not been fully evaluated.

Species groups and gear groups were used to tabulate and stratify observer and "landings" data (landings and hail weights in this analysis were hail weights for individual tows recorded by observers) at the trip level (Tables A4-A6). The species groups and gear groups used for silver hake were similar to the groups used for spiny dogfish (NEFSC 2003) with some modifications. All species potentially landed were assigned to a species group and all potential gear types are assigned to a gear group.

In the first step, kept (and presumably landed) weight $K_{G,S,T}$ is tabulated for each trip (T) in the observer database by species group (S) and gear group (G). Information about total silver hake discards on each trip ($D_{G,S,T}$) is retained but information about discard of other species is not. At the end of the first step, there is one record for each observed trip. The record contains total silver hake discards (which may be zero) and landings in each of the species groups. The sum of landings for all species groups equals total landings for the trip.

In the second step, the primary species group is determined based on the species group with highest landings. The secondary species group with second highest landings is used for diagnostic plots and identified as well (Rago et al. 2005). At the end of the second step, there is one record for each trip that contains the total silver hake discard, variables that identify the primary and secondary species group, a variable that identifies the gear group, and landings in the primary and secondary species groups.

The third step is to calculate DK ratios for each species group and gear group using the ratio estimator:

$$R_{G,S} = \frac{\sum_T D_{G,S,T}}{\sum_T K_{G,S,T}}$$

where $R_{G,S}$ is the DK ratio. The variance of the ratio estimator (Cochran 1977) is approximately:

$$Var(R_{G,S}) = \frac{Var(D_{G,S}) + R_{G,S}^2 Var(K_{G,S}) - 2R_{G,S}Cov(D_{G,S}, K_{G,S})}{n\overline{K}_{G,S}^2}$$

As shown in Cochran (1977) the ratio estimator is biased with:

$$bias = -\frac{Cov(R,\overline{K})}{\overline{k}} = -\frac{\rho \sigma_R \sigma_{\overline{L}}}{\overline{k}}$$

where $\overline{K}$ is average landed weight estimated from observer data and $\overline{k}$ is the true (unknown) value. Note that the absolute value of the bias increases with the variance and correlation in R and $\overline{K}$. It is therefore advantageous, in terms of minimizing both bias and variance, to pool data and choose primary species groups and gear groups that minimize the variance in these quantities.

In the final step, total landings in weight ($L_{G,S}$, based on dealer records) is calculated for each species gear and gear group. Total discard (Λ) is:

$$\Delta = \sum_G \sum_S L_{G,S} R_{G,S}$$

Assuming that landings are measured without error, the variance is:

$$Var(\Delta) = \sum_G \sum_S L_{G,S}^2 Var\left(R_{G,S}\right)$$

For silver hake in this assessment, observer data for 2001-2004 were pooled to estimate one set of DK ratios and average annual discard estimates for 2001-2004. Pooling observer data for adjacent years, and use of relatively broad species groups and gear groups increased sample size and decreased variance. However, bias may have increases as well because of non-representative sampling and discard rates that probably varied among years, gear groups and primary species groups. The potential importance of these potential problems was not evaluated. However, the statistical (not sampling related) bias of ratio estimators is proportional to their CV (Cocharan 1977) and it seemed reasonable to pool data sufficiently to reduce CVs.

Results

Mean annual discards during 2001-2004 are presented for gear and species groups with DK ratios > 0.0001 (Table A7). During 2001-2004, silver hake discards averaged about 3,820 mt y^{-1} (CV 17%). Trips with hakes and ocean pout as the primary species group in the other/unknown and bottom trawl gear groups had the highest DK ratios. The highest level of average annual silver hake discards were for crab/shrimps in shrimp trawls, and hakes and ocean pout in bottom trawls. See Appendix A4 for diagnostic plots (NEFSC 2003) presented to reviewers but not originally included in this assessment.

Discards were not estimated separately for northern and southern stock areas but it was possible to prorate estimates approximately for the most important primary species and gear groups with discards of at least 70 mt y^{-1} based on general knowledge about the fisheries (Table A7). On this basis, discards of silver hake in the northern stock area averaged at least 1,580 mt y^{-1} and discards in the southern stock area averaged at least 1998 mt y^{-1} during 2001-2004. For comparison, silver hake landings during the same period averaged 2,142 mt y^{-1} in the north and 7,153 mt y^{-1} in the south (Table A1).

4.0 SURVEY INFORMATION

Trends in survey biomass indices for the two silver hake stocks are evaluated in a subsequent section under the heading “Biomass And Fishing Mortality”. Analyses in this section are confined to trends in recruitment and related factors. Survey recruitment trends show that recruitment to the fishery (silver hake ≥ 20 cm TL) was at least average in the north during recent years. In the south, recruitment to the fishable stock fluctuated around average levels in recent years. Despite average or better recruitment, survey trends show reductions in abundance of relatively large silver hake and reduction in mean weight of individual fish that are analogous to reductions in abundance of old fish mentioned above.

A number of analyses were carried out to measure environmental effects on silver hake catches in NEFSC surveys, by size group, age, and stock area. Results suggest an ontogenetic shift at about the size and age of sexual maturity. In particular, relatively large and old fish are found further north and in deeper water (further offshore). Survey catches are highest at night, contrary to expectations, suggesting that silver hake have a reverse diel migration pattern. Depth seems to be more important than temperature in determining the distribution of silver hake. Small/young silver hake inhabit relatively shallow waters and larger/older silver hake inhabit deeper waters year around, despite large seasonal fluctuations in bottom temperatures.

Survey data are used to track the average position of silver hake in both stock areas and to test for trends in average position over time that might explain recent reductions in abundance of larger and older silver hake. Results generally suggest a shift in the distribution of larger fish to the north and offshore over time.

North-south movements of silver hake between stock areas is likely because the center of distribution for large fish n the northern area during the spring and small fish in the southern area during the fall is close to the boundary between the two stocks. It seems unlikely that silver hake in the north and south are separate populations but, depending on management goals, differences between the two areas are clear enough to justify use of the northern and southern regions as separate management areas.

Survey age data were examined to determine if relatively old silver hake observed historically might have been mis-aged or mis-identified offshore hake. Results indicate some imprecision in age estimation and a positive bias in historical ages (age reading criteria used historically result in ages 1-2 y higher than criteria used recently). The factors do not, however, completely explain the absence of older fish during recent years.

Spatial patterns in NEFSC survey catches

Maps showing locations and size of survey catches for all inshore and offshore strata sampled since 1979 (when inshore strata were first sampled consistently during spring and fall, Figures A11-A13) show how ubiquitous and widely distributed silver hake are in all seasons. Nearshore areas at 35°-38° N Lat. have a relatively high proportion of zero tows during fall and winter but not during spring. In addition, the southern flank of Georges Bank north of 40° N Lat. has a relatively high proportion of zero tows in winter, but not during spring or fall. Silver hake were distributed in an apparently normal fashion during the most recent NEFSC surveys (Figures A14-A16).

None of the NEFSC bottom trawl surveys appear to cover the entire range of the silver hake stocks (Figures A11-A13). Catches were relatively high in deep water during winter, spring and fall along the 100-fathom contour and eastern edge of the area surveyed. In addition, catches from coastal areas north of 38^{o} N Lat. were relatively high during spring and fall (inshore strata were not sampled during winter).

"Traditional" and "Special" strata sets for survey data

In this assessment, "traditional" strata sets are those used in previous assessments to describe trends in silver hake stock biomass (Brodziak et al. 2001). In particular, trends in abundance and biomass of silver hake for the northern stock area are traditionally measured using NEFSC fall and spring survey data from offshore strata 01200-01300 and 01360-01400 (NEFSC 2001). Strata 01610-01760 were not sampled during 1963-1966 so the survey biomass for sampled strata during 1963-1966 was increased by 1.8% in Brodziak et al. (2001), the long-term average proportion of silver hake biomass in strata 01610-01760. In this assessment, data for 1963-1966 were usually ignored. Previous assessments did not typically use inshore survey strata for silver hake, although inshore habitats are used by young and small silver hake, because inshore strata were not sampled consistently until 1979.

Different "special" strata sets were used for survey data in this assessment for environmental and trend analyses described below. Special strata sets for each survey and season were considered carefully with the goals of: 1) using as much information over the widest range of environmental conditions as possible; 2) using as many inshore strata as possible (small silver hake are most common in relatively shallow water; and 3) avoiding spurious results due to lack of sampling in some years. The primary criterion for choosing strata was consistency of sampling (i.e., was the stratum sampled during all years?). Winter and spring survey data were available through 2005. Fall survey data were available only through 2004.

Beginning in 1979, offshore and inshore strata were sampled consistently in the northern and southern stock areas (Tables A8-A11). The winter survey is carried out in offshore strata and in the southern stock area exclusively (Table A12). Based on this information, stock-specific strata sets were derived for the fall and spring surveys beginning in 1979 and for the winter survey beginning in 1992 (Table A13). In this assessment, special strata sets are consistently sampled inshore and offshore strata starting in 1979 (fall and spring surveys) or 1992 (winter surveys).

Mean weight and recruitment trends

Using the special strata sets, mean body weight of silver hake in NEFSC spring and fall surveys and north and south stock areas combined declined steadily during 1979 to 2005 (Figure A17). There were similar trends using the traditional strata sets for individual stock areas (results not shown). Mean weights were usually highest in the northern stock area because larger fish tend to be found further north than smaller individuals. Survey length composition data show progressive reductions in abundance of large individuals (Figure A18).

Fall survey biomass indices (delta mean kg/tow) for recruit (< 20 cm TL) and fishable (≥ 20 cm TL) silver hake in the northern stock show variable but generally increasing trends in abundance since 1967 (Figures A19-A20). In the southern stock area, recruit and fishable abundance during fall surveys varied without trend (Figures A19-A20).

Based on spring survey data, recruit and fishable biomass peaked in both the north and south during 1973-1974 and then declined to relatively low levels by 1980 (Figures A19-A20). In the north, recruit and fishable biomass indices show noisy but generally increasing trends since the early 1980s. In the south, recruit biomass was low during 1982-1998 but may have increased somewhat during 1999-2005. Fishable biomass, in contrast, showed a variable but declining trend during the same period (Figures A19-A20).

Environmental effects on silver hake density and occurrence

Environmental effects on catchability of large or small silver hake may contribute to issues in interpreting survey data trends. The special set of survey strata were used in these analyses. A few tows in anomalously deep water (> 400 m), and tows with missing temperature, depth or time of day data were omitted. Analyses were carried out for the southern and northern stocks independently and combined.

Models were developed for the probability of occurrence of at least one silver hake in survey bottom trawl tows, and for numbers of silver hake caught in tows where at least one silver hake was caught. The first type of model measures probability of occurrence. The second measures density in areas where silver hake occur. Both types of models were fit to tow-by-tow data for individual length groups. Based on preliminary analyses, five cm length groups (1-5.9, 6-10.9, 11-15. 9, 16-20.9, 21-25.9 and 26+ cm) were used in modeling. Very few small silver hake (1-5.9 cm TL) were captured during the spring survey in the northern stock areas. Therefore, the smallest size group was excluded from analyses for the northern stock area and for the northern and southern stock areas combined.

Relationships between environmental variables and the probability of occurrence were evaluated using step-wise logistic regression and generalized additive models (GAMs). Relationships between environmental variables and catch in positive tows were evaluated in a similar manner using step-wise log-linear regression and GAM models. The step-wise procedure used in both cases (step.gam in Splus) minimized the AIC statistic for a set of models.

The most complicated model considered for probability of occurrence was:

```
          gam(P ~ as.factor(Y) + lo(T) + lo(D) + lo(L),
family=binomial)
```

where the dependent variable *P* was either one (if at least one silver hake of appropriate size was caught in the tow) or zero (if no silver hake of appropriate size were caught). The most complicated model for density in positive tows was similar:

```
          gam(log(d) ~ as.factor(Y) + lo(T) + lo(D) +
lo(L))
```

where the dependent variable was the logarithm of the number of silver hake of appropriate size taken in the tow. In both models, the independent variables were year (*Y*), bottom temperature (*T*), average depth of the tow (*D*) and time of day (*L*, decimal EST time; e.g. 23.5 for 11:30 pm). The term lo(x) is the loess locally linear scatter plot smoother fit with a span of 0.5 (Hastie and Tibshirani 1990).

Year (*Y*) was a categorical variable that was "forced" in each model (i.e. the step-wise procedure could not eliminate it). Other independent variables could enter the model either as a loess term, quadratic polynomial, linear term or could be omitted completely. Latitude and longitude were omitted in modeling because they were highly correlated with depth and bottom temperature and because the purpose was to understand environmental effects. Latitudinal and longitudinal patterns are explored in subsequent analyses (see below).

Results - probability of occurrence

Based on GAM model results (Table A14 and Figures A21-A25), small silver hake were most likely to be found in relatively shallow waters that tend to be relatively warm during autumn surveys and cool during spring and winter surveys. Depth and temperature distributions for positive tows confirm GAM results (Figures A26 to A28). Patterns related to depth and temperature were strongest for the southern stock probably because of the wider area sampled in the south.

Depth seemed more important than bottom temperature in predicting occurrence of silver hake because small individuals were found in relatively shallow water for both stocks during all surveys. Relationships between probability of occurrence for silver hake size and temperature differed in the winter, spring and fall surveys.

The probability of a positive tow for small silver hake was generally highest at night with the northern stock and fall survey being the notable exception (Table A14). This "reverse" diel pattern was first noted by Bowman and Bowman (1980) and is unexpected because most mesopelagic organisms migrate off bottom during the night time so that catch rates are highest during the day. Bowman and Bowman (1980) attributed low catch rates during the day to behavior of silver hake. They hypothesized that silver hake were very close to the bottom during the day and not efficiently captured by survey bottom trawls with roller gear, which might roll over them. Reverse diel migration patterns are not as strong for silver hake in winter surveys which use bottom trawls that have cables, rather than rollers, as ground gear (Tables A14-A15).

Results-catch in positive tows

GAM results for catches of silver hake in positive survey tows were generally similar to results for probability of occurrence although patterns were clearer for density with more significant loess terms in models (Table A15). In particular, density of small silver hake was highest in relatively shallow waters. The highest catches of large silver hake (> 21 cm) were at depths of at least 150 m at or near the offshore edge of the bottom trawl surveys. Bottom temperature, depth and time of day were significant in 30, 31 and 27 out of 31 total cases. All models with significant time of day effects predicted highest catch rates at night.

Temporal patterns in stock distribution

Mean depth, latitude, longitude and bottom temperature for silver hake of different sizes in the northern and southern stock areas were computed as catch weighted averages so that the latitude of a tow with a large catch received a higher weight than the latitude of a tow with a small catch (special strata set). Tows with zero catches were, in effect, omitted from the analysis because they received zero weight. Murawski (1993) and Overholtz and Friedland (2002) carried out similar analyses for latitude and longitude in a variety of species but used unweighted means. The weighted means used here should more accurately measure average position and environmental variables encountered by silver hake stocks. Linear regression analyses with year as the independent variable and mean latitude or longitude as the dependent variable were used to test for trends in location of silver hake. Both linear and loess regression lines were plotted to help visualize trends.

Results

Results (not shown) for trends in average temperature and depth supported results from the GAM model analysis because larger fish were found in deeper water that was relatively cold during fall surveys and relatively warm during spring and winter surveys. Variation in average temperature and depth was irregular and inconsistent. It did not indicate steady unidirectional trends or abrupt shifts in average depth or temperature of silver hake in any size group.

Results for trends in average location (latitude and longitude, Figures A29-A35) show that small silver hake (< 6 cm) in the northern stock area during the fall and southern stock area during the spring are located further south (lower mean latitude) than larger individuals. Larger individuals were located further offshore (at lower mean longitude) during the spring and winter surveys in the southern stock area.

Differences between location and size were clearest when the northern and southern stock areas combined (Figure A31 and A34). In particular, small silver hake tend to occur over inshore regions in the south while larger individuals are further north and offshore. As pointed out by reviewers, trends towards the north and offshore might be spurious and due to increasing abundance in the north of the northern and southern stocks are, in fact, independent populations.

Average latitude results indicate that substantial interchange of silver hake is likely between the northern and southern stock areas. The northern and southern stock areas are divided at approximately 41-42° N (Figure A1). Average locations of silver hake in the northern stock were generally close to the northern boundary of the southern stock area (Figures A29 and A32). Similarly, average locations of silver hake in the southern stock area during fall when water temperatures are warm were generally close to the southern boundary of the northern stock area (Figures A30).

Trends in mean bottom temperature over time were statistically significant (Table A16) in only two out of 40 possible cases. In particular, there were negative trends for two size groups in the fall survey with north and south stock areas combined. Trends in mean depth were statistically significant and positive in 12 out of 40 possible cases, most often for combined north and south stock areas during the fall.). Two apparently significant trends would be expected under the null hypothesis of no trends in bottom temperature using *p*-value 0.05.

Trends in latitude and longitude (Table A16 and Figures A29 to A35) indicate a general shift in the distribution of silver hake to the north and offshore. In particular, trends in mean latitude were statistically significant in 16 out of 40 cases. Trends in mean longitude were statistically significant in eight out of 40 cases (significant trends were positive in two cases and negative in eight cases). Two apparently significant trends would be expected under the null hypothesis of no trends in bottom temperature using *p*-value 0.05.

Trends in distribution may be confounded with changes in relative abundance of the north and south stocks because higher abundance in the north would result in a positive shift in mean latitude and a negative shift in mean longitude. Omitting cases with the southern and northern stocks combined, there were significant positive trends in mean latitude in ten cases and significant trends in mean longitude in six out of 30 cases (four negative trends and two positive trends, Table A16). One or two apparently significant trends would be expected under the null hypothesis of no trends in bottom temperature using *p*-value 0.05.

What happened to the old fish?

NEFSC survey age composition data for silver hake are currently being audited to remove some duplicate records. The provisional survey age data used here were corrected for obvious errors by the assessment authors and are meant only for use in this assessment.

Survey age composition data were not updated for silver hake in this assessment but age-specific abundance indices for silver hake from Brodziak et al (2001) show the declining trends in abundance of old fish despite trends for young fish that increased in recent years (Figure A36). Trends for relatively old silver hake are similar to results for relatively large fish (Figures A18-A20).

Several analyses indicate that normal variability in age reader data may exaggerate the apparent decline old silver hake in survey catches (see below). However, age data errors do not appear to be sufficient to completely explain the decline of old silver hake. As shown above, relatively abundance of relatively large silver hake have declined in abundance as well.

Accounting for changes in criteria used to age silver hake (see below), the small number of old fish observed, and age estimation errors (see below), it appears likely that the apparent decline in maximum age from 14 to 6 years represents an actual decline from perhaps 10 to 6 years (see below). Based on the provisional survey data and original age estimates (Table A17), only sixteen "old" individuals (originally aged 11-14 years) have been observed out of roughly 100,000 age estimates for silver hake taken in NEFSC fall and spring surveys during 1973-2005. Sixteen age estimation errors of at least +2 y are plausible given experimental results shown below.

It is unlikely that old silver hake observed in surveys were all or mostly offshore hake, although the two species are similar in appearance (Collette and Klein-MacPhee 2002). Plots (not shown) of length versus age for all silver hake in the NEFSC survey database indicate that lengths at age for relatively old individuals were not anomalous. Geographic distributions of silver hake ages 8+ and offshore hake overlap (Figures A11-A12 and A37-A38). However, survey staffs are aware of potential misidentification problems with silver hake and are generally alert to the possibility of misidentification in areas where both species occur. Moreover, otoliths from the two species differ in shape (Figure A39) and age readers are able to distinguish otoliths from the two species.

An environmental change that shifted large silver hake into deeper water might explain the apparent decline in abundance (Brodziak et al. 2001). Relatively old and large silver hake are most common in deep water at the limit of depths sampled in NEFSC surveys (Figure A40-A41). Trends in the mean locations of large and presumably old silver hake have been noted (see above). However, despite a range of potential candidates (Brodziak et al 2001), no environmental factor with a definitive mechanism that might cause a shift to the north or offshore has been clearly identified.

Distribution plots for relatively old silver hake may indicate a north-south seasonal migration pattern (prepared after this assessment was completed and presented to reviewers, Appendix A4). During spring surveys, silver hake ages 8+ were found south of Georges Bank. During fall surveys, in contrast, silver hake ages 8+ were almost entirely north of Georges Bank.

Age reader experiments

Three experiments were undertaken to determine the precision of current and historic age estimates for silver hake in NEFSC surveys. In the first experiment, the primary age reader who estimated ages for silver hake in the 2001-2005 surveys re-aged a sample of 99 fish originally aged 1-5 y. The sample size at ages 3 y and older was small but percent agreement declines for older silver hake (Table A18).

In the second experiment, an alternate age reader who was experienced in ageing silver hake re-aged the 99 specimens used in the first experiment. Percent agreement between readings was generally lower than in the first experiment. As in the first experiment, the sample size was small for ages 3 y and older but percent agreement appears to have declined with age (Table A19).

In the third experiment, a sample of 17 fish from fall and spring surveys during 1973-1975, 1979 and 1982 originally aged 7-14 y were re-aged by the primary reader. Although sample size was small, it appears that current criteria for ageing silver hake would result in age estimates that would be 1-2 y lower than originally (Table A20).

Relationships between age and depth

Cumulative distributions for silver hake of different ages in fall and spring surveys (all strata and tows) show older fish in deeper water with an apparent shift to deep water during fall between ages 2-3 y (Figure A42). Cumulative distributions for age and temperature show older fish in relatively warm water during the fall and relatively cool water during the spring. Patterns for old fish are similar to those described above for large fish. In particular, depth seems to be more important than temperature in determining habitat for silver hake of different size.

Supplemental "Transect" bottom trawl survey

Bottom trawl data from the Supplemental Finfish Survey Targeting Mid-Atlantic Migratory Species were used in this assessment to estimate lower bounds for catchability in NEFSC bottom trawl surveys and to better characterize the distribution of silver hake in deep water along the shelf break (Tables A21-A22). The survey is described in general terms below and in Appendix A2. See HSRL (2005) for a more complete description.

Supplemental survey data for silver hake in this assessment were collected during March of 2004-2005 following transects along the northern flank of Baltimore and Hudson canyons (transects and tow locations were the same in all years, Figure A43). Data for 2003 were not used because silver hake and offshore hake were not distinguished in survey catch records. Baltimore canyon stations included in this analysis were in NEFSC survey strata 01020-01040. Hudson canyon stations were in NEFSC survey strata 01700-01720 (Figure A1). For simplicity in this analysis, "fixed" stations along transects are treated like random samples from NEFSC survey strata. Supplemental survey data used in the analysis were from fixed stations at target depths of 73, 91, 110, 146, 183, 229 and 274 m (40, 50, 60, 80, 100, 125 and 150 fathoms) that were occupied during the daytime. Deeper stations were occupied at night and omitted from this analysis except in estimating survey length composition.

The F/V Jason and Danielle (96 ft and 1080 hp) was used in 2003-2004 Supplemental surveys and the F/V Luke & Sarah (120 ft and 1500 hp) was used during 2005. The captain, bottom trawl gear and sampling protocols were the same in all surveys.

The commercial 4 seam box net bottom trawl used in supplemental surveys was the same in each year. The wingspread averaged about 67 m and head rope height averaged about 5.5 m. In contrast, the Yankee #36 standard bottom trawl currently used in NEFSC fall and spring surveys is smaller with a wingspread of about 12 m and head rope height of about 2 m. The commercial bottom trawl has a larger liner in the cod end (6 cm vs. 1.27 cm). The sweep of the commercial net is covered with 3 inch rubber cookies. The Yankee #36 bottom trawl has a combination of 5 and 15 inch rollers. The Yankee #36 bottom trawl used in NEFSC surveys catches more small whiting (< 20 cm TL, Figure A44).

Supplemental survey tows were made at 3 knots in a direction perpendicular to the slope and transect. NEFSC survey tows were made at 3.8 knots in the direction of the next station. The amount of wire let out was constant for all tows at the same depth. Distance towed in the Supplemental survey was determined based on a depth data from a depth sensor on the trawl.

Twenty cm is a reasonable lower bound for defining the fishable stock of silver hake. Silver hake captured by the commercial bottom trawl used in Supplemental surveys are seldom < 20 cm TL (Figure A45). Small silver hake are more common in NEFSC surveys but not often encountered in the areas of interest during the spring (Figure A44). In analyses that follow, catch was in kg per tow for silver hake ≥ 20 cm TL in NEFSC surveys and total catch for Supplemental surveys. Densities of silver hake (kg/km^2) were calculated for each tow by dividing catch by area swept (Table A22).

Relationships between density and depth were generally similar for the two surveys (Figures A45-A47). Densities measured by the Supplemental Survey were substantially higher and less variable.

5.0 BIOMASS AND MORTALITY ESTIMATES

Three methods were used to characterize biomass and fishing mortality for silver hake in the northern and southern stock areas, and for the stocks combined. The first method is based on trends in biomass and exploitation indices that are calculated from landings and NEFSC fall survey data. The first method is the current standard and used by managers to specify management targets and thresholds and to define overfishing and overfished stock conditions. The second and third methods provide lower bound estimates for stock biomass and upper bound estimates for fishing mortality based on NEFSC survey, landings, discard and Supplemental survey data. The later two methods are new and have not been used previously. They are not intended to displace the standard method. Rather, they provide information about the scale (magnitude) of biomass and fishing mortality for silver hake.

Silver hake appear to be at relatively high biomass levels in both the northern and southern stock areas. Fishing mortality rates were low during recent years and much higher historically.

Trends in biomass and exploitation indices

Survey biomass trends for both the northern and southern stock areas (delta mean kg/tow for fall surveys during 1967-2004, calculated for "traditional" offshore strata) indicate that stock biomass is relatively high and near target levels used in management (Tables A22-A23 and Figures A48-A49). Relative exploitation indices (landings divided by the survey stock biomass index) indicate that fishing mortality rates are low in both stock areas and less than threshold levels used in management (Tables A22-A23 and Figures A48-A49).

A conventional age-structured stock assessment model was not used in this assessment for silver hake due to lack of time, uncertainty about stock structure, uncertainty about natural mortality stemming from trends in maximum age, ongoing audit of silver hake age data, low levels of fishing mortality during recent years (particularly in the north) which may complicate modeling, lack of a hypothesis regarding old fish to test in modeling, uncertainty about the magnitude of discards, a new stock assessment author, and the apparently misleading results from previous modeling efforts. In lieu of an age-structured stock assessment model, two approaches were used to estimate lower bounds for silver hake biomass and upper bounds for fishing mortality rates.

Bounds for fishable biomass and fishing mortality

(EDITOR'S NOTE: THIS PART OF THE WORKING GROUP REPORT HAS BEEN OMITTED. IT WAS NOT ACCEPTED BY THE REVIEW PANEL.)

Bounds based on NEFSC and Supplemental surveys

(EDITOR'S NOTE: THIS PART OF THE WORKING GROUP REPORT HAS BEEN OMITTED. IT WAS NOT ACCEPTED BY THE REVIEW PANEL.)

Bounds based on historical landings and concurrent survey data

(EDITOR'S NOTE: THIS PART OF THE WORKING GROUP REPORT HAS BEEN OMITTED. IT WAS NOT ACCEPTED BY THE REVIEW PANEL.)

A bridge between the current and last assessment

Trends in biomass and exploitation indices suggest that results from a virtual population analysis for silver hake in the previous assessment were overly pessimistic (NEFSC 2001). It appears that the virtual population analysis (VPA) used in the last assessment mistakenly interpreted trends in abundance of old silver hake as evidence of low abundance and high fishing mortality. A Bayesian surplus production model in the last assessment appears to have given more plausible results with generally increasing biomass trends for the stock as a whole.

6.0 OVERFISHING DEFINITIONS AND STATUS

Overfishing definitions and biological reference points used by managers for the northern and southern stocks of silver hake are summarized below and in NEFMC (2002).

Summary of biolgical reference points used in overfishing definitions for silver hake. The new exploitation based target for silver hake in the southern stock area is 60% of the threshold, F_{MSY} proxy level. The biomass based reference points include an adjustment made in NEFSC (2001) to accommodate recalculation of survey biomass indices.

Stock	Biomass target (B_{MSY} proxy, average delta mean kg tow for NEFSC fall survey during 1973-1982)	Biomass threshold (1/2 BMSY proxy, delta mean kg tow in NEFSC fall survey)	New exploitation index reference points (landings / biomass index)		Original fishing mortality (F) based reference points in Ammendment 12 (y^{-1})	
			Target	Threshold (F_{MSY} proxy)	Target	Threshold (F_{MSY} proxy)
North	6.63	3.31	2.57	2.57	$F < F_{0.1}$	$F_{0.1}$ = 0.41
South	1.78	0.89	20.63	34.39	$F < F_{0.1}$	$F_{0.1}$ = 0.39

The B_{MSY} proxies and biomass reference points used for both stocks of silver hake in this assessment and in NEFSC (2002) are based on average catch rates in the NEFSC fall survey (delta mean kg/tow) during 1973-1982, a period of relative stability in the fishery (Figure A48-A49). The biomass reference points for silver hake are compared to the most recent three-year averages of fall survey biomass (delta mean kg/tow) to determine if either stock is overfished.

The F_{MSY} proxies and associated reference points used for silver hake in this assessment and in NEFSC (2002) are based on exploitation indices (landings / fall survey delta mean kg/tow), are new since the last assessment (NEFSC 2001), and differ from the reference points in Amendment 12 of the Northeast Multispecies Fishery Management Plan. In particular, the F_{MSY} proxies and fishing mortality reference points used for silver hake in this assessment are based on exploitation indices (landings / fall survey delta mean kg/tow) during 1973-1982, a period of relative stability in the fisheries that is already used to define biomass reference points (Figure A48-A49). The new reference points for silver hake are compared to the most recent three-year averages of the exploitation rates indices (landings over delta mean kg/tow) to determine if overfishing is occurring in either stock.

The new reference points based on exploitation indices were developed since the last assessment and used annually by the New England Council's Whiting Monitoring Committee because fishing mortality rates were not estimated for whiting in the last assessment (NEFSC 2001) and because it was not possible to use the original fishing mortality based reference points ($F_{0.1}$) in Amendment 12.

The Whiting Monitoring Committee's new reference points were reviewed and used in this assessment because fishing mortality rates were not estimated. The exploitation index approach is common in northeast fisheries when fishing mortality cannot be estimated, and it was based on the original reference points to the extent possible. The exploitation based target for the southern stock is set at 60% of the F_{MSY} proxy and is more risk averse than the original approach in Amendment 12. The target and threshold reference points for defining overfishing in the northern stock are identical.

Northern stock

The northern stock of silver hake is not overfished and overfishing is not occurring (Table A22 and Figure A48). In particular, the three-year average biomass index for 2002-2004 (6.72 kg/tow) was above the management threshold level (3.31 kg/tow) and near the target level (6.63 kg/tow). The three-year average exploitation index for 2002-2004 (0.24) was below the management threshold and target level (2.57).

The northern stock of silver hake was not overfished based on results from the last assessment (NEFSC 2001). Overfishing was not evaluated in the last assessment because fishing mortality rates were not estimated.

Southern stock

Based on current reference points, the southern stock of silver hake is not overfished and overfishing is not occurring (Table A23 and Figure A49). In particular, the three year average biomass index for 2002-2004 (1.37 kg/tow) was above the management threshold level (0.89 kg/tow) and near the target level (1.78 kg/tow). The three year average exploitation index for 2002-2004 (4.85) was below the management threshold level (34.39) and below the management target level (20.63).

The southern stock of silver hake was overfished based on results from the last assessment (NEFSC 2001). Overfishing was not evaluated in the last assessment because fishing mortality rates were not estimated. The change in status is due to increases in stock biomass indices for the southern stock of silver hake.

7.0 STOCK PROJECTIONS

Stock projections were not carried out because current age structure, abundance and were not estimated biomass in absolute terms. However, stock biomass levels are relatively high and current fishing mortality rates are very low in the north and probably low in the south also. Recent recruitments have been roughly average. Uncertainties exist because old fish are still absent and the cause is unknown. Given these factors, a qualitative analysis suggests that significant declines in stock biomass due to fishing are unlikely in the short term.

8.0 TOTAL ALLOWABLE LANDINGS (TAL)

Total allowable landings (TAL) for 2005 were calculated based on fall survey data through 2004 and exploitation index reference points (Table A27). In particular, target exploitation indices (landings / three year average survey) were multiplied by the most recent three-year average survey abundance index to estimate landings at the target exploitation level. Assuming that the reference points are exact, CVs measuring uncertainty in TAL calculations are the same as the CV for the three year average survey.

For the northern stock area during 2005, where the target and threshold reference points are the same, TAL < 17.3 mt. For the southern stock area during 2005 based on the target reference point, TAL=28.3 mt. For comparison, annual landings averaged 1.71 thousand mt in the north and 6.65 thousand mt in the south during 2002-2004.

9.0 SOURCES OF UNCERTAINTY AND NEW RESEARCH RECOMMENDATIONS

The most important uncertainties stem from clearly decreasing trends in abundance of relatively old and large individuals. These reductions have occurred despite apparently normal growth patterns, low fishing mortality rates and relatively high biomass levels during recent years. The possibility of increased natural mortality rates due to predation or other ecosystem level effect is a key area for future research.

Survey data indicate that relatively large silver hake may move around Georges Bank from the southern stock area to the northern. Uncertainty about north-south movements of adult silver is important because of uncertainty about linkages between the northern and southern stock areas.

Considerable amounts of silver hake biomass may occur midwater and on the bottom at depths that are not effectively sampled by NEFSC bottom trawl surveys. Stock biomass would be better estimated if more information about use of midwater habitat information was available and if the lower depth distribution of silver hake was determined.

10.0 RESEARCH RECOMMENDATIONS FROM PREVIOUS ASSESSMENTS

1) Develop survey information that covers the offshore range of the population. *The Supplemental ("Transect") survey during 2003-2005 sampled relatively deep water along several transects.*

2) Conduct surveys of spawning aggregations on the southern flank of Georges Bank. *This research recommendation was not addressed.*

3) Investigate bathymetric demography of population. *The current assessment includes extensive analysis of relationships between location, depth, size and age based on bottom trawl survey data.*

4) Investigate spatial distribution, stock structure and movements of silver hake within Georges Bank, the Gulf of Maine, and the Scotian shelf in relation to physical oceanography. *The current assessment includes extensive analysis of survey data to determine trends in locations of highest silver hake density (catch*

weighted mean latitude and longitude) and to determine environmental factors that affect density of silver hake of different sizes and at different times of the year.

5) Quantify age-specific fecundity of silver hake. *This research recommendation was not addressed.*

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