Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

Canadian Science Advisory Secretariat (CSAS)

Research Document 2013/008

Maritimes Region

Silver Hake 2012 Framework Assessment: Data Inputs and Exploratory Modelling

H.H. Stone[1], D. Themelis[2], A.M. Cook[2], D.S. Clark[1],
M.A. Showell[2], G.Young[2], W.E. Gross[1], P.A. Comeau[2], and L.A. Alade[3]

[1]DFO Maritimes, Saint Andrews Biological Station
531 Brandy Cove Road, Saint Andrews, New Brunswick, Canada E5B 2L9

[2]DFO Maritimes, Bedford Institute of Oceanography
1 Challenger Drive, P.O. Box 1006, Dartmouth, Nova Scotia, Canada B2Y 4A2

[3]NOAA Fisheries, Northeast Fisheries Science Center, Population Dynamics Branch
166 Water Street, Woods Hole, Massachusetts, USA 02543

November 2013

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Stone, H.H., Themelis, D., Cook, A.M., Clark, D.S., Showell, M.A., Young, G., Gross, W.E., Comeau, P.A., and Allade, L.A. 2013. Silver Hake 2012 Framework Assessment: Data Inputs and Exploratory Modelling. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/008. v + 133 p.

TABLE OF CONTENTS

ABSTRACT

In 2012, the Maritimes Region of Fisheries and Oceans Canada undertook a framework assessment of 4VWX silver hake (*Merluccius bilinearis*). Such assessments are intended to be a comprehensive review of the biology, stock structure, the fishery, abundance indices, current assessment methodology and approaches for determining acceptable harvest limits. The results of updated analyses on stock structure, spatial and temporal patterns in distribution and relative abundance, fishery catch rates, biological attributes (length and weight-at-age, sex ratio at size and age, condition factor, maturity) and other data inputs for stock assessment (recruitment, relative fishing mortality, total mortality, partial recruitment patterns) are described here. In addition, population dynamics were modelled using several approaches to determine which model best fit the observed data. The commercial fishery footprint relative to the Scotian Shelf as well as habitat associations, prey and predators of silver hake, were also examined. This research document is intended to provide an update on several biological and fishery attributes for future framework evaluations.

Évaluation du cadre de travail de 2012 pour le merlu argenté : Saisie de données et modélisation exploratoire

RÉSUMÉ

En 2012, la Région des Maritimes de Pêches et Océans Canada a entrepris une évaluation du cadre de travail pour le merlu argenté (*Merluccius bilinearis*) pêché dans la division 4VWX. Ces évaluations se veulent un examen exhaustif de la biologie, de la structure des stocks, de la pêche, des indices d'abondance, de la méthode d'évaluation actuelle et des approches en vue de déterminer les limites acceptables de récolte. Les résultats des analyses à jour sur la structure des stocks, les tendances spatiales et temporelles dans la répartition et l'abondance relative, les taux de capture de la pêche, les caractéristiques biologiques (longueur et poids selon l'âge, sex-ratio pour la taille et l'âge, coefficient de condition, maturité) ainsi que d'autres saisies de données concernant l'évaluation des stocks (recrutement, mortalité relative par la pêche, mortalité totale, tendance de recrutement partiel) sont décrits ci-dessous. En outre, la dynamique des populations a été modélisée à l'aide de plusieurs approches afin de déterminer le modèle qui correspond le mieux aux données observées. L'empreinte de la pêche commerciale relative au plateau néo-écossais ainsi que les associations d'habitat, les proies et les prédateurs du merlu argenté ont aussi été examinés. Ce document de recherche a pour but de faire le point sur plusieurs caractéristiques biologiques et halieutiques pour les évaluations futures du cadre de travail.

INTRODUCTION

Silver hake (*Merluccius bilinearis*) is a member of the gadid family found from Cape Hatteras to the southern Grand Banks and Gulf of St. Lawrence. It is a demersal-pelagic fish occurring in shallow waters to depths of 400 m. The distribution of silver hake juveniles and adults are associated with warm, bottom temperatures of 5-12°C and 7-10°C, respectively. A population of silver hake occurs on the Scotian Shelf in Northwest Atlantic Fisheries Organization (NAFO) Divisions 4VWX and is considered to be a self-reproducing stock (Rikhter et al. 2001). This population aggregates in the deepwater depressions of the Scotian Shelf (Emerald and LaHave basins) and in the warm slope water, except during the spawning period from July-September when large numbers occur on the shelf in shallow waters surrounding Sable Island Bank.

The last assessment of the status of Scotian Shelf silver hake was conducted in 2009 (DFO 2010). A new assessment has been requested by Fisheries and Oceans Canada (DFO) Resource Management Branch to provide harvest advice in support of the fishery in the Maritimes Region. DFO Science Branch has been asked to review and evaluate the biological and fishery information on 4VWX silver hake status and characterize the uncertainty of the results; specifically, to provide information on distribution, biomass estimates, length and age composition and condition, highlighting any trends over the long-term (length of assessment), mid-term (past 15 years), and most recent period (5 years). Given known problems with the assessment model for this stock (as described in the 2009 assessment), it was determined that a new framework was required. The review of the framework and assessment for 4VWX was conducted in three parts: review of data inputs, review of the model, and then the assessment.

The first meeting to review the data sources for the framework occurred on May 30-31, 2012. The Terms of Reference for this initial Data Inputs meeting were as follows:

- Describe the basis of the management unit
- Review fisheries and survey data sources, including
  - Fishery sampling: commercial catch, distribution, length and age composition
  - DFO Research Vessel (RV) survey sampling: survey catch, distribution, length and age composition, condition
  - Industry (ITQ) survey sampling: survey catch, distribution
- Review catch-at-age, including
  - Documentation of past aging approach
  - New aging approach using otolith weights
- Review relevant biological and ecological information, including
  - Biology: growth, age, life history, sex, fecundity, natural mortality, spawning location and timing, recruitment
  - Ecosystem information: bycatch, trophic information, temperature, fishery footprint
- Review indices of abundance, including
  - RV survey indices
  - ITQ survey indices
  - CPUE (catch-per-unit-effort) index

The objectives of the meeting were to describe the basis of the management unit and to review the data available from the commercial fishery and independent research surveys, the methods used to derive a catch at age, relevant biological and ecological information and indices of abundance.

Several recommendations were made at this meeting for additional sources of information or re-analyses of the data. This research document presents the data sources for the silver hake framework, updated to meet the recommendations of the initial data review. Exploratory results from Virtual Population Analyses (VPA), the Iterative Statistical Catch at Age (iSCAM) and Age Structured Assessment Program (ASAP) models are also included.

REVIEW OF MANAGEMENT UNIT

The management unit for silver hake reviewed in this assessment includes NAFO areas 4VWX (Figure 1). This population has been considered separate from two silver hake stocks managed in USA waters, i.e. a northern stock in the Gulf of Maine and northern Georges Bank, and a southern stock occupying southern Georges Bank and the mid-Atlantic Bight area (Figure 2).

In recent stock assessments, trends in biomass and abundance have been calculated for the Scotian Shelf portion of 4VWX only (strata 440-483 in Figure 18), excluding the Bay of Fundy (strata 484-495). Showell (1998) showed a discontinuity in the distribution of silver hake between the Scotian Shelf and Bay of Fundy based on American and Canadian trawl surveys conducted from 1970-1994. He reported that numbers of fish per tow in summer research surveys from 1979-1998 were similar between the Gulf of Maine and Bay of Fundy, but not between the Bay of Fundy and the Scotian Shelf or between the Gulf of Maine and the Scotian Shelf. Removal of the Bay of Fundy portion of the survey catches also tended to improve tracking of age classes. He concluded that the silver hake caught by the July RV survey in the Bay of Fundy were associated with the northern Georges Bank/Gulf of Maine stock rather than the Scotian Shelf stock.

More recent analyses for this framework review indicated that the biomass index for Bay of Fundy strata (484-495) was highly variable and showed little concurrence with the Scotian Shelf index (strata 440-483) (Figure 3). While total biomass for the Bay of Fundy was considerably lower than the Scotian Shelf, both series showed an increasing trend in recent years. A comparison of the stratified total abundance at age for the Bay of Fundy and Scotian Shelf indicated that age 1 fish represented most of the catch in the Bay (Figure 4) (Note for some years (1973, 2000-2006) no aging was conducted). Given the high variability in the abundance index for age 1 in the Bay of Fundy strata, including these data with the Scotian Shelf series would only add more “noise” to the index of abundance for this age group. Therefore, as indicated by Showell (1998), it is not unreasonable to exclude it from the time series.

Two silver hake stocks are identified in USA waters based on morphometric differences and are managed separately due to differences in exploitation patterns. Trends in biomass from the National Marine Fisheries Service (NMFS) fall survey indices for the northern stock (Gulf of Maine) show some concurrence with the Bay of Fundy strata (Figure 5; upper panel), while the NMFS fall index for the southern stock (Georges Bank/mid-Atlantic Bight) shows similarities with the Scotian Shelf index (Figure 5; lower panel). Biomass has been increasing on the Scotian Shelf and in the Gulf of Maine since 2006 and for the Georges Bank-mid Atlantic Bight region since 2007. The recent increase in the Bay of Fundy strata are probably linked to increases in the Gulf of Maine.

Data were available on the distribution of silver hake eggs and larvae from 1979 to 1982 from the Scotian Shelf Ichthyoplankton Program (SSIP) database and from 1982 to 1985 from the Fisheries Ecology Program (FEP) database. Egg distributions indicated the presence of silver hake spawning on the Scotian Shelf from May through October, with peak spawning occurring on most of the Scotian Shelf banks in August and September (Appendix Figure 1). Eggs were also present on northeastern Georges Bank indicating that spawning occurred in this region during July and August as well. Silver hake larvae were distributed on the Scotian Shelf in SSIP surveys from July through November, with highest abundance on the Scotian Shelf during September and October (Appendix Figure 2). Silver hake eggs and larvae were also collected and identified from larval herring surveys conducted in the Bay of Fundy/Western 4X region during the 1970s, 1980s and 1990s indicating that spawning occurs in this region as well as on the Scotian Shelf (Appendix figures 3 and 4). Some eggs were also collected from the area of Browns Bank in February through June from FEP surveys (Appendix Figure 5). While it can be concluded that the Scotian Shelf banks are important spawning areas for silver hake, it is not clear from this data if the spawning areas on Georges Bank, off southwestern Nova Scotia and in the Bay of Fundy are from separate stocks.

A comparison of the mean length-at-age by sex for age 1 and 2 silver hake indicated that there was not much difference between the Scotian Shelf and Bay of Fundy in terms of growth (Figure 6). Bay of Fundy fish may be slightly smaller at age 2 but not at age 1. Small sample sizes and lack of age information for some years compromised this comparison, but in general growth patterns appear to be similar for both areas at least during the first two years of life.

DFO research surveys sampling the Scotian Shelf/Bay of Fundy region were conducted annually during spring, summer and fall from 1979-1984 (Figure 7). Spring survey catch distributions (mean weight (kg)/10 minute square,1979-1984) indicate that silver hake were concentrated along the shelf slope, the “Scotian Gulf” (region between Emerald and LaHave banks) and in the basins (areas of warm water). Summer RV survey distributions were more widespread on the shelf, particularly on Sable Island Bank, Western Bank and in the basins. Fall RV surveys showed a distribution closer to the coast (compared to the summer RV survey) rather than offshore, with some occurrences in the western 4X/Bay of Fundy areas. In all three seasons, there was a discontinuity in distribution between the Bay of Fundy and the Scotian Shelf, with low catches on Browns Bank.

The distribution of silver hake catches (t per 10 minute square) from foreign and domestic mobile gear fishing operations reported by Canadian at-sea observers (1977-2005) show that most catches occurred along the shelf edge in the 1980s and 1990s with some catches in the basins during the 1970s (Figure 8). The distribution of silver hake catches (t per 10 minute square) from Canadian mobile gear log record data (2008-2011) indicate the domestic fishery currently takes place in Emerald and LaHave basins (4Xm, 4Wkl), with some catches along shelf slope (4Xl, 4WL) (Figure 9). The main point is that both foreign and domestic fishery catches have occurred in the basins and along the shelf slope with very minor catches in western 4X and the Bay of Fundy.

CONCLUSIONS

The stock structure of silver hake in the northwest Atlantic has not been clearly defined. Comparisons of microsatellite and mitrochondrial DNA of hake from Gulf of Maine, Browns Bank, Georges Bank and mid-Atlantic Bight found significant differences between hake in the Gulf of Maine and offshore on Browns implying separate stocks (Machado-Schiaffino et al. 2011). A review by Rikhter et al. (2001) concluded that silver hake on the Scotian Shelf is a self-reproducing stock. While this may be the case, foreign and domestic commercial fishery catch distributions indicate that there has been little or no fishing in Bay of Fundy. The summer RV survey indicates that most catches occur on the Scotian Shelf, and while there have been some catches in western 4X in the 2000s, these may be linked to increasing abundance in the Gulf of Maine as indicated by the NMFS fall survey abundance trends. Survey trends in Bay of Fundy strata are much more variable than those for Scotian Shelf strata; however, Bay of Fundy strata biomass represents < 10% of total (4VWX) survey biomass. Bay of Fundy strata were comprised mostly of age 1 fish, and it is likely that if they were included in the overall index it would add more “noise” to the index of age one abundance. While it is not clear if the Bay of Fundy component represents a biologically separate stock, the recommendation is to continue using strata 440-483 in the calculation of survey indices since this spatial coverage is more representative of the geographic area covered by the fishery (which has negligible landings in the Bay of Fundy).

THE FISHERY

A significant fishery for silver hake on the Scotian Shelf (NAFO Div. 4VWX) began in the early 1960s with the arrival of the distant water fleets of Russia, Japan and Cuba. Through the 1960s and early 1970s, fishing was unrestricted in terms of area, mesh size, season and effort (Table 1). Fishing was conducted over the entire shelf, excluding the 12 mile zone, during all seasons of year and with trawl mesh in the cod-end as low as 40 mm. A total allowable catch (TAC) was first implemented in 1974 at 95,000 t. Following the extension of jurisdiction to 200 miles by coastal states in 1977, Canada implemented the *Coastal Fisheries Protection Act*, which restricted fishing for this species to the seaward side of the Small Mesh Gear Line (SMGL; Figure 10), west of 60^{o} W longitude, with a minimum mesh size of 60 mm. The SMGL coincided approximately with the 100 m depth contour. Fishing was restricted to April 15th to November 15th. A portion of the fleet (4-6 vessels) was allowed to fish on the Scotian Shelf inside the SMGL during 1978 and 1979 on an experimental basis (Figure 8; top left panel) with the requirement of 100% observer coverage. From 1980 through 1983, fishing was permitted by condition of license in an eastern extension of the Silver Hake Box as far as 57^{o} W longitude; from 1984 to present, this eastern extension has been restricted to 59^{o} W longitude. In 1994, further restrictions were introduced to minimize the bycatch of cod, haddock and pollock in the silver hake fishery. These included repositioning the SMGL to the 190 m depth contour and the use of a separator grate with 40 mm bar spacing inserted in the lengthening piece of the trawl.

The foreign fleet consisted of large tonnage class 7 vessels, mainly Russian and Cuban (Table 2). Russia ceased fishing for silver hake after 1993. No foreign allocations were made after 1997, but Cuba continued fishing seaward of the SMGL under charter arrangements with Canadian partners. Foreign vessel participation in the silver hake fishery declined through the 1990s and ended in 2004 (Figure 11).

Canadian fishing interests have engaged in experimental harvesting of silver hake since 1975, however, a commercial fishery only started in 1995 (Showell and Cooper 1997). From 1995 to present, a commercial fishery has been conducted by the Canadian tonnage class 3 (< 65’) mobile gear fleet in and around Emerald and LaHave basins (Figure 10). This area is entirely contained within RV survey strata 461 and 471 (Figure 21). The fishery is restricted to depths greater than 190 m.

Concern over the harvesting of small fish as fishing in the basins developed, led in 1999 to a mandatory requirement for 55 mm square mesh, rather than 60 mm diamond mesh in the codend. A topside chafer was required to support the codend during haulback, as the tensile strength of the twine used to manufacture the square mesh was lower than that of traditional diamond mesh. However, the chafer had the potential to block the meshes, thus mitigating the benefits of the square mesh. A codend using stronger twine was designed to address this problem and topside chaffers have not been used in the fishery since 2000.

Landings of 4VWX silver hake have ranged from nearly 299,000 t in 1973 to 8,000 t in 1994 (Table 3; Figure 11). The TAC has been set at 15,000 t since 2003, but landings have been lower, averaging 11,100 t for the years 2003-2011. Landings are constrained by market conditions, and there is no indication that reduced catch, or a catch lower than the quota, is related to low abundance. Landings of silver hake in the fishing years ending in 2010 and 2011 were 8,396 and 9,231 t, respectively. As shown previously in figures 8 and 9, the fishery has shifted from shelf-wide in the early 1970s, to the shelf edge in the 1980s and 1990s. As the inshore Canadian fishery has developed, proportions of the catch harvested by the inshore (Basin) fleet and offshore (Slope) fleet changed. Since 1998, the catch by the inshore fleet has exceeded that of the offshore fleet (Figure 12), and less than 5% of the silver hake landed from 2008-2011 were caught outside the basins.

FISHERY CATCH-AT-AGE AND WEIGHTS-AT-AGE

The commercial catch-at-age was constructed using a combination of at-sea observer samples, DFO port samples, and industry samples. Prior to 1995, the commercial catch-at-age was constructed using monthly age-length keys from samples collected by at-sea observers. Since the development of the Canadian fishery, quarterly age-length keys have been constructed using a combination of at-sea observer and DFO port samples. Industry samplers have contributed length frequency samples since 1999, and these are incorporated into the catch-at-age. A comparison using a reference collection was conducted by the primary ager indicating that agreement between current and past age determinations was 84% with a coefficient of variation (CV) of 3.9%, and was considered to be acceptable for production aging (Appendix Figure 6).

The commercial catch-at-age was calculated using the standard Population Ecology Division (PED) Catch-at-Age application. This calculation uses length frequency samples from at-sea observers, DFO port samplers, and industry samplers, quarterly age-length keys by sex from at-sea observer and DFO port samples, and separate sex length-weight relationships from the DFO July ecosystem RV survey (Table 4).

The detailed breakdown of the construction of the catch-at-age from 1999-2011 is presented in Table 5. From 1999-2003, the catch-at-age was calculated by quarter for domestic and foreign vessels and then summed to create the annual catch-at-age. Table 5 shows cases where there were no samples or catch (i.e. 4th quarter foreign in most years). Since 2004, only samples from the Canadian fishery have been used to construct the catch-at-age. With the exception of 2004, 2005 and 2009, quarterly catch-at-age was calculated and then summed to develop the annual catch-at-age.

In 2004, there were insufficient samples with otoliths collected to be able to construct meaningful quarterly age-length keys. As a result, half year age-length keys were constructed and applied to the half year size composition and landings data. In 2005, there were insufficient otoliths collected in the first quarter. As a result, the second quarter age-length key was applied to the first quarter length frequency and landings data. In 2009, there were insufficient otoliths collected in each of the quarters. As a result, half year age-length keys were constructed (quarter 1 combined with quarter 2; quarter 3 combined with quarter 4). These half year age-length keys were then applied to the quarterly length frequency and landings data (Table 5). The resulting commercial catch-at-age is presented in Table 6.

The age groups on which the fishery is conducted have changed over time (Table 6; Figure 13). Until the late 1980s, most of the catch was ages 2-4. The catch-at-age shows declining numbers for ages 4+ beginning in early 1990s. From 1990 to 1998, the catch shifted to predominantly ages 2 and 3. This temporal shift occurred during the transition of the foreign fishery on the shelf edge to the domestic fishery in the basins. The domestic fishery also used codends with 55 mm square rather than 60 mm diamond mesh and separator grates, resulting in changes in gear selectivity. Since 1999, a high proportion of the catch has been age 1 fish (Figure 14). The strong 2009 year class made a significant contribution to the catch-at-age 2 in 2011.

Most of the catch of 1 and 2 year old fish have been taken by the Canadian fleet fishing primarily in Emerald and LaHave basins. Age 1 fish are caught primarily in the second half of the year. Growth at age 1 is very fast and these fish reach a size where they are vulnerable to the fishery in the second half of the year. The foreign fishery took place primarily in the first half of the year, which will have contributed to the low partial recruitment (PR) of age 1 fish in this fishery.

The commercial mean weight-at-age is calculated using the output of the Catch-at-Age application. To calculate the annual mean weight-at-age the mean is calculated weighting each quarter by the catch in that quarter. Commercial mean weight-at-age was weighted by monthly catches prior to 1999. Annual mean weight-at-age is presented in Table 7.

As has been noted in the past for this stock, commercial weight-at-age declined from 1977 to 1994, but has stayed relatively stable at a lower level in subsequent years (Table 7; Figure 15). Noteworthy are the exceptionally high weight-at-age values for 1977 which appear to be erroneously high (Table 7).

COMMERCIAL CATCH RATES

When the foreign fleet was active, a catch rate series was developed for 1979-1999, incorporating month, country and NAFO area. Despite the usual suspicion of catch rate data, this series was thought to be acceptable because the same vessels, often with the same captains, fished the same limited area. Technological change was also very limited in this fleet. This CPUE series was discontinued when the foreign fleet was no longer permitted to fish in Canadian waters (Figure 16).

The previous two assessments (Showell et al. 2005; 2010) conducted an analysis of deviance using a Generalized Linear Modelling approach (GLM) with S-Plus 6.1 to determine magnitudes of influence of year, month and area on commercial catch rates of Canadian silver hake fishers. The CPUE was calculated as sub-trip tons per fishing day, with the model output predicting catch rates on an annual basis (Figure 17). The results of this analysis were not supported by Industry, due to concerns that assigning experience by fishing vessels failed to capture the required information, since captains were changing.

For this assessment, a CPUE series was developed for five selected vessels from 1999-2011 using a GLM model to standardize the effects of season, vessel and location. The per trip catch rates were calculated as:

$$\frac{L_{TRIP}}{h_{TRIP}} \cdot 24$$

where L_{TRIP} is the reported landings per trip and h_{TRIP} are the number of fishing hours reported per trip. Trips where effort was not recorded were not included in this analysis. These catch rates were standardized using a multiplicative model (Gavaris 1980) with fixed effects of:

Year – {1999:2011}
Vessel – CFV {105153,105507,104489,104994,160881}
Period – 1 {Dec-Feb}; 2 {Mar-May}
Area – {4Wl, 4Wk, 4Wh, 4Xn, 4Xm}

The *Area* factor was limited to regions north of 43°N to exclude fishing outside of the basin areas (Figure 18) which, for most recent years, is the core of the fishing activity. Influential data points (Cook's D>2), and obvious outliers identified from quantile plots were removed and the analysis was repeated. A reduced model with just the main effects is presented due to the lack of significant interactive effects.

The model showed a significant annual effect with an upward trend in catch rate during the most recent years (Table 8; Figure 19). There were also differences between periods, vessels and NAFO subunits. Specifically, higher catch rates were observed during period 1, and in 4W subunits (Figure 20). However, the increasing catch rate for the first few years can be attributed to increased fishing knowledge as the domestic fleet developed. Also, the decline in catch rates in 2009 and 2010, relative to 2008 is not substantiated by the biomass trends in the summer RV survey (Figure 26) and in part may have been influenced by market conditions. Consequently, the catch rate series was not considered an effective abundance index.

RESEARCH VESSEL SURVEYS

FISHERIES AND OCEANS CANADA BOTTOM TRAWL SURVEYS

Since 1970, DFO has conducted bottom trawl surveys of the Scotian Shelf area using a stratified random sampling design for tow locations. Survey coverage of the Scotian Shelf/Bay of Fundy region included a spring and fall series in 4VWX from 1979-1984 and a summer series in 4VWX from 1970-2012 (Figure 21). In addition, a March (spring) series in 4VsW was conducted from 1986-2010 but was discontinued in 2011 (Figure 22). While the 4VsW March survey covers the eastern part of the stock area, as well as some of the deeper waters along the shelf slope, it does not provide coverage of Emerald or LaHave basins which are important habitats for silver hake and where much of the domestic fishery now occurs.

The longest running series, the summer RV survey has been conducted on the Scotian Shelf and Bay of Fundy using four Canadian research vessels: the *A.T. Cameron* from 1970-1981, the *Lady Hammond* in 1982, the Canadian Coast Guard Ship (*CCGS) Alfred Needler* from 1983-2012 and the *CCGS Teleost* in 2004 and 2007. Based on an analysis of comparative fishing experiments by Fanning (1985), a conversion factor of 2.3 is applied to the total abundance and age-specific abundance series prior to 1982 to account for the effect of vessel and gear changes between the *A.T. Cameron* and the *Hammond/Needler* (Note: this is not a length-based conversion). The same conversion factor was used to adjust biomass estimates. No conversion factor is required between the *Lady Hammond* and the *Alfred Needler* for this period. An analysis of comparative fishing experiments showed no conversion factor was required between the *Alfred Needler* and the *Teleost* for silver hake (Fowler and Showell 2009).

Silver hake found in the Bay of Fundy have been considered to be part of the Gulf of Maine/Northern Georges Bank silver hake stock, rather than the Scotian Shelf stock. For analytical assessments, survey indices for total abundance, total biomass and total abundance at age are calculated for the Scotian Shelf portion of 4VWX (strata 440-483) and exclude the western portion of 4X and the Bay of Fundy (strata 484-495; Figure 21).

INDIVIDUAL TRANSFERABLE QUOTA FIXED STATION SURVEY

A mobile gear fixed station survey of NAFO Area 4X has been conducted by the ITQ mobile gear < 65’ fleet from 1996 to the present. This survey covers the western part of the stock area and includes sets in some inshore areas which are not sampled during the summer RV survey (Figure 23). The survey sampling distribution, however, has no overlap with the domestic fishery as it does not include any sets in the deep water of Emerald or LaHave basins. A comparison of trends in mean weight per tow shows some synchrony between the summer RV series, the 4VsW March and the ITQ surveys since 2000 but not in earlier years (Figure 24a; Table 9). Stratified total biomass from the ITQ and the 4VsW spring survey were used as indices in exploratory iSCAM model runs but not for VPA which was based entirely on the summer RV survey. The summer RV survey has been the main tuning index used for past analytical assessments of this stock and indicates much higher levels of biomass compared to the other series.

SUMMER RESEARCH VESSEL SURVEY CATCH DISTRIBUTION

Summer RV survey catches of silver hake indicate an increase in relative abundance and an expansion in spatial distribution on the Scotian Shelf from the 1970s to the 1980s (Figure 24b; upper panel). This period coincided with the switch from the Yankee 36 bottom trawl to the

Western IIA trawl and the increased catches in part may be attributed to this change in gear type. Catches in the 1980s occurred mainly around Emerald and LaHave basins and also Western and Sable Island banks. Noteworthy were the good catches which occurred along the shelf edge in the late 1980s. During the 1990s, most catches occurred on the central Scotian Shelf (Figure 24b; lower panel). A broader spatial distribution was apparent in the 2000s with higher catches in western 4X and the Bay of Fundy; a pattern which is probably linked to the recent increase in abundance in the Gulf of Maine as indicated by the NMFS fall surveys. Also apparent is that catches along the shelf edge are much lower now compared to the late 1980s.

SUMMER RESEARCH VESSEL SURVEY DEPTH COVERAGE

Of interest was whether or not the summer RV survey had provided complete sampling coverage of the depth range of the commercial fishery, particularly for those years when the foreign fishery was concentrated on the shelf edge (i.e. are the indices of abundance representative of the depth ranges occupied by the commercial fishery). A comparison of the number of sets by depth range from the survey and the commercial fishery grouped by 100 m intervals (1-100 m, 101-200 m, 201-300 m, 301-400 m, > 400 m) indicated that the summer RV survey has covered depths to 400 m in all years, with most tows occurring within the 50-200 m depth range (Figure 25; upper panel). Observed sets from the commercial fishery indicated that most tows were conducted between 100-300 m with very few tows at depths > 400 m (Figure 25; lower panel). (Note: The foreign fishery was restricted to depths > 100 m in 1977 and then to depths > 190 m in 1994*).*

Based on these data, it was concluded that the survey covered most of depth ranges/habitat where silver hake are fished commercially, with the exception of depths > 400 m, which made up only a small portion of the sets.

The summer RV survey depth range expanded in 1995 to include new strata on the shelf edge down to 750 m. Silver hake have been caught in these strata in eight years since 1995, with the biomass estimated for these deep strata accounting for < 1% of the total biomass in all but one year. This indicates silver hake have not been abundant at depths > 400 m during this time span. Since these strata have not been sampled throughout the full survey time series and silver hake are rare in these strata, they are not included in deriving indices of abundance for the stock.

SUMMER RESEARCH VESSEL SURVEY INDICES, WEIGHT-AT-AGE, LENGTH-AT-AGE AND SIZE COMPOSITION

The biomass index from the summer RV survey (after application of the *A.T. Cameron* vessel/net conversion factor for 1970-1981) shows a period of high but variable biomass from the early 1970s to the late 1980s followed by a period of lower biomass through the 1990s (Table 10; Figure 26). A sharp increase occurs in 2004 followed by a sharp drop in 2005 after which total biomass increases steadily to 2012. Current levels are comparable to those in the late 1980s. Both the age 2+ biomass (a proxy for spawning stock biomass [SSB]) and 2+ female biomass have also increased since 2008. Age 2+ biomass represents about 85% of total biomass over the time series. Age 2+ female biomass represents on average about 55% of total biomass over the time series with the exception of the past two years when it has dropped to 45%.

The summer RV survey age-disaggregated indices for strata 440-483 show that there are few ages beyond age 7 after 1990 and that ages 1-3 dominate the catches throughout the time series (Table 11; Figure 27). The 2009 year class appears to be strong at age 1 in 2010 and age 2 in 2011.

RV survey annual mean weights-at-age for silver hake by sex (equivalent to mid-year population weight-at-age) follow a declining trend from the early 1970s to the mid-1990s for ages 1-5 males (Table 12a; Figure 28; upper panel) and ages 1-6 females (Table 12b, Figure 28; lower panel), then level off or show an increasing trend to 2010, with a slight decline for older ages (both sexes) in 2011. Trends in annual mean length-at-age are similar to weight-at-age but less pronounced. A declining trend is apparent for ages 1-5 males (Table 13a; Figure 29; upper panel) and ages 1-6 females (Table 13b; Figure 29; lower panel) from the early 1970s to mid-1990s, then levels off or increases for most ages. The overall pattern in weight-at-age and length-at-age indicates that aging has been consistent.

The survey catch-at-size for silver hake in 2011 and 2012 was above the long -term average (1982-2010; Western IIA time series; updated from Emberley and Clark 2011) for lengths below 29 cm, but below average for larger fish (Figure 30). Modes at 17-19 cm (approximately age 1) and 25-29 cm (approximately ages 2-3) are typical of long-term patterns. A progression in modal size is apparent from 2011 (22-23 cm) to 2012 (25-27) and likely reflects the increase in size of the 2009 year class, which was strong at age 1 in 2010 and at age 2 in 2011 (Figure 30).

RECRUITMENT

Estimates of age 1 abundance are available from the summer RV survey (Table 11). Age data are not available for the 2011 year class, but an approximation can be made based on the minimum abundance at length (21 cm) between the two modes in the catch-at-size from the 2012 summer RV survey. Recruitment has been variable but generally above the long-term average in recent years. The 2002, 2004, and 2005 year classes were large, however, the 2006, 2008 and 2010 year classes were near average abundance (Figure 31). The 2009 year class is the largest in the time series. Current prospects for the 2011 year class (based on survey length data) are that it is above average.

CONDITION FACTOR

Previous analyses (Showell et al. 2005) have shown that both condition (weight for given length, males and females averaged) and mean length-at-age have declined from 1971 to 1995, with the two factors combining to produce very low mean weights-at-age relative to the early period in the time series. An analysis of condition factor, (updated from Emberley and Clark 2011) using Fulton's K (weight/length^3) rather than predicted weight at 25 cm, indicates that condition declined for silver hake (length range: 21-44 cm) from 1970 to the early 2000s, followed by an increase to 2007, then a subsequent decline to 2012 (Figure 32). Condition is currently near the lowest level in the time series and has been below the long-term average (1970-2012) since 1993.

OVERALL SEX RATIO AND PROPORTION FEMALE AT AGE AND LENGTH

Annual sex ratios from the DFO summer RV survey (1970-2012) based on annual estimates of total stratified abundance by sex indicate that more female silver hake were present in survey catches from the 1970s to mid-1980s, followed by roughly equal (1:1) proportions of males and females up to the late 2000s (Figure 33). Over the past two years, males have dominated catches but only slightly.

Silver hake are sexually dimorphic; females live longer and grow larger than males. Survey total abundance at age data by sex indicates that the proportion of females at age increases after age 2; with about 80% of catches being female by age 5 (Figure 34). It appears that few males survive beyond age 5, with none caught above this age in the survey in many years. Survey total abundance at size data indicates that the proportion female at size increases rapidly after 30 cm, with > 80% female at 32 cm (Figure 35). This implies a higher natural mortality (M) on males compared to females.

MATURITY AT SIZE

An analysis of the proportion of mature fish (maturity stages 2-8) at size for male and female silver hake was conducted using maturity stage data grouped into 10-year periods. While the size at 50% maturity tends to be larger for females compared to males, a temporal shift was apparent in the size at maturity for both sexes with a general progression of decreasing size at maturity over the time series (Figure 36). Silver hake are currently maturing at smaller sizes (2010-2012) compared to the early part of the time series (1970-1979). For males and females respectively, the current size at 50% maturity is 20 cm and 21 cm for 2010-2012 compared to - 24 cm and 26 cm for 1971-1979. A similar size at 50% maturity was reported for the early period of the survey series by Doubleday and Halliday (1976).

SEASONAL AND GEOGRAPHIC DIFFERENCES IN ABUNDANCE, SIZE AND AGE COMPOSITION

The seasonal (spring, summer, fall) and geographic (shelf slope, shelf basins) size and age composition for silver hake were compared using the average total stratified abundance at size and age from spring, summer and fall surveys conducted from 1979-1984. In this analysis, data were compared for basin strata (461 and 471) and slope strata (466 and 478).

Overall, there were more silver hake caught in the basins in all seasons compared to the shelf slope (Figure 37). A modal progression in size was apparent in both areas from spring through summer and fall, however, there was not much difference in abundance at size between areas with exception of spring surveys when larger fish were present along the shelf slope. Fall surveys also indicated the presence of young of the year fish (0 group; mode at 5-7 cm).

Similar proportions of age 1 fish were observed during spring surveys for both regions (Figure 38). Proportionally, more age 2 fish occurred in Basin strata but more ages 3-4 fish occurred in shelf slope strata. During summer, there were similar proportions at age for both regions, while in the fall, there was a higher proportion of ages 1-2 in basin strata and ages 3-5 in the slope strata. This pattern suggests that some of the larger fish over-winter on the shelf slope (feeding area), move onto banks during summer (spawning area) and then back to the slope region in fall (feeding area).

A modal progression in size was also apparent from the total stratified abundance at size for the 2012 spring and summer RV surveys (Figure 39). The spring survey showed a large peak in abundance at 12 cm, followed by a second peak at 26-27 cm (approximately ages 1 and 2-3). The summer RV survey showed a progression in size of age 1 fish with the peak occurring at 17-18 cm. A second mode is observed at 26-27 cm, which is the same as in the spring survey (ages 2-3), indicating that growth is less for these age groups.

SURVEY Z, COMMERCIAL CATCH-CURVE Z AND RELATIVE F

Total mortality (Z) was calculated from summer RV survey catch-at-age data as follows:

$$Zagex = \ln\left(\frac{Catch\ Age\ x_{year\ y}}{Catch\ Age\ x+1_{year\ y+1}}\right)$$

A comparison of Z by age from the full survey time series indicates that Z has generally increased with age from ages 1-4, but is fairly consistent for ages 4 and above. Z for older ages has peaked above 1.5 (Figure 40).

Total mortality, Z, can be calculated as the slope from a linear regression of ln(catch) against age, using either commercial catch-at-age data or survey indices. Catch-curve Z's were calculated using the aggregated catch from 1993–2011 separately for the commercial catch and the survey catch (Figure 41). The slope was taken from a regression of ages 3-7. The Z from both regressions were above 1, but the commercial catch-curve Z was markedly higher. This reflects that silver hake disappear more quickly from the catch than from the survey. The difference in the slopes can be used to derive a measure of PR patterns to the fishery.

Relative fishing mortality at age (Relative F) was calculated as the ratio of the age-specific fishery catch-at-age over the age-specific summer RV survey catch-at-age. This statistic does not give an absolute estimate of the true fishing mortality, but trends over time can be useful in examining exploitation patterns. If one assumes that the catchability of silver hake in the RV survey is flat-topped, then the ratio of Relative F for older ages to the average Relative F for ages 3 and 4 can be used as a proxy for PR patterns in the fishery (Figure 42). This indicates that PR is strongly domed in recent years, but may have been flat-topped during the period of the foreign fishery. In the recent period, PR has declined to roughly 0.12 by age 7.

Relative F and survey Z were smoothed using a three-year running average and compared for ages 1, 2-3 and 4-6. For age 1, there has been an increase in both Z and Relative F since the mid-1990s, which is coincident with the development of the Canadian fishery (Figure 43). For ages 2-3, Relative F declined in the early 1990s (end of the foreign fishery) but Z remained high with no decline. Similarly, for ages 4-6, Relative F declined in the early 1990s but Z remained high with no decline. These patterns for Z and Relative F indicate that fishing mortality has clearly increased on age one fish as the Canadian fishery has developed. For older ages (2-3 and 4-6), the pattern is less clear. Since F appears to have declined but Z still remains relatively high, it is possible that M on these age groups has increased.

While silver hake are caught throughout much of the survey area (Figure 24b), the commercial fishery takes place almost entirely within the boundaries of strata 461 and 471. These strata account for between 7% and 30% of the catch of silver hake in the summer survey. An examination of data from surveys conducted in February and March (1978-1984, Figure 7) similarly indicates that these strata only account for 3-18% of the survey biomass index.

Given the geographic restrictions on the distribution of the fishery, the low Relative F is not surprising. Even if the fishery caught all the silver hake in the area fished, it would seem unlikely that the exploitation could exceed 30% (F = 0.5), the maximum proportion of the stock estimated to occur within these strata. With Z reaching levels of 1.5 and above, this also suggests that M is high and may exceed 1.0.

Differences in mortality rates between male and female silver hake were explored using both survey and fishery data. Commercial catch can be partitioned by sex from 1999 onward. Using the average catch-at-age for this period, Z for males is 2.4 while for females it is 1.5 (Figure 44). The survey Z's are also generally higher for males than for females and have increased for both sexes in the recent period. Survey Z was similar for males and females at age 1 in the period prior to the commencement of the domestic fishery, but in the recent period (after 1999), Z is higher for males even at age 1 (Figure 45). At age 4, the Z for male silver hake is 1.9; 0.8 higher than for females.

Both commercial data and survey data indicate Z is much higher for males than females. Since males are not more common in the commercial landings, this difference must reflect higher natural mortality. If M is 0.8 – 0.9 higher for males than females, then M must exceed 1.0 for males and may well be in the range of 1.0 for both sexes combined.

ECOSYSTEM CONSIDERATIONS

DIET AND PREDATION

Diet analyses were conducted as per the methods outlined in Cook and Bundy (2010) for silver hake sampled on the Scotian Shelf (strata 440-483) during summer RV surveys between 1999 and 2009. Figure 46 shows the rate of increase of observed species in silver hake diets as more stomachs are examined. Results suggest that the diet of silver hake on the Scotian Shelf has been well described in recent years with the main prey items being decapod shrimp (Unidentified decapoda), sand lance (Ammodytidae) and krill (Euphausiidae: Figure 47). There were no appreciable dietary changes with size (data not shown) and although cannibalism has been suggested to be important source of mortality for silver hake elsewhere (Link et al. 2012) and on the Scotian Shelf in the 1980s (Waldron 1992), it does not appear to be a large contributor to the overall mortality on the Scotian Shelf now. The most common predators of silver hake were monkfish, pollock, white hake, Atlantic halibut and cod (Figure 48). Analyses of seal diets on Sable Island indicate that silver hake are also a prey item for seals (Bowen and Harrison 2007).

HABITAT ASSOCIATIONS

Determining the relationship between species distribution and the habitat variables temperature and depth for trawl data was done using the methods outlined by Perry and Smith (1994). Cumulative distribution functions (cdf) described species associations with temperature and depth as the cdf for each habitat variable (x) for each set (i) in a stratum (h) incorporating the survey design as follows:

$$f(t)=\sum_h \sum_i \frac{W_h}{n_h} I(x_{hi}) \qquad I(x_{hi})=\begin{cases}1, & if\ x_{hi} \le t;\\ 0, & otherwise.\end{cases}$$

where W_h is the proportion of the survey area in stratum h, n_h is the number of sets performed within the stratum and t is an index ranging between the minimum and maximum levels of the observed habitat variable. Similarly, the cdf for catch of a particular species within a set (y_{hi}) with specific habitat conditions is:

$$g(t)=\sum_h \sum_i \frac{W_h}{n_h} \frac{y_{hi}}{\bar{y}_{st}} I(x_{hi}) \qquad I(x_{hi})=\begin{cases}1, & if\ x_{hi} \le t;\\ 0, & otherwise.\end{cases}$$

By scaling the catch to the stratified mean ($\bar{y}_{st}$) the sum of g(t) equals 1 across all values of t. If large values of $y_{hi}/\bar{y}_{st}$ are consistently associated with a particular habitat condition, this suggests strong associations. Randomization tests were used to test the significance of habitat associations. The test statistic, L, is the maximum absolute difference between the f(t) and g(t) curves. Statistical significance of L was determined by its comparison with to the distribution of values from 2999 random perturbations of the data (3000 repetitions, including L; Perry and Smith 1994).

Figure 49 shows an example in which f(t) is the effort as a function of depth and g(t) is the catch. The median of the catch and the maximum difference in the two cumulatives are shown. These metrics are shown as time series in Figure 50.

The cumulative catch of small (< 20 cm) and large (> 20 cm) silver hake was examined in relation to salinity, temperature and depth encountered during the summer RV survey with the location of the maximum deviation of cumulative distributions from catch and effort interpreted to be indicative of habitat preference. Median salinity, temperature and depth preferences of small silver hake are consistently greater than the median values for the survey, as are the median temperature preferences of large silver hake. The most stable habitat association for small silver hake was that with depth as fish are captured in the summer at a much higher rate at depths between 150 m and 200 m across all years. The distribution of juveniles and adults is associated with warm bottom temperatures of 5-10°C. Silver hake, regardless of size, were found at higher water temperatures than many other species with an overall mean of 8.3°C.

BYCATCH

Although the silver hake fishery primarily uses small mesh, bycatch is limited because fishing activity is restricted to deeper water in the inshore basins or off the edge of the shelf. A mandatory separator grate with vertical bars spaced at 40 mm inserted into the codend restricts the catch of larger fish.

DFO at-sea fishery observers are routinely deployed to the silver hake fleet to monitor catches and discards of the directed species and bycatch. While observer coverage levels can be calculated in several ways (% trips, % days fished), the proportion of the main species observed to landed catches is most representative. Using this method, observer coverage on the silver hake fleet in recent years (2002–2011) ranged from approximately 2% to 22%, with an average of 6%.

Based on observer records (Table 14), 95% of the catch in observed silver hake trips (by weight) was the directed species. Discarding of silver hake was minimal, at 10.1% of the total catch. The most common bycatch species were Atlantic herring (1% of total catch), red hake (0.8%), unspecified redfish (0.4%) and spiny dogfish (0.4%). Other species of possible concern occur rarely as bycatch such as basking shark (0.1%).

FISHERY FOOTPRINT

The relative impact of the fishery on the Scotian Shelf was examined through spatial analysis, a technique in which the potential fishing area of the Scotian Shelf and Bay of Fundy was divided into a total of 1117 ten minute cells. Each cell was classified as belonging the top one third, middle third or bottom third of all silver hake landings from 2007-2011 (Figure 51) and only 2011 (Figure 52). This characterizes the relative importance of the cells to the fishing sector. Fishing activity was also characterized by the number of vessel-days that the cell was fished from 2007-2011 (Figure 51) or during 2011 alone (Figure 52) Most cells were occupied for less than two weeks and only a few cells contributed to most of the landings. An analysis of the 2011 fishery shows a smaller footprint but similar results with less than 10 cells contributing the top two thirds of landings and more than 60 days of fishing effort (Figure 52).

The fishery footprint was also examined by dividing the Scotian Shelf into two minute cells and calculating the total silver hake taken as directed catch or bycatch for each cell (Oceans Coastal Management Division, Fisheries and Oceans Canada). This analysis shows, most of the fishing occurs in the basins, with relatively small amounts taken on the shelf edge and the western portion of 4X (Figure 53).

MODELLING

VIRTUAL POPULATION ANALYSES

Estimates of population abundance in numbers for the middle of the terminal year were obtained by calibrating a simple VPA with the bottom trawl survey indices. This class of models makes the assumption that errors in the observed catch-at-age are negligible compared to the errors in the abundance indices. Such an assumption allows a deterministic application of the catch equation recursively to derive the abundance of a year class at any time given the observed catch-at-age and an estimate of abundance for that year class at only one point in time.

A series of model formulations were investigated. The intention was to begin with a formulation which would closely resemble the VPA formulation used in the last assessment. This formulation had a serious retrospective problem, so further formulations were employed which were intended to address the potential causes of the retrospective. Misspecification of natural mortality, or changes in natural mortality was one potential problem. Misspecification of PR patterns with age could also have contributed to the retrospective problem. Finally, errors in historical landings data or changes in stock structure or dynamics could have contributed to the retrospective.

The initial model formulation (basic long-term), expected to be consistent with formulations used in past assessments, was:

Observations

$C_{a,y}$ = catch-at-age for *a* = 1 to 9 and *y* = 1978 to terminal year.
$I_{s,a,t}$ = survey abundance index for:
s= RV survey ages *a=1 to 7, years t = 1978.5 to present.*

Parameters

$\theta_{a,y}$ = *ln* abundance for *a* = 1 to 8 in *y* = terminal year.
κ_{sa} = calibration constants for RV and ITQ surveys for ages *a = 1 2,…7.*

Structural Conditioning

M assumed to be 0.4 for all ages and years.
Fishing mortality on age 9 for 1978 to 2011 assumed to be equal to the population number weighted average fishing mortality on ages 7 and 8.

Error Conditioning

Catch-at-age error was assumed negligible compared to the index error.
Error on the *ln* index observations was assumed to be independent and identically distributed.

Estimation

Parameters were obtained by minimizing the objective function.

$$\sum_{i,a,y}\left(I_{i,a,y} - \hat{I}_{i,a,y}[\theta,\kappa]\right)^2$$

Additional formulations which will be discussed were:

Basic short-term:

For this VPA run, the set-up was identical to the Basic long-term except the data series was truncated to include landings and survey data starting in 1993.

Around the corner (AC):

For this VPA run, the set-up was the same as the basic long-term except that additional parameters are estimated as:

$\theta_{a,y}$ = *ln* abundance for *a* = 1 to 8 in *y* = terminal year, and for *a* = 9 in *y* = 1996 to terminal year.

Around the corner, flattop q (AC flattop):

For this VPA run, the set-up was the same as the AC except:

κ_{sa} = calibration constants for RV survey for ages *a = 1, 2, 3, 4-7.*

Long-term estimate M:

For this VPA run, the set-up was identical to the Basic long-term except that M was estimated in years 1993–resent in VPA for ages 3 and 4 as a block and for ages 5+ as a block.

Short-term high M (high M):

For this VPA run, the set-up was identical to the Basic short-term except that flat-topped survey q was used (as in AC flattop), M was assumed to be 0.7 for ages 3 and 4 and 1.0 for ages 5 – 9, and fishing mortality on age 7 for 1993 to 2009 assumed to be 12% of the fishing mortality on age 3.

VIRTUAL POPULATION ANALYSIS RESULTS AND DISCUSSION

The basic long-term VPA did not perform well. There was a strong residual pattern – all negative before 1993 and all positive after 1993. The high landings in the early part of the assessment period result in a high population estimate, while low landings since 1994 result in low population estimates (Figure 54). This dichotomy is not consistent with the survey trends, and thus results in a strong pattern in residuals. This also results in an implausible pattern in survey q at-age.

The survey q at-age increases continuously from 0.2 at age 1 to 0.8 at age 4 and 4.1 at age 7, reflecting the mismatch in survey and commercial fishery catch at-age. Without something to inform the VPA that there are still old fish in the population, the model estimates the population in accordance with the commercial catch curve, resulting in a q that is unreasonably high for older ages.

The divergence in survey and commercial catch-curves indicates that the commercial data likely overestimates mortality in the population. This is evidenced in the VPA output, with fishing mortality estimates well above 1.0 in many years. Fishing mortality rates this high seem unlikely, given the restricted geographic range of the fishery relative to the population distribution. In particular, high F estimates for older fish are unlikely, given that the separator grate should exclude larger older fish from the catch.

The AC formulation resolves some of these issues. By estimating the population for more cohorts, the VPA is freed from the assumption that the fishery has flat-topped PR. This formulation has lower fishing mortality estimates, and strongly domed PR, with F at older ages much lower than at ages 3 and 4 for years after 1993. The population biomass estimates in recent years are higher from this formulation than from the base model (Figure 54). The survey q estimates from this formulation, however, continue to increase with age, and exceed 1.0 for age 7.

The AC flattop formulation is very similar in output to the AC formulation. Biomass estimates in the most recent years are slightly lower, and q for the oldest age block (4–7) is 0.8. Of these three formulations which use the full time series of data and a constant M of 0.4, the AC flattop seems least problematic.

The population abundance at age shows the 2009 year class to be very strong, and also indicates some recent improvement in population age structure (Figure 55). Abundance at ages 4–7 has increased to levels not seen since the early 1990s. This is consistent with the observations from recent surveys.

Although the AC flattop resolves some of the diagnostic concerns, it still has difficulty fitting the data. The residuals display a strong pattern (Figure 56) which suggests the difficulty of fitting the data from the full time period remains. A comparison of the VPA biomass estimates with the RV biomass index illustrates the problem (Figure 57). The range in annual biomass estimates over time is much greater than the range in survey indices.

Annual q's can be estimated by dividing the summed survey indices-at-age by the VPA population estimate. The result is a trend in q estimates over time (Figure 58), with much higher q's after 1993 than before 1993. This will result in a pronounced retrospective pattern, as each additional year of data reduces the influence of the low q's in the early period on the overall average q's.

The assumed M of 0.4 seems low in relation to the high Z estimated from both commercial and survey data. Furthermore, there is a mismatch in trends in survey Z and Relative F over time for silver hake which seems to indicate that natural mortality may have increased over time. An increase in M for the recent period may help to address the patterns seen in the VPA residuals, since a higher M in the recent period will result in higher population estimates.

When M is estimated in the VPA for the period after 1993, the estimates of M are slightly above 1. This does not seem unreasonable in comparison to the Z estimates derived from survey or commercial fishery data, which are also above 1. The population biomass estimated from this formulation is higher in recent years than for other formulations explored. The population biomass, however, still poorly tracks the trend in the survey, where the biomass index in recent years has returned to similar levels to those seen in the early part of the series.

The mismatch between data from pre-1993 and post-1993 is very difficult to reconcile, and has not been adequately addressed in any of these model formulations. The switch in residuals from positive to negative in the VPA output coincides with the period when the fishery switched from foreign to domestic and from the shelf edge to the basins. The use of a separator grate in the net and the switch to square mesh from diamond also occurred at this time. In addition, large scale changes in the ecosystem were underway at this time, with the collapse of the cod stocks on the eastern Scotian Shelf, and increased natural mortality for cod also estimated around this time (Mohn and Rowe 2012). It may be that there are several factors contributing to the difficulties in modelling the population through this period of upheaval which available data may not be sufficient to resolve.

In light of the difficulties in developing an acceptable model formulation for the full time series, additional formulations were explored which exclude survey and landings data from before 1993. The basic short-term formulation was not an improvement on other model runs. This formulation estimates very low population biomass. With low landings, and few old fish present in the catch, this formulation had no information to indicate the population may be high, so it estimated very low biomass (Figure 54) and high F. The survey q's from this model increased with age, peaking at over 13.0 for age 7. This is utterly implausible.

Additional runs were conducted using higher natural mortality, with the values for M informed by the survey Z and by the M estimated in earlier model runs. In addition, domed PR was used. The degree of doming was informed by the PR estimated from Relative F at-age. Some exploratory runs were undertaken with the goal of finding levels of M which were consistent with the Z and Relative F estimates and which also resulted in flat-top survey q's. There is no reason to expect that survey q would not be flat-topped, so this was used as a diagnostic in deciding what M to use.

The short-term high-M model appears to provide a reasonable fit to the data series used (Figure 59). There is no clear pattern in the residuals from this model (Figure 60). The population numbers indicate that the 2009 year class is the strongest in the time series

(Table 15), and in 2012 at age 3 it was twice the size of any other year class at age 3. The fishing mortality estimates are strongly domed (Table 16). Fishing mortality is also consistent with the expectation that F should not generally exceed 0.5, given the restricted proportion of the population which the RV survey indicates is in the basins and available to the fishery. In addition, the q at-age estimates are plausible as estimates of survey catchability, and are flat-topped (Table 17).

While this model formulation appears to fit the data, there are some reasons for concern about its suitability. While informed by the exploratory data analyses, the selection of values for M and PR in this formulation needs additional exploration. Natural mortality is clearly high and PR must be domed, but the exact magnitude of these parameters is difficult to precisely estimate. Furthermore, the level of bias indicated in parameter estimates is unusually high.

While this VPA appears to reasonably represent the population, the reliability of projections may be questionable. With a very large 2009 year class at age 3 in 2012, the available yield for 2013 and future population biomass trajectory are completely dependent on the magnitude of natural mortality. Current levels of fishery removal are unlikely to be excessive, with the population biomass estimated at over 100,000 t, but there are many assumptions and uncertainties in the parameterization of this model. Exploration of other simpler approaches to providing advice to management should be considered.

STATISTICAL CATCH-AT-AGE MODEL

Silver hake population abundance was modelled using an iSCAM, developed by Steve Martell (University of British Columbia). Information on the model, structure, code is available through the ISCAM project website.

Basic Model

The data used in the initial (Basic) model were total landings for the foreign (1977- 2004) and domestic (1994-2011) fisheries, summer RV survey abundance indices (1977-2011), commercial catch-at-age data split at 1996 into foreign and domestic fisheries and numbers at age from the summer RV series. Parameters for the Von Bertalanffy (VB) growth equation were assumed to be 49.16 cm ($L\infty$), 0.247 (k) and -0.95 (t_o). Length-weight parameters were 2.66x10-6 (a) and 3.24 (b). The age at 50% maturity was calculated as 2.54 from the equation ln(3.0/k) where k is the Von Bertalanffy parameter and equal to 0.247. Natural mortality, M, was fixed at 0.4.

The selectivities chosen for the three gear types were a selectivity coefficient for the domestic fishery; logistic selectivity coefficient for the foreign fishery (age at 50% maturity = 2) and a constant cubic spline for the RV survey. A penalty weight for a dome-shape was applied to the domestic fishery. The stock-recruitment model was Beverton-Holt and the fraction of Z taking place prior to fishing was set at 50%. The minimum proportion to consider in age-proportions was set to 0.005. Natural mortality was increased in steps of 0.05 to see the effect on the objective function and model parameters. The minimal objective function occurred in the area of 0.4 - 0.5 M. The estimate for initial biomass did not change much between 0.4 and 0.45 M compared to 0.2-0.25 M, and the estimate of current biomass remained below the initial biomass (Table 18). Therefore, an M = 0.4 seemed a reasonable point at which to fix M.

Results: Basic Model

The initial population biomass of 468 kt population declined rapidly in the early 1990s and only recovered to a number above B_{MSY} in the last few years (Figure 61). The fit between the model and the survey series was poor initially but improved in the 1998-2011 period. With selectivity and natural mortality fixed, the model attributed the decline in the population to very high fishing mortality which only declined in the most recent few years (Figure 61). A retrospective plot of

SSB showed an upward bias in the estimates as the terminal year was removed with an inflection point near 1995 around which the biomass estimates rotate (Figure 62).

Model Variations

Three variations on the basic model were tried to introduce some flexibility that would allow the model to fit catch and survey data in both the early time period and current conditions. The first variation (Twos) split the survey time series at 1993 by attributing the surveys before and after to different gears. This allowed the model to treat the earlier (1977-1992) survey abundance index separately from 1993-2011. The second (Short series) shortened the time series to the recent period 1993-2011. Within a few years around 1993, a codend separator grate and 55 mm square mesh were introduced to reduce bycatch, the fishery shifted from a primarily foreign fleet fishing the shelf edge to a domestic fleet fishing the basins of the Scotian Shelf and the proportion of younger fish in the landings increased. The third variation (Smart model) was to add a penalized time-varying selectivity for the survey gear. The selectivity for the RV survey was set to a time varying cubic spline with age-nodes. A penalty weight of 200 was added to limit how quick selectivity could change over time:

Penalty wt for 2nd diffs over time w=1/2*sig^2)

Output and objective functions for the four models and other formulations are shown in Table 18. Estimates of total biomass and SSB, depletion and survey abundances are shown in figures 63-66.

<u>Results: Model Variations</u>

Trends in biomass were similar to the basic model (Figure 63). Recent biomass estimates were all lower than the basic model and the stock remains below 80% of B_{MSY} in the two survey and Smart models (Figure 64). Both of these models improved the fit between predicted and observed RV abundances at the start of the time period (Figure 65). Shortening the time series to 1993-2011 had a large effect on the model estimates for total and SSB. The short model estimates were one half or less of the estimates from the models using the whole time series. Catchabilities were all above 1, with the exception of the two survey model. The early survey catchability was 0.6 while the more recent (1993-2011) survey had a very high q of 2.1.

Conclusions

All of the model runs showed that population status has been poor since about 1990 and has only improved in the last few years. Splitting the RV survey and allowing selectivity to vary both improved model fit, as shown by the decrease in retrospective patterns in abundance as the terminal biomass year was removed (Figure 66). Shortening the time series had a larger effect on biomass estimates than splitting the RV series or assuming changes in survey q through time. The model is sensitive to the minimum proportions considered in the age composition data. A contraction in age composition in the mid-1990s and declining catches are explained by very high fishing mortality. In general, iSCAM had trouble resolving conflicting signals from the survey indices and commercial catches. A random walk mortality or penalized time-varying selectivity gave the model more flexibility and improved the fit between the observed and predicted survey indices. As the survey vessel and gear have been mainly consistent since 1982, it is likely that natural mortality has changed.

The iSCAM model is also sensitive to the choice of selectivity parameters. As the options for these are very broad, an investigation and validation of the kinds of selectivity parameters appropriate for the commercial and survey gear would improve confidence in the model output. Development of the data and control files for the iSCAM model is straightforward, and the associated R scripts allow quick, visual examination of different hypotheses.

ASAP (AGE STRUCTURED ASSESSMENT PROGRAM) MODEL

Development of an ASAP Statistical Catch-at-Age Model

A statistical catch-at-age model, ASAP (v.2.0.20, Legault and Restrepo 1998), obtained from NOAA Fisheries Toolbox (NFT) was explored for the Scotian Shelf silver hake assessment. ASAP was considered as an alternative modelling framework in this assessment for a variety of reasons including: the ability to explore alternative model formulations to counter/lend support to the VPA, ISCAM and production model results, the ability to explore starting condition assumptions and estimate stock-recruit relationship internal to the model, and the ability to explicitly model data uncertainty. Given some of the changes that have occurred in the silver hake fishery (gear, selectivity, targeting and management), an age structured model such as ASAP provides a very flexible platform to account for the time varying dynamics within the population.

As described at the NFT software website, ASAP uses forward computations assuming separability of fishing mortality into year and age components to estimate population sizes, given observed catches, catch-at-age, and indices of abundance. Discards can be treated explicitly. The separability assumption can be partially relaxed by allowing fleet-specific computations and allowing the selectivity at age to change in blocks of years. Weights are input for different components of the objective functions which allows for configurations ranging from relatively simple age-structured production models to fully parameterize statistical catch-at-age models. The objective function is the sum of the negative log-likelihood of the fit to various model components. Catch-at-age and survey age composition are modelled assuming a multinomial distribution, while most other model components are assumed to have lognormal error including total catch in weight by fleet, survey indices, stock recruit relationship, and annual deviations in fishing mortality. Recruitment deviations are also assumed to follow a lognormal distribution, with annual deviations estimated as a bounded vector to force them to sum to zero (this centers the predictions on the expected stock recruit relationship). For more technical details, the reader can refer to the technical manual described by Legault 2008.

ASAP Model Configuration

In developing the ASAP model formulation, 12 model configurations were explored. These model configurations took advantage of ASAP's flexibility of handling selectivity time blocks in the fishery to reflect changes in gear and mesh regulations over time. A summary of selected ASAP model configurations runs is presented in Table 19. The decision to use an age 9 plus group in the ASAP model configuration was based on the working group's (WG) recommendation and the likelihood of estimating older ages with little precision due to the appearance of a continued truncation in the age structure in most recent years.

Initial exploratory model runs used data back to1977 and allowed selectivity at age to be freely estimated for both the fishery and the RV summer survey. In subsequent explorations, selectivity for both the fishery and the RV summer survey were then fixed at 1.0 for ages 2 and older. The initial choice for the flattop selectivity pattern for was informed by the VPA results, which suggested increasing catchability with age, and the likelihood calculated in ASAP for dome versus flat-topped scenarios. Additionally, there was no known biological mechanism to suggest decreasing selectivity with age.

Starting with a single selectivity for the fishery (i.e. the same selectivity assumed for years 1977-2011), the diagnostics were examined for trends in age composition residuals (Run 1, Table 20a). Notably, there were strong trends in the age composition residuals with runs of positives and negatives. Several intermediate models were then explored for various selectivity blocks to resolve the patterning in the residuals based on known major changes in the fisheries regulations (Table 20a-c), specifically, periods of changes in mesh regulations in years 1977, 1993 and 1999. The period 1993 encompasses major implementations of the SMGL and a major shift in the participation of foreign fleets with restricted participation of the Russian vessels such that only Cuban vessels remained as the foreign fleet. It is also noteworthy to recognize that the 1990s marked the development of a directed domestic fishery by Canadian vessels. Given these major changes in the fishery and the difficulty to resolve a model with reasonable diagnostics, the WG sought an alternative model exploration that started the model time series in 1993. This resulted in a substantial improvement in the model diagnostics both in the likelihood components and patterning of the residuals. The model with two fishery selectivity time blocks (1993-1998 and 1999-2011) and a single time invariant selectivity block for the RV summer survey offered the best fit to the aggregate and age composition (Run 12; Table 20c). Subsequent examination of model 12 fits to the landings data suggested a need for additional down weighting of the landings CV's. A constant of 0.2 was added to each of the landing's CV and resulted in further improvement of model 12.

The effective sample size (ESS) estimated for both the fishery and survey catch-at-age (which are both treated as multinomial) was compared to the input ESS in an iterative fashion until the ESS specified more or less matched the model estimated value, or until no further improvement in trying to match the estimated value could be made. Additionally, following Francis (2011), minor adjustment in the ESS's were informed by the overall fit between the predicted and observed mean age of the catch. The final ESS for the fishery was set to 50 for the commercial landings and 10 for the RV summer survey.

ASAP Model Diagnostics (Model 12)

As indicated earlier, model 12 fits to the fishery catches were reasonable, with no strong patterning of residuals over time and generally in good agreement between the model and observed catches (Figure 67). Fishery ESS of 50 appeared reasonable (figures 68 and 69), and achieved reasonable fits between the observed catch-at-age (figures 70a-70c) with no large runs or obvious year class effects apparent in the residual patterning (Figure 71). Model fits to the observed mean catch-at-age were generally acceptable, with a Root Mean Square Error (RMSE) equal to 1.28 (Figure 69). The commercial fishery selectivities were estimated with domed pattern (Figure 72) with higher selectivity for ages 1-2 and 5-7 in the second block. This is consistent to the period when the domestic fleet was targeting more of the smaller fish sizes (19-24 cm) and the foreign fleet class 7 vessels targeting > 24 cm fish.

Fit to the summer RV survey index exhibited no strong residual patterning (Figure 73). The input ESS was generally supported by the modelled estimates (Figure 74 and 75) with no strong patterning to the index age composition (Figure 76). Fits to the mean age were reasonable (RMSE = 1.05) lending additional support to the input ESS (Figure 75).

The summer RV selectivity was estimated as flat-topped, with almost 100% recruitment at ages 2 9, Figure 77). The summer RV survey catchability (q) was approximately 0.71, suggesting that the survey is 70% efficient (Figure 78). This could possibly be related to the observed decline in the resource in recent years, thereby resulting in limited availability to the survey gear. However, caution needs to be taken when interpreting the area swept converted q's given the assumption inherent in the calculations, such as constant tow length, no herding by the gear, 100% of survey area is habitable and the survey area is identical to the stock area which the catches come from.

ASAP Model Results

The assessment indicates that the total biomass ranged from 31,422 to 83,338 t during the assessment time period, with current biomass in 2011 estimated at 60,687 t (Table 21; Figure 79). Currently total SSB is estimated at 33,988 t. Current F's are near historic lows (Figure 79), with F_{avg} 4-9(2011) = 0.11 (Table 22; Figure 79). Fishing mortalities at age are also presented in Table 22. Age 1 recruitment over the past two decades has been relatively stable between 2006 and 2009. There was a strong 2009 year class, with age 1 recruitment estimated at approximately 617 million fish and considered highest over the assessment time series. The other relatively strong recruitment events over the assessment period were spawned in 1999 and 2002 when SSB were at moderate stock sizes (approximately 17,000 t and 14,000 t, respectively; Figure 80). The current population structure is comprised primarily of ages 1-3, consisting of approximately 93% and 96% of the population in 2010 and 2011, respectively. Since 2009 and onward, there has been some subtle expansion in the ages 5+ group, however, they are still relatively minor compared to the younger age classes (Table 23 and figures 81-82).

Markov chain Monte Carlo (MCMC) simulations were performed to obtain posterior distributions of total biomass, SSB, and F time series. Two MCMC chains of initial length of 10,000 were simulated with every 200th value saved. The trace of each chain was inspected for trends and suggested good mixing of the random draws. As the MCMC simulations appear to converge, the 90% probability intervals, as well as plots of the posteriors for 2011 total biomass and SSB are shown in figures 83-84.

Retrospective analyses for the 2006-2011 terminal years indicates minimal retrospective error in F, total biomass and SSB with little to no trends in the directionality of the errors. F retrospective error ranged from -0.59 in 2006 to 0.52 in 2008, with a Mohn's Rho estimate of -0.020. Total biomass retrospective error ranged from -0.15 in 2008 to 0.62 in 2006 and a retrospective and a Mohn's Rho estimate equal to 0.09. SSB retrospective bias ranged from -0.26 in 2008 to 0.76 in 2006, with a Mohn's Rho average estimated at 0.12. Finally, retrospective error for age 1 recruitment varied from -0.33 in 2010 to 0.89 in 2006 and a Mohn's Rho estimate equal to 0.11 (Table 24; figures 85-88).

ASAP Model Biological Reference Points

Biological reference points based on a parametric stock-recruit relationship was explored in ASAP. Initial attempts to fit a Beverton-Holt function occurred without success due to the lack of model convergence and the lack of contrast between the recruitment and SSB short time series. Hence, a proxy reference point was explored as an alternative. Fishing reference points were derived from a Yield per recruit (YPR) analysis using the most recent five-year average (2007-2011) for weights at age, and selectivity at age. The rest of the inputs, maturity at age and selectivity for natural mortality were time invariant. Inputs for the YPR analyses can be found in Table 25. In this exploration, YPR analyses was based on F40% as a proxy for F_{MSY} and was estimated at 0.31 (Table 26).

To approximate the distribution of B_{MSY}, SSB_{MSY} and $_{MSY}$ distributions, long-term projections were made from 1,000 estimates of numbers at age in 2011, which were derived by performing MCMC simulation of the ASAP model 12. The recruitment estimate was based on the average recruitment from the entire ASAP assessment time series (1993-2011). The resulting reference points and their 90% confidence interval corresponding with F40% are presented in Table 26. Estimates of biomass reference indicated that B_{MSY} = 69,670 t (58,600 – 85,170 t), SSB_{MSY} = 41,890 t (35,110 – 50,840 t) and MSY = 11,020 t (8,820-14,080 t).

ASAP Model Conclusions

The series of ASAP model explorations show that the model formulation with a shorter time series (i.e. starting in 1993) and two selectivity time blocks in the fishery appears to be the most reasonable (Run 12). The model diagnostics show considerable improved fit to the aggregate and age composition data for the fishery and RV summer index. The retrospective biases (F, total biomass and SSB) were generally minimal suggesting some degree of consistency and stability in the model estimates. Trends in biomass show that the population has been and currently is still below B_{MSY} with continuous decline in fishing mortality since 2010. The incoherence of survey trends relative to levels of removals in the extended model (i.e. starting in 1977) is likely due to movement of fish in and out of the stock areas and, therefore, the survey may only reflect seasonal abundances rather than trends for the stock. Alternatively, natural mortality may have increased over time likely due to predatory consumption of silver hake. However, the scale of predatory removals is unknown and should be further investigated in the future.

As observed in the ISCAM model, ASAP model explorations that took advantage of the longer time series (i.e. starting in 1977) showed a strong correlation between selectivity estimated for the survey index and for the directed fleet. Assuming flattop in the survey selectivity in many cases resulted in a flattop in the directed fleet. This often resulted in age compositions residuals that were acceptable accompanied by a deteriorated fit to the aggregate total (landings or survey). Therefore, the choice of the most desirable model depended to some extent on the amount of confidence in the age composition data relative to the aggregate landings and index. The choice to start the time series in 1993 appears reasonable as this time frame coincides with the period where there was least uncertainty about the fishery catch and sampling.

Comparison of Model Trends

Several model types, including statistical catch-at-age, VPA and production modelling, were used in an effort to fit the silver hake data and identify an optimal model and formulation for informing management advice. All models employed (VPA, iSCAM, ASAP, states base production) had difficulty modelling the full time series of data without introducing changes in model parameters such as natural mortality or survey catchability. All model types reflected the general trend in survey indices, with biomass high in the early period, low through the late 1990s and increasing after 2007.

The inability to model the full time series of data in an acceptable fashion with any model is of concern. Landings were much higher prior to 1993 than they have been since; using a short time series model fails to capture this information.

The relative scaling of the recent biomass increase is similar for the VPA and production models. Biomass is estimated to have increased from a low of about 50,000-60,000 t in the early 2000s to above 100,000 t in 2010 and 2011 (Figure 59; Cook 2013). The Short iSCAM formulation provided biomass estimates which were roughly half of the VPA and production model estimates. The ASAP results were intermediate between these two levels.

The similarity in biomass estimates for the VPA and production models is reassuring. With the current biomass estimated at over 100,000 t, they indicate that there is little risk of overfishing at recent levels of removals. There remain, however, concerns with each of these models. There are concerns with excluding the cohort information and combining all elements of production into a single factor, as is done in the production model (Cook 2013). There are also concerns with the high levels of natural mortality which are used in the VPA. The production model will be used for the assessment until the next framework review for silver hake. In the interim, efforts should be made to resolve the difficulty in modelling the full time series of data. Collection of age-based data should continue with the intention that age-based models be further explored for the next framework.

FUTURE RECOMMENDATIONS

Selection of otoliths for aging from the survey should be done separately by sex and length from strata 440-483 (if that remains the area for the survey index) to ensure there are ages for all lengths from the area in question for each sex. The selection in 2010 appears to have been 10 otoliths per 1 cm length group, but at 21 cm, all of the otoliths were for males, and the catch-at-length for females at 21 cm was unassigned. Otoliths for the 2010 survey should be aged at those lengths which have been missed.

Some aging should continue to be done for strata outside the 440-483 area. If none are aged, there is no opportunity to include this data in any analyses.

Ages should be assigned to any unaged lengths, for deriving both the survey indices and commercial catch-at-age.

Age 0 and age 1 in the summer survey indices should be combined as age 1; the division is arbitrary and starts in 1997, but the birth date by convention is January 1.

Continued development of age based population models.

The scale of predation is unknown and should be further investigated in the future.

CONCLUSIONS

- Since the early 1970s, there has been a decline in the age structure for both the fishery and survey catch-at-age; currently most of the fish caught in the survey are < 4 years old and the fishery catches primarily ages 1-2.
- Commercial catch rates for the shelf basins show an increasing trend from 2000-2011 but are not considered to be reliable indices of abundance.
- Survey biomass on the Scotian Shelf has been increasing since 2008; landings during this period have been approximately 10,000 t. Total survey biomass in 2012 declined slightly from 2011 but still remains quite high. Both age 2+ and female age 2+ have also increased since 2008.
- Abundance at size from the 2012 summer survey indicates that the 2009 year class appears to be strong at age 3 in 2012 and that the 2010 and 2011 year classes at age 1 are above average strength.
- Males appear to experience higher natural mortality than females. Differences in natural mortality should be considered when developing population models for silver hake.
- There has been a decline in the length at 50% maturity for both sexes.
- There has been a decline in condition, weight-at-age and length-at-age early from 1970s to mid1990s. Condition is at the lowest level observed in the time series.
- The DFO summer RV survey covers most of the depths fished by the commercial fishery with the exception of depths > 400 m, although only a small portion of the commercial catch comes from these depths. The survey covers important areas of silver hake habitat (i.e. basins, shelf slope) during summer when they migrate onto the banks during spawning.
- Proportionately more old fish occur in the shelf slope strata during spring surveys compared to basin strata; however, total stratified biomass in the basin strata is 10 times higher.
- Survey Z and Relative F has increased on age 1 since the mid-1990s reflecting higher exploitation of age 1 in the basins from the domestic fishery.
- Survey Z has remained high on ages 2-3 and 4-6 despite reductions in F, which could be explained by higher M or a change in q/selectivity.
- Efforts to model the population using the full time series of landings and survey data were not successful. Restricting the time series from 1993 to the present allowed the development of model formulations which did not have a strong retrospective pattern or unacceptable patterns in residuals and survey q's. For the statistical catch-at-age model, biomass estimates were reduced to one half or less of the estimates produced using the entire time series
- The VPA formulation which best fit the data used natural mortality levels of 1.0 for silver hake over age 4. This model estimated current biomass as 110,000t.

- Splitting the RV series or allowing survey q to vary improved the fit of the statistical catch-at age-model. These estimated current biomass as 125,000 t (split model) and 217,000 t, respectively.

REFERENCES

Bowen, W.D., and Harrison, G. 2007. Seasonal and interannual variability in grey seal diets on Sable Island, eastern Scotian Shelf. *In* Grey seals in the North Atlantic and the Baltic. Edited by T. Haug, M. Hammill, and D. Olafsdottir. Nammco Scientific Publications Vol. 6. The North Atlantic Marine Mammal Commission, Tromso, Grafisk Nord, Finnsnes. p. 123-134.

Branton, R. 1998. Effects of Scotian Shelf small mesh gear fishery regulations on the catch rate of silver hake and bycatch rates of cod, haddock, and pollock in the period 1983-98. DFO Atl. Fish. Res. Doc. 98/139. 13 p.

Cook, A.M. 2013. Bayesian state space surplus production model for 4VWX silver hake. DFO Can. Sci. Advis. Sec. Res. Doc. 2013\009.

Cook, A.M., and Bundy, A. 2010. The food habits database: An update, determination of sampling adequacy and estimation of diet for key species. Can. Tech. Rep. Fish. Aquat. Sci. 2884.

DFO. 2010. Silver hake on the Scotian Shelf (Divisions 4VWX). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/007.

Doubleday, W.G., and Halliday, R.G. 1976. An analysis of the silver hake fishery on the Scotian Shelf. ICNAF Sel. Pap. 1: 41-58.

Emberley, J., and Clark, D.S. 2011. Update of the 2011 summer Scotian Shelf and Bay of Fundy research vessel survey. Can. Data Rep. Fish. Aquat. Sci. 1240.

Fanning, L.P. 1985. Intercalibration of research survey results obtained by different vessels. Can. Atl. Fish. Sci. Advis. Comm. Res. Doc. 85-3. 43 p.

Fowler, G.M., and Showell, M.A. 2009. Calibration of bottom trawl survey vessels: Comparative fishing between the *Alfred Needler* and *Teleost* on the Scotian Shelf during the summer of 2005. Can. Tech. Rep. Aquat. Sci. 2824.

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124-1138.

Gavaris, S. 1980. Use of a multiplicative model to estimate catch rate and effort from commercial data. Can. J. Fish. Aquat. Sci. 37: 2272-2275.

Halliday, R.G. 1973. The silver hake fishery of the Scotian Shelf. Int. Comm. Int. Comm. Northw. Atl. Fish. Res.Doc. 73/103. Ser. No. 3065. 21 p.

Halliday, R.G., and Cooper, C.G. 1997. The effect of codend separator grates on silver hake otter trawl catch rate. NAFO SCR Doc. 97/51 Serial No. N2885. 17 p.

Legault, C.M. 2008. Technical documentation for ASAP version 2.0, NOAA Fisheries Toolbox (last accessed 31 July 2013).

Legault, C.M., and Restrepo, V.R. 1998. A flexible forward age-structured assessment program. Int. Comm. Cons. Atl. Tunas, Coll. Vol. Sci. Pap. 49(2): 246-253.

Link, J.S., Luceya, S.M., and Melgey, J.H. 2012. Examining cannibalism in relation to recruitment of silver hake *Merluccius bilinearis* in the U.S. northwest Atlantic. Fish. Res. 114: 31-41.

Machado-Schiaffino, G., Juanes, F., and Garcia-Vazquez, E. 2011. Identifying unique populations in long-dispersal marine species: Gulfs as priority conservation areas. Biol. Cons. 144: 330-338.

Mohn, R.K., and Rowe, S. 2012. Recovery potential assessment for the Laurentian South designatable unit of Atlantic cod (*Gadus morhua*): The eastern Scotian Shelf cod stock (NAFO Div. 4VsW). DFO Can. Sci. Advis. Sec. Res. Doc. 2011/138: viii + 71 p.

Perry, R.I., and Smith, S.J. 1994. Identifying habitat associations of marine fishes using survey data: An application to the northwest Atlantic. Can. J. Fish. Aquat. Sci. 51: 589-602.

Rikhter, V.A., Sigaev, I.K., Vinogradov, V.A., and Isakov, V.I. 2001. Silver hake of Scotian Shelf: fishery, environmental conditions, distribution and biology and abundance dynamics. J. Northw. Atl. Fish. Sci. Vol. 29: 51-92.

Showell, M.A. 1998. Assessment of the Scotian Shelf silver hake population in 1997, with projection of yield to 1999. DFO Can. Stock Assess. Sec. Res. Doc. 98/141. 44 p.

Showell, M.A., and Cooper, C.G. 1997. Development of the Canadian silver hake fishery, 1987-96. NAFO SCR Doc. 97/54, Ser. No. N2888. 10 p.

Showell, M.A., Young, G., Mohn, R.K., and Fowler, G.M. 2005. Assessment of the Scotian Shelf silver hake population through 2005. DFO Can. Stock Assess. Sec. Res. Doc. 2005/084. 37 p.

Showell, M.A., Young, G., and Fowler, G.M. 2010.Assessment of the Scotian Shelf silver hake population through 2009. DFO Can. Sci. Adv. Sec. Res. Doc. 2010/072. 41 p.

Waldron, D.E. 1992. Diet of silver hake (*Merluccius bilinearis*) on the Scotian Shelf. J. Northw. Atl. Fish. Sci. 14: 87-101.

TABLES

Table 1. Overview of foreign and domestic silver hake fishery and regulatory measures implemented in 4VWX from 1962-2012 (SMGL – Small Mesh Gear Line; EEZ – Exclusive Economic Zone).

Year	Foreign Fleet	Domestic Fleet	Regulatory Measure	Source
1962	First directed fishing by Russian vessels;		unrestricted mesh size, access and season	Rikhter et al. 2001; Halliday 1973
1965	Fishery collapsed			
1973	Highest catches recorded			
1974			NAFO introduces catch restriction	Rikhter et al. 2001
1977	Substantial squid fishery 1977-1982 with high (12%) silver hake bycatch; Cuban, Russian and Japanese using off bottom chain north of SMGL;		Introduction of EEZ: mandatory use of 60 mm codend mesh, implementation of silver hake box and SMGL (90 m isobath) with exceptions to fish eastward; trip bycatch limits (1% 4X cod; 5% 4VsW cod; 5% pollock; 1% haddock); fishing restricted to April-November	Branton 1998
1978-1979	4-6 vessels allowed to fish landward of SMGL			
1980-1983			Fishing permitted under license east to 57°W	
1984			No fishing permitted east of 59 °W	
1987		Experimental Canadian fishery, 90 mm mesh codend, seaward of SMGL	100% observer coverage required for foreign fleet	Showell and Cooper 1997
1990		First Canadian fishing in basins		
1992		Testing of separator grate, fishing seaward of SMGL and in basins	Trip bycatch reduced to 0.5% cod, haddock, flatfish; 1% pollock	Showell and Cooper 1997; Branton 1998
1993	Last year for Russian vessels	No directed fishing by Canadian vessels	Mandatory use of grate (40 mm bar spacing) implemented at end of fishing season to reduce bycatch: allows about 5% silver hake escapement	Halliday and Cooper 1997
1994	Foreign fleet consists mainly of Cuban vessels	Gear comparisons using 55 mm square or 60 mm diamond mesh codend	SMGL moved to 190 m isobath, no fishing allowed east of 60°W Numerous exceptions to SMGL allowed Loss of the extension had little effect on silver hake catch rates, but decreased haddock bycatch	Branton 1998
1995		Commercial fishery, basins, mostly July-August	Modifications and exemptions allowed to improve catches for foreign fleet; 50% observer coverage of domestic fleet	Showell and Cooper 1997
1996		About equal use of 55 mm square or 60 mm diamond mesh, mainly May-June,	25% observer coverage of domestic fleet	

Year	Foreign Fleet	Domestic Fleet	Regulatory Measure	Source
1997	Fishing continues seaward of SMGL by Class 7 vessels under charter to Canadians; catching larger (>24 cm fish)	Fishing Emerald and LaHave basins; catching mainly 19-24 cm fish	Continued 100% coverage of foreign fleet; two observed trips by Canadian vessels	Showell 1998
1998	Last year for Cuban fleet			
1999-present	Relatively small amount of fishing	Discontinued use of topside chafer to support codend	Mandatory use of 55 mm square mesh	Showell et al. 2005

Table 2. Reported landings (t) by country for 4VWX silver hake, 1970-2011.

Country	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**
Bulgaria	0	0	0	0	0	1722	3088	862	606	4639
Canada	0	0	0	0	11	101	26	10	26	13
Cuba	0	0	201	0	0	1724	12572	1847	3436	1798
France	0	0	0	0	0	0	0	15	0	0
FRG*	0	0	10	0	296	106	97	684	0	0
GDR*	0	0	0	0	0	0	0	0	3	0
Ireland	0	0	0	0	0	108	106	0	0	9
Italy	0	0	0	0	0	0	0	38	106	5
Japan	129	8	63	88	67	54	78	19	161	219
Poland	0	0	0	0	0	0	0	295	2	0
Portugal	0	0	0	0	0	0	0	0	0	0
Romania	0	0	0	0	0	0	0	10	0	1
Spain	0	15	0	0	0	6	0	0	2	0
USA*	0	1	1	1	1	7	1	14	0	0
USSR*	168916	128633	113774	299445	95371	112566	81216	33301	44062	45076
Total	169045	128657	114048	299533	95745	116394	97184	37095	48404	51760

Country	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**
Bulgaria	817	0	0	0	0	0	0	0	0	0
Canada	104	6	38	15	10	2	9	13	9	337
Cuba	2287	642	11969	7418	14496	17683	16041	20219	9016	14541
France	0	0	2	0	0	0	0	0	0	0
FRG*	0	0	0	0	0	0	0	0	0	0
GDR*	0	0	0	0	93	0	0	0	0	0
Ireland	0	0	0	0	0	0	0	0	0	0
Italy	0	541	37	22	0	0	0	0	0	0
Japan	239	120	937	649	530	120	66	144	0	194
Poland	0	1	31	0	0	0	0	0	0	0
Portugal	56	2044	2	378	1714	1338	0	0	0	0
Romania	0	0	0	0	0	0	0	0	0	0
Spain	40	0	0	0	0	0	0	0	0	0
USA*	0	3	2	0	0	0	1	0	0	
USSR*	40982	41243	47261	27377	57423	56337	66571	41329	65349	72917
Total	44525	44600	60251	35839	74266	75480	82688	61705	74374	87989

*Country codes: FRG: Federal Republic of Germany; GDR: German Democratic Republic; USA: United States of America; USSR: Union of Soviet Socialist Republics.

Table 2 continued. Reported landings (t) by country for 4VWX silver hake, 1970-2011.

Country	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Bulgaria	88	0	0	0	0	0	0	0	0	0	0
Canada	10	34	100	73	74	277	3484	4209	10489	9676	10052
Cuba	13888	23708	16528	22018	7788	16835	21773	12259	6092	4082	1517
France	0	0	0	0	0	0	0	0	0	0	0
FRG*	0	0	0	0	0	0	0	0	0	0	0
GDR*	0	0	0	0	0	0	0	0	0	0	0
Ireland	0	0	0	0	0	0	0	0	0	0	0
Italy	0	0	0	0	0	0	0	0	0	0	0
Japan	315	781	547	0	0	0	0	0	0	0	0
Poland	0	0	0	0	0	0	0	0	0	0	0
Portugal	0	0	0	0	0	0	0	0	0	0	0
Romania	0	0	0	0	0	0	0	0	0	0	0
Spain	0	0	0	0	0	0	0	0	0	0	0
USA*	0	0	0	0	0	0	0	0	0	0	0
USSR*	55429	40786	14716	7139	0	0	669	0	168	0	0
Total	69730	65309	31891	29230	7862	17112	25926	16,468	16062	16700	11569

Country	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Bulgaria	0	0	0	0	0	0	0	0	0	0	0
Canada	15842	13359	11131	13372	11361	12331	12058	12464	10712	8221	8835
Cuba	2054	2478	0	0	0	0	0	0	0	0	0
France	0	0	2	0	0	0	0	0	0	0	0
FRG*	0	0	0	0	0	0	0	0	0	0	0
GDR*	0	0	0	0	0	0	0	0	0	0	0
Ireland	0	0	0	0	0	0	0	0	0	0	0
Italy	0	0	0	0	0	0	0	0	0	0	0
Japan	0	0	0	0	0	0	0	0	0	0	0
Poland	0	0	0	0	0	0	0	0	0	0	0
Portugal	0	0	0	0	0	0	0	0	0	0	0
Romania	0	0	0	0	0	0	0	0	0	0	0
Spain	0	0	0	0	0	0	0	0	0	0	0
USA	0	0	0	0	0	0	0	0	0	0	0
USSR	0	0	447	534	0	0	0	0		0	0
Total	17896	15837	11578	13906	11361	12331	12058	12464	10712	8,221	8835

*Country codes: FRG: Federal Republic of Germany; GDR: German Democratic Republic; USA: United States of America; USSR: Union of Soviet Socialist Republics.

Table 3. Landings and TAC of silver hake in 4VWX (t x 10^3).

Year	1970-1979	1980-1989	1990-1999[2]	2000[3]	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
TAC	90.2[4]	98.5	53.3	20.0	20.0	20.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Canada[1]	0.0	0.0	3.7	12.9	18.0	15.7	12.2	12.8	11.8	12.3	12.0	12.1	10.4	8.4	9.2
Foreign	115.6	64.2	27.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	115.6	64.2	31.5	12.9	18.0	15.7	12.2	12.8	11.8	12.3	12.0	12.1	10.4	8.4	9.2

1. Includes developmental allocations fished by foreign flagged vessels, ending in 2004.
2. Fishing year, landings and TAC refer to the 15 month period from January 1, 1999 to March 31, 2000.
3. Commencing in 2000, fishing year, landings and TAC refer to the period from April 1st of the current year to March 31st of the following year.
4. Averaged TAC for 1974-79 period.

Table 4. Length-weight regressions for 4VWX silver hake: male and female alphas (intercepts) and betas (slopes) from the DFO summer RV survey of the Scotian Shelf (strata 440-483 only).

Year	Male - Alpha	Male-Beta	Female -Alpha	Female - Beta
1977	0.00908	2.95047	0.00665	3.04667
1978	0.00349	3.22016	0.00276	3.28219
1979	0.00684	3.0183	0.0048	3.1245
1980	0.00142	3.47344	0.00179	3.40029
1981	0.00709	3.00921	0.00529	3.10611
1982	0.0075	2.98837	0.00536	3.08766
1983	0.00645	2.9971	0.00373	3.17121
1984	0.01718	2.72224	0.00653	3.02655
1985	0.0123	2.81156	0.00428	3.13932
1986	0.00508	3.07251	0.00265	3.26848
1987	0.01047	2.86664	0.00435	3.13919
1988	0.01593	2.76333	0.00509	3.10754
1989	0.00402	3.15269	0.00322	3.2223
1990	0.03071	2.55616	0.01455	2.7991
1991	0.00682	2.99656	0.0032	3.22812
1992	0.00352	3.21645	0.00284	3.2844
1993	0.00282	3.24462	0.00266	3.26617
1994	0.00294	3.23555	0.00264	3.27289
1995	0.00306	3.24388	0.00238	3.32263
1996	0.00231	3.31959	0.00222	3.33331
1997	0.00272	3.27416	0.00227	3.33107
1998	0.00362	3.18172	0.00305	3.23813
1999	0.00285	3.25257	0.00284	3.25508
2000	0.00324	3.19579	0.00243	3.29204
2001	0.00284	3.25133	0.00223	3.32712
2002	0.00269	3.26972	0.00225	3.32176
2003	0.00292	3.25307	0.00196	3.3769
2005	0.00223	3.33853	0.00237	3.31655
2006	0.003	3.23839	0.00272	3.27192
2008	0.00262	3.28889	0.00253	3.30105
2009	0.00278	3.26594	0.0024	3.31285
2010	0.00254	3.29042	0.00234	3.31406
2011	0.00313	3.22906	0.00231	3.32437

Table 5. Sampling data used to generate the commercial catch-at-age of 4VWX silver hake, 1999-2011.

Year	Quarter	Keys	Samples	Measured	Aged	Catch (t)
1999	1	Domestic	51	11684	240	974
		Foreign	102	22044	145	1374
	Total		153	33728	385	2348
	2	Domestic	126	26229	323	4845
		Foreign	301	72564	296	3080
	Total		427	98793	619	7925
	3	Domestic	40	9101	240	2336
		Foreign	52	11381	86	383
	Total		92	20482	326	2719
	4	Domestic	16	3377	162	3659
		Foreign	12	2691	58	50
	Total		28	6068	220	3709
		Total	700	159071	1550	16701
2000	1	Domestic	90	19155	95	3177
		Foreign	110	24456	89	546
	Total		200	43611	184	3723
	2	Domestic	96	17040	114	3950
		Foreign	71	15981	70	486
	Total		167	33021	184	4436
	3	Domestic	87	18406	163	1560
		Foreign	47	10185	29	216
	Total		134	28591	192	1776
	4	Domestic	43	8534	115	2966
		Foreign	-	-	-	-
	Total		43	8534	115	2966
		Total	544	113757	675	12901
2001	1	Domestic	52	9974	173	3886
		Foreign	16	3474	56	126
	Total		68	13448	229	4012
	2	Domestic	100	18584	205	5926
		Foreign	120	25793	133	1651
	Total		220	44377	338	7577
	3	Domestic	34	6326	123	2526
		Foreign	17	3633	33	194
	Total		51	9959	156	2720
	4	Domestic	39	6842	169	3691
		Foreign	-	-	-	-
	Total		39	6842	169	3691
		Total	378	74626	892	18000

Table 5 continued. Sampling data used to generate the commercial catch-at-age.

Year	Quarter	Keys	Samples	Measured	Aged	Catch (t)
2002	1	Domestic	96	17186	200	3399
		Foreign	-	-	-	(650)
	Total		96	17186	200	3399
	2	Domestic	53	9306	157	4074
		Foreign	82	17035	113	2556 (1906+650)
	Total		135	26341	270	6630
	3	Domestic	44	8149	126	3025
		Foreign	-	-	-	-
	Total		44	8149	126	3025
	4	Domestic	30	4760	104	3647
		Foreign	-	-	-	-
	Total		30	4760	104	3647
		Total	305	56436	700	16701
2003	1	Domestic	57	9946	175	2786
		Foreign	61(+3)	12520 (+645)	-	314 (+117)
	Total		121	23111	175	3217
	2	Domestic	58	9497	279	3627
		Foreign	(3)	(645)	-	(117)*
	Total		58	9497	279	3627
	3	Domestic	22	3657	130	1088
		Foreign	11	2435	-	17
	Total		33	6092	130	1105
	4	Domestic	19	3183	110	3629
		Foreign	-	-	-	-
	Total		19	3183	110	3629
		Total	231	41883	694	11578
2004	H1	H1	101	20320	257	8481**
	H2	H2	28	1924	80	5400
		Total	129	22244	337	12911
	1	Domestic	20	4736	-	3302
	2	Domestic	23	6714	481	3404
	3	Domestic	16	7109	312	1547
2005	4	Domestic	19	3960	279	3113
		Total	78	22519	1072	11364

Table 5 continued. Sampling data used to generate the commercial catch-at-age.

Year	Quarter	Keys	Samples	Measured	Aged	Catch (t)
2006	1	Domestic	31	14081	530	3726
	2	Domestic	23	6487	505	1037
	3	Domestic	15	2952	213	2348
	4	Domestic	19	4202	224	2977
		Total	88	27722	1472	10089
	1	Domestic	21	4189	254	3657
	2	Domestic	13	4407	319	3351
	3	Domestic	18	4706	128	2452
2007	4	Domestic	16	4006	234	2599
		Total	68	17308	935	12059
2008	1	Domestic	24	8607	291	3551
	2	Domestic	27	9622	293	3753
	3	Domestic	18	4213	181	2636
	4	Domestic	14	2495	150	2524
		Total	83	24937	915	12464
2009	1	Domestic	26	4526	246	3136
	2	Domestic	26	4494	-	2653
	3	Domestic	33	6167	299	2238
	4	Domestic	19	3162	-	2684
		Total	104	18349	545	10711
2010	1	Domestic	36	6310	137	2755
	2	Domestic	39	6620	180	2828
	3	Domestic	16	2967	112	911
	4	Domestic	29	5533	173	1727
		Total	120	21430	602	8221
2011	1	Domestic	35	7340	139	3014
	2	Domestic	32	6482	188	2590
	3	Domestic	28	5237	129	885
	4	Domestic	36	7146	177	2345
		Total	131	26205	633	8834

*added to Quarter 1 Foreign.
**in 2004, Russia was included in the Canadian catch. Catch by this fleet occurred only in March 2004 (334 t).

Table 6. Commercial catch-at-age (x 10^3) for 4VWX silver hake, 1977-2011.

	Age									
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1977	0	17911	72529	59862	15070	2218	725	97	91	4
1978	0	20940	70302	80196	35025	12709	5227	1906	1168	338
1979	0	20569	57893	72891	36669	22380	9970	3168	495	374
1980	0	16588	70696	70391	32032	14465	5184	1431	451	98
1981	0	2358	25214	109035	37573	11928	3234	1201	290	141
1982	0	20189	52976	75876	68400	31752	5945	2042	465	64
1983	0	5849	96852	56158	29282	11388	3395	819	253	88
1984	0	59588	45828	206900	82911	19344	4268	1038	183	10
1985	0	14970	130814	98346	128365	34110	9327	2344	226	85
1986	0	45598	70269	229126	84097	28635	8760	1436	497	111
1987	0	6804	214235	114417	54211	13063	6045	347	156	117
1988	0	5110	62791	265307	39242	21303	3106	2133	208	143
1989	0	24264	85846	158745	145105	20025	9369	1569	1166	39
1990	0	6516	209620	142862	41215	11741	1648	640	107	40
1991	0	5738	117305	201243	46414	12154	3954	290	181	50
1992	0	7461	74491	73526	27777	3461	1247	159	33	5
1993	0	31572	83140	70735	35222	5511	595	71	30	3
1994	0	1651	13265	35250	8847	1283	150	18	8	0.1
1995	0	3500	35925	45615	31316	5183	457	58	41	3
1996	0	33501	92030	43686	23234	4928	888	148	75	0.1
1997	0	16132	34018	37497	25384	3579	339	29	27	2
1998	0	14232	44018	40311	11447	1690	235	22	4	0.1
1999	0	77953	44851	28690	9436	609	176	29	0.2	0
2000	0	90579	54947	13791	2253	385	31	4	1	0
2001	0	50803	130923	21905	4375	420	121	30	9	0.1
2002	0	43064	79296	50459	4594	549	134	16	0.3	0
2003	0	54508	44136	20357	3906	456	58	63	7	0
2004	0	21350	82264	25909	5117	681	290	29	24	1
2005	0	18428	52458	26221	3359	1306	263	160	2	2
2006	0	55764	36456	18612	6879	1377	158	28	25	0
2007	0	80550	62525	13342	3454	475	147	15	8	0
2008	0	60407	50173	17108	4439	553	129	35	0.1	1
2009	0	34455	41281	24027	3892	768	203	64	0.01	0
2010	0	12376	35091	18449	5453	991	402	12	26	0
2011	0	18236	51702	7022	2114	253	93	1	0	0

Table 7. Commercial mean weight-at-age (kg) for 4VWX silver hake, 1977-2011.

	Age								
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1977	0.065	0.183	0.264	0.34	0.446	0.632	0.886	0.922	2.12
1978	0.074	0.153	0.229	0.266	0.335	0.405	0.438	0.54	0.892
1979	0.076	0.178	0.227	0.274	0.304	0.389	0.455	0.838	0.838
1980	0.04	0.151	0.223	0.287	0.341	0.391	0.531	0.839	0.859
1981	0.061	0.168	0.215	0.276	0.326	0.401	0.553	0.923	1.137
1982	0.066	0.169	0.231	0.275	0.317	0.394	0.446	0.513	0.506
1983	0.067	0.128	0.196	0.239	0.289	0.365	0.395	0.457	0.444
1984	0.07	0.146	0.181	0.224	0.272	0.353	0.405	0.624	0.65
1985	0.068	0.136	0.177	0.21	0.244	0.295	0.41	0.582	0.669
1986	0.053	0.145	0.184	0.25	0.25	0.274	0.392	0.514	0.644
1987	0.045	0.119	0.168	0.211	0.248	0.286	0.453	0.422	0.518
1988	0.045	0.139	0.185	0.227	0.26	0.292	0.401	0.497	0.688
1989	0.06	0.135	0.195	0.224	0.278	0.349	0.403	0.511	0.82
1990	0.063	0.139	0.184	0.217	0.24	0.315	0.37	0.401	0.545
1991	0.047	0.139	0.189	0.215	0.263	0.314	0.471	0.511	0.568
1992	0.08	0.14	0.19	0.21	0.26	0.28	0.37	0.41	0.69
1993	0.06	0.11	0.15	0.19	0.23	0.28	0.38	0.32	0.96
1994	0.05	0.1	0.13	0.17	0.19	0.27	0.38	0.42	0.717
1995	0.06	0.1	0.14	0.17	0.21	0.31	0.41	0.44	0.62
1996	0.04	0.1	0.139	0.169	0.207	0.293	0.505	0.433	0.717
1997	0.05	0.1	0.136	0.17	0.202	0.291	0.432	0.431	0.685
1998	0.07	0.105	0.14	0.175	0.21	0.295	0.28	0.73	0.674
1999	0.067	0.096	0.137	0.165	0.23	0.321	0.347	0.567	-
2000	0.06	0.095	0.129	0.165	0.237	0.338	0.283	0.495	-
2001	0.063	0.086	0.127	0.159	0.223	0.282	0.445	0.419	0.759
2002	0.068	0.1	0.131	0.174	0.237	0.281	0.439	0.751	-
2003	0.051	0.108	0.134	0.172	0.23	0.304	0.524	0.373	-
2004	0.054	0.094	0.14	0.2	0.248	0.304	0.464	0.542	-
2005	0.069	0.103	0.137	0.185	0.248	0.29	0.346	0.582	0.789
2006	0.055	0.094	0.133	0.17	0.222	0.254	0.444	0.368	-
2007	0.05	0.086	0.135	0.186	0.268	0.351	0.498	0.421	-
2008	0.065	0.101	0.151	0.159	0.262	0.332	0.557	-	0.78
2009	0.079	0.101	0.119	0.165	0.256	0.324	0.443	0.813	-
2010	0.054	0.099	0.138	0.189	0.255	0.303	0.449	0.418	-
2011	0.041	0.067	0.132	0.17	0.262	0.339	0.529	0.456	0.538

Table 8. Predicted catch rate (t/day) and CV for silver hake in NAFO 4XmnWkl from 1999-2011.

Year	Catch rate	CV
1999	12.1	0.14
2000	12.94	0.16
2001	23.74	0.17
2002	22.47	0.13
2003	18.91	0.10
2004	23.14	0.10
2005	24.53	0.11
2006	22.23	0.10
2007	28.24	0.09
2008	28.64	0.09
2009	21.97	0.09
2010	20.16	0.09
2011	31.7	0.09

Table 9. Biomass (kg/tow) of 4VWX silver hake in the DFO summer RV survey, 4VsW March Survey and ITQ survey (Bay of Fundy strata excluded).

Year	Summer RV Survey	4VsW March Survey	ITQ Survey
1986	13.51	63.49	-
1987	15.77	10.39	-
1988	12.08	36.23	-
1989	6.6	69.13	-
1990	6.86	13.19	-
1991	7.25	32.2	-
1992	5.84	9.71	-
1993	8.43	5.2	-
1994	6.43	22.01	-
1995	11.95	11.56	-
1996	12.28	6.39	7.54
1997	8.67	11.11	5.08
1998	5.54	-	0.99
1999	4.79	4.75	8.17
2000	6.45	11.02	5.88
2001	8.11	13.19	4
2002	3.15	4.75	1.95
2003	4.9	11.06	2.62
2004	12.53	-	12.54
2005	3.42	3.76	3.44
2006	5.57	10.91	2.27
2007	4.32	9.74	3.69
2008	5.13	8.65	4.73
2009	10.56	3.81	3.75
2010	10.7	15.64	7.25
2011	14.55	-	2.49

Table 10. Total numbers (x 10^6,) biomass (x 10^3 t) and CV of 4VWX silver hake in the DFO summer RV survey (strata 440-483 only; years 1971-1981 corrected by 2.3 to account for vessel effect).

Year	Numbers	Biomass	CV
1970	275.4	45.63	0.38
1971	81.1	14.02	0.31
1972	164.1	29.43	0.53
1973	438.5	73.14	0.26
1974	319.7	64.02	0.17
1975	65.7	13.01	0.33
1976	152.2	30.14	0.33
1977	56.5	14.59	0.13
1978	84.0	21.43	0.20
1979	329.8	69.29	0.16
1980	77.3	19.01	0.41
1981	333.3	75.89	0.37
1982	654.8	107.79	0.58
1983	214.8	33.27	0.25
1984	512.9	79.78	0.28
1985	346.1	62.77	0.39
1986	454.4	48.4	0.17
1987	469.0	56.51	0.24
1988	276.2	43.29	0.43
1989	232.4	23.65	0.21
1990	270.9	35.49	0.24
1991	178.5	25.98	0.29
1992	148.7	20.91	0.38
1993	298.1	30.22	0.38
1994	235.5	23.03	0.21
1995	324.0	42.8	0.29
1996	378.2	44.51	0.20
1997	339.3	30.94	0.17
1998	181.9	19.85	0.33
1999	220.7	16.85	0.22
2000	268.2	23.11	0.32
2001	276.4	29.07	0.22
2002	116.7	11.3	0.15
2003	292.3	17.57	0.22
2004	343.2	44.9	0.56
2005	227.8	12.48	0.22
2006	302.5	19.96	0.21
2007	199.1	15.51	0.28
2008	189.7	18.26	0.24
2009	311.0	37.85	0.24
2010	515.7	38.35	0.18
2011	516.9	51.92	0.28

Table 11.Total numbers-at-age (x 10^6) of 4VWX silver hake in the DFO summer RV survey from 1971-2011(strata 440-483 only; years 1971 to 1981 multiplied by factor of 2.3 to account for vessel effect).

					Age					2+
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Biomass**
1971	24.55	30.34	15.30	4.05	1.89	0.20	0.00	0.29	0.00	52.07
1972	48.60	87.47	12.65	7.16	2.95	1.88	0.39	0.64	0.13	113.26
1973	134.06	248.88	15.93	13.88	12.55	6.82	2.50	1.70	0.12	302.37
1974	59.29	178.60	60.23	6.09	6.70	5.99	0.89	0.48	0.00	258.99
1975	19.71	29.58	5.09	3.95	1.57	0.94	0.28	0.42	0.04	41.87
1976	36.24	89.89	14.12	6.96	2.75	1.39	0.35	0.12	0.30	115.87
1977	4.68	23.53	19.42	4.56	1.36	1.21	0.94	0.33	0.28	51.63
1978	23.50	22.78	16.12	8.92	6.70	3.05	1.29	0.50	0.87	60.23
1979	68.12	146.69	69.09	20.33	11.56	5.08	2.67	0.97	0.28	256.66
1980	11.49	19.27	28.03	7.86	4.28	3.35	1.47	0.80	0.38	65.43
1981	29.84	84.25	130.22	60.08	16.11	5.24	2.43	0.79	0.65	299.77
1982	177.58	291.09	77.43	62.01	32.09	8.17	3.50	2.52	0.33	477.14
1983	41.54	99.32	38.24	18.99	10.60	2.78	0.88	0.40	0.33	171.55
1984	174.50	65.03	209.25	39.60	12.12	8.04	2.87	1.14	0.52	338.56
1985	37.66	163.45	33.87	73.79	22.53	9.95	2.66	1.22	0.21	307.69
1986	260.15	73.83	74.01	22.64	13.55	4.15	1.66	0.71	0.33	190.88
1987	139.67	253.80	42.29	18.62	6.07	4.10	1.26	0.67	0.48	327.28
1988	68.47	87.12	82.64	16.95	14.21	2.50	2.35	0.47	0.12	206.35
1989	128.82	60.12	23.08	13.00	3.54	1.74	0.70	0.32	0.13	102.62
1990	86.28	115.01	46.42	13.86	4.06	1.16	0.41	0.21	0.08	181.20
1991	37.19	80.87	35.04	13.16	6.62	2.42	0.40	0.14	0.12	138.77
1992	11.92	55.07	45.72	11.07	4.46	2.23	0.42	0.14	0.19	119.31
1993	113.90	89.80	63.19	27.28	2.53	0.81	0.58	0.10	0.04	184.32
1994	86.68	56.32	57.24	25.35	7.80	1.14	0.33	0.21	0.13	148.52
1995	90.26	72.14	82.58	56.66	15.60	3.41	1.29	0.61	0.65	232.95
1996	94.27	170.11	57.25	42.98	10.62	1.58	0.30	0.57	0.16	283.57
1997	142.81	122.65	53.56	6.06	3.66	0.59	0.09	0.08	0.02	186.72
1998	33.67	92.84	35.21	13.68	2.12	1.31	0.28	0.00	0.00	145.44
1999	130.93	54.75	21.96	6.09	1.98	0.29	0.07	0.01	0.01	85.15
2000	163.50	71.15	21.96	5.75	1.24	0.64	0.17	0.22	0.04	101.17
2001	53.42	176.01	32.90	6.87	2.29	0.26	0.50	0.24	0.33	219.38
2002	48.60	34.00	23.82	6.09	0.79	0.43	0.05	0.11	0.10	65.38
2003	239.08	22.81	19.99	8.35	0.88	0.27	0.39	0.00	0.07	52.76
2004	59.23	152.83	77.75	39.73	10.11	1.26	0.18	0.06	0.21	282.13
2005	176.84	26.97	17.05	3.15	1.58	0.31	0.10	0.07	0.00	49.24
2006	230.18	51.59	13.18	4.16	1.86	0.79	0.31	0.07	0.00	71.95
2007	111.48	63.93	13.14	5.01	0.93	0.47	0.12	0.11	0.14	83.85
2008	68.83	87.44	16.36	6.32	2.38	0.58	0.54	0.16	0.04	113.82
2009	95.02	106.68	72.57	23.04	4.58	3.36	1.16	0.27	0.16	211.81
2010	321.77	81.63	54.23	17.18	6.41	1.78	0.63	0.12	0.17	162.16
2011	114.61	319.89	41.86	27.10	4.46	4.88	1.40	0.91	0.16	400.64

Table 12a. Mean weight-at-age (g) for ***male*** *4VWX silver hake in the DFO summer RV survey (strata 440-483 only).*

	Age								
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1971	52.5	153.7	175.2	183.2	325.0	-	-	-	-
1972	52.6	135.5	178.9	218.6	244.2	280.5	225.0	-	-
1973	56.4	154.3	202.9	236.9	245.4	303.8	250.0	-	-
1974	58.3	147.1	182.7	300.0	222.1	-	400.0	-	-
1975	77.8	189.6	217.1	206.6	-	225.0	-	-	-
1976	78.8	162.5	209.4	239.6	250.0	275.0	-	-	-
1977	61.2	155.4	209.3	279.1	0.0	323.6	-	-	-
1978	53.2	128.1	211.7	245.6	258.2	377.0	300.0	-	-
1979	67.8	159.0	192.6	238.3	280.7	311.0	351.7	-	600.0
1980	70.7	121.9	199.1	225.0	260.5	285.1	274.3	-	
1981	59.3	147.8	189.8	228.6	263.6	306.8	409.5	-	450.0
1982	52.7	137.7	215.9	235.9	275.3	291.1	315.8	-	-
1983	62.6	108.5	171.8	216.7	262.5	272.2	326.9	450.0	-
1984	63.9	138.1	160.2	211.9	228.0	267.4	269.5	324.3	-
1985	60.7	133.1	188.0	184.7	224.0	282.8	-	-	-
1986	53.9	132.3	168.7	202.9	233.0	258.7	253.8	-	275.0
1987	52.3	111.2	179.2	202.3	213.6	245.8	538.4	400.0	-
1988	54.4	132.4	166.7	189.2	252.9	235.5	241.5	-	-
1989	56.2	119.2	159.2	164.7	222.6	227.0	288.9	300.0	-
1990	58.7	129.9	155.4	219.4	251.1	-	-	-	-
1991	42.7	119.3	161.5	201.6	214.7	266.7	275.0	-	-
1992	41.2	123.3	151.7	198.5	238.6	218.3	241.1	-	-
1993	39.4	116.0	133.9	174.7	214.2	-	-	-	-
1994	24.9	89.8	120.7	139.0	173.4	200.9	-	-	-
1995	38.8	84.2	124.0	165.9	194.1	340.0	235.0	-	-
1996	43.2	114.5	132.4	165.5	148.4	226.6	-	-	-
1997	28.2	100.1	150.1	206.7	205.9	-	-	-	-
1998	23.8	94.8	138.3	181.1	200.0	218.0	-	-	-
1999	41.4	93.2	135.9	160.5	160.6	-	-	-	-
2000	55.9	101.1	132.5	166.8	180.0	-	-	-	-
2001	38.7	99.2	136.8	159.5	141.1	310.0	-	-	-
2002	37.4	104.8	132.5	154.1	176.0	296.0	-	-	-
2003	35.6	107.1	139.6	190.7	242.0	-	-	-	-
2004	45.6	110.7	150.8	157.0	196.9	296.0	-	-	-
2005	27.5	115.4	141.8	128.7	180.0	-	266.0	-	-
2006	43.0	94.6	128.8	153.1	185.2	310.0	-	-	-
2007	35.1	101.0	152.2	174.5	201.0	-	-	-	-
2008	38.8	101.9	150.7	175.6	225.0	-	-	336.0	-
2009	47.3	102.0	153.9	159.1	163.2	193.7	-	930.0	-
2010	32.3	107.6	152.8	175.3	182.8	224.0	-	-	-
2011	42.2	93.7	144.3	167.6	146.0	184.4	-	-	-

*Table 12b. Mean weight-at-age (g) for **female** 4VWX silver hake in the DFO summer RV survey (strata 440-483 only).*

	Age								
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1971	52.2	181.1	228.1	299.3	386.2	925.0	-	-	-
1972	55.8	163.1	271.1	334.4	371.0	789.6	609.5	-	-
1973	40.2	173.1	256.3	340.8	428.9	557.9	810.8	-	-
1974	43.0	166.6	267.1	388.3	579.8	713.5	1169.4	-	-
1975	67.1	219.7	301.9	363.5	575.3	768.6	1238.9	-	-
1976	67.3	203.6	308.5	367.3	493.6	973.6	784.6	-	-
1977	62.7	172.8	289.2	387.1	488.5	639.6	1173.9	811.0	1676.8
1978	51.9	131.8	253.2	350.3	424.2	526.7	971.8	1276.9	1474.3
1979	38.7	173.5	239.4	303.0	449.0	683.2	786.7	-	-
1980	60.8	124.6	246.9	285.8	453.8	659.7	793.3	789.2	1018.2
1981	56.1	159.9	241.6	300.5	404.2	548.9	691.7	884.8	1532.5
1982	53.0	174.7	248.4	319.9	361.7	431.0	796.9	1053.2	971.1
1983	60.9	128.6	215.7	283.0	387.0	514.3	717.7	763.2	1027.7
1984	68.2	156.1	205.4	262.8	327.1	426.2	562.7	759.2	920.6
1985	66.5	151.9	214.3	261.0	311.1	408.9	524.3	831.9	1093.0
1986	54.1	149.5	199.1	253.2	300.9	372.1	550.0	784.3	965.8
1987	54.2	120.6	208.6	269.5	337.5	436.3	614.5	827.3	905.6
1988	53.2	150.5	208.1	241.5	311.2	396.2	503.6	652.4	956.3
1989	59.9	129.6	175.5	201.7	274.4	449.1	549.2	717.2	1194.7
1990	55.1	141.8	179.7	228.3	323.2	415.2	523.3	621.3	472.9
1991	46.0	135.1	207.5	250.8	301.2	355.3	500.5	1020.1	719.2
1992	42.5	134.2	196.3	242.8	294.5	374.8	633.5	874.7	869.8
1993	32.5	121.2	162.0	209.4	271.5	335.1	337.3	422.4	552.0
1994	27.8	96.6	149.3	183.1	228.8	403.6	563.6	705.6	692.4
1995	45.2	96.0	146.0	201.4	275.1	374.7	545.7	750.4	1069.8
1996	36.5	129.1	173.1	191.8	218.9	446.0	484.7	920.3	1328.1
1997	34.3	117.0	183.0	271.5	335.2	427.5	1296.8	1413.2	782.0
1998	27.1	107.1	183.2	213.9	274.7	440.1	417.6	-	-
1999	32.7	112.8	165.1	224.4	267.8	380.7	420.3	802.0	594.0
2000	57.4	127.5	175.0	213.1	378.0	490.1	400.2	554.3	1339.7
2001	34.7	109.2	174.5	231.4	298.3	441.1	798.7	854.0	705.3
2002	38.4	122.6	148.8	206.7	251.4	297.3	543.9	799.8	614.2
2003	36.6	128.3	188.2	221.9	298.2	472.9	536.4	-	1055.4
2004	50.2	121.5	173.6	236.6	267.3	341.6	642.7	483.0	732.0
2005	28.3	128.0	165.6	215.9	237.9	395.4	551.6	560.0	-
2006	47.4	118.2	166.8	228.2	271.5	398.2	484.9	593.1	-
2007	36.9	123.5	180.7	254.6	337.7	466.0	515.2	786.7	967.5
2008	41.4	112.0	207.1	235.7	337.3	539.4	518.2	658.8	922.0
2009	49.4	118.4	175.4	226.1	293.3	388.9	433.7	722.8	609.4
2010	33.3	128.0	198.7	242.6	293.1	334.2	454.1	550.1	557.8
2011	39.2	98.8	184.8	230.3	250.8	335.8	588.0	711.0	922.2

*Table 13a. Mean length-at-age (cm) for **male** 4VWX silver hake in the DFO summer RV survey (strata 440-483 only).*

	Age								
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1971	18.77	27.56	29.29	31.88	33.00	-	-	-	-
1972	19.56	26.72	29.62	31.37	33.02	34.66	31.00	-	-
1973	19.93	27.58	30.53	31.39	32.06	34.10	34.00	-	-
1974	19.9	27.77	30.28	34.00	33.12	-	36.00	-	-
1975	20.51	28.97	30.55	30.43	-	32.00	-	-	-
1976	21.69	28.06	31.58	32.83	35.00	38.00	-	-	-
1977	17.29	27.04	29.97	33.04	-	34.82	-	-	-
1978	16.05	25.90	30.37	31.95	32.58	37.23	36.00	-	-
1979	19.94	27.69	29.30	32.61	33.39	34.53	36.07	-	40.00
1980	16.96	25.98	29.94	31.07	32.76	33.79	34.51	-	
1981	18.02	27.24	29.33	31.11	32.34	33.98	39.06	-	38.00
1982	17.17	26.90	30.56	31.13	33.34	34.00	35.76	35.06	-
1983	19.51	24.99	27.49	28.51	30.37	30.37	-	46.00	-
1984	19.60	26.99	28.76	30.97	32.20	34.03	35.88	36.11	-
1985	18.90	27.12	29.85	30.61	31.61	33.01	-	-	-
1986	18.00	27.19	29.33	30.75	31.97	33.01	34.09		33.00
1987	18.36	25.28	29.13	30.88	31.27	32.69	42.07	36.73	-
1988	16.41	26.41	28.45	30.37	31.17	31.63	32.71		-
1989	18.40	25.72	28.16	29.64	31.63	32.54	34.76	33.00	-
1990	18.42	26.41	28.62	31.00	32.09	-	-	-	-
1991	18.30	25.90	28.54	30.82	30.65	32.95	35.00	-	-
1992	18.04	25.71	27.56	29.78	30.68	30.56	33.11	-	-
1993	18.03	25.96	27.97	29.36	32.20	-	-	-	-
1994	15.96	24.16	26.60	27.78	29.54	31.94	-	-	-
1995	18.62	23.12	26.16	28.47	30.90	36.00	33.00	-	-
1996	18.57	25.69	27.40	29.02	27.74	30.42	-	-	-
1997	16.37	24.71	27.92	29.75	31.00	-	-	-	-
1998	15.98	24.19	27.74	29.62	31.00	32.00	-	-	-
1999	18.19	23.99	27.50	28.89	28.69	-	-	-	-
2000	20.62	25.37	27.53	29.17	31.00	-	-	-	-
2001	18.41	24.59	27.52	29.13	30.32	36.00	-	-	-
2002	18.00	25.10	27.12	28.43	29.26	34.00	-	-	-
2003	18.03	25.37	27.38	28.97	31.00	-	-	-	-
2004	19.53	25.09	27.77	28.50	30.25	33.00	-	-	-
2005	16.48	25.30	27.09	28.02	29.00	-	34.00	-	-
2006	19.22	24.17	26.85	29.32	29.48	36.00	-	-	-
2007	17.44	24.74	27.46	29.44	31.16	-	-	-	-
2008	18.31	24.40	27.88	28.93	32.00	-	-	37.00	-
2009	19.51	24.99	27.49	28.51	30.37	30.37	-	46.00	-
2010	17.40	25.43	28.15	29.10	30.05	33.00	-	-	-
2011	18.66	24.08	27.84	28.41	30.00	29.20	-	-	-

Table 13b. Mean length-at-age (cm) for female 4VWX silver hake in the DFO summer RV survey (strata 440-483).

	Age								
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1971	18.89	28.59	31.54	33.72	36.51	47.00	-	45.00	-
1972	20.36	27.99	32.99	35.24	36.32	45.61	42.48	56.29	50.00
1973	19.82	28.84	32.9	35.85	38.56	41.58	46.31	51.02	57.00
1974	20.49	28.75	33.05	37.24	42.20	45.82	51.31	56.76	-
1975	20.54	30.4	33.73	34.76	40.81	45.5	53.42	54.98	61.00
1976	21.23	29.9	35.09	37.10	39.81	47.94	47.12	50.35	52.33
1977	17.65	27.97	33.10	36.50	39.79	42.15	50.59	47.15	57.24
1978	17.26	26.29	31.97	35.49	37.78	40.40	48.71	51.81	52.82
1979	18.97	28.85	31.71	35.34	38.76	44.49	47.63	55.03	53.25
1980	17.23	26.35	31.92	33.85	38.53	42.83	45.61	45.34	51.62
1981	17.56	27.50	31.37	33.99	37.24	40.99	44.61	46.63	54.32
1982	17.18	28.82	32.76	34.75	36.03	37.80	45.46	50.61	50.64
1983	19.61	25.98	29.37	31.62	34.08	36.84	37.72	42.99	41.26
1984	19.79	28.05	30.17	33.19	36.09	38.60	41.66	46.52	48.97
1985	19.81	27.98	31.50	33.46	34.96	37.75	41.46	47.39	51.14
1986	18.11	28.01	30.76	33.16	34.80	36.62	41.53	45.04	47.72
1987	18.51	26.07	30.82	33.08	35.64	38.60	42.48	46.41	48.10
1988	16.66	27.36	30.38	32.11	34.05	37.43	40.10	43.54	49.18
1989	18.75	27.00	29.99	31.32	33.81	38.18	40.06	43.78	52.68
1990	18.62	27.38	29.56	32.37	34.82	37.84	40.01	43.60	41.64
1991	18.67	26.85	30.16	32.80	34.66	36.13	40.67	49.20	44.59
1992	18.24	26.47	29.57	31.49	33.18	34.61	40.16	46.75	46.28
1993	17.59	26.35	29.07	30.97	34.13	36.01	36.75	38.44	45.00
1994	16.63	24.63	28.22	30.10	32.00	37.84	40.47	43.73	43.67
1995	18.99	24.09	27.69	30.45	33.37	36.88	40.43	43.77	47.16
1996	17.98	26.47	29.17	30.23	31.71	37.74	40.02	44.97	51.44
1997	17.32	25.61	29.70	32.61	35.40	36.91	51.78	53.15	46.00
1998	16.52	25.09	29.72	31.02	33.58	37.72	38.15	-	-
1999	17.49	25.58	29.10	31.49	33.35	37.42	37.89	45.00	46.00
2000	20.82	26.88	29.52	31.50	37.08	39.94	37.83	41.66	50.78
2001	17.92	25.52	29.70	31.88	33.86	37.92	44.14	45.51	43.99
2002	18.16	26.36	28.28	31.05	33.02	34.56	41.92	45.09	42.50
2003	18.09	26.65	29.55	31.06	34.15	38.46	39.35	-	46.66
2004	20.17	26.10	29.11	31.50	32.92	35.30	41.10	39.42	43.04
2005	16.56	26.41	28.84	31.53	32.34	36.30	39.42	40.00	42.50
2006	19.55	25.95	28.89	32.07	33.57	36.78	39.94	40.64	-
2007	17.77	25.84	29.08	32.52	35.55	37.94	39.41	44.58	46.32
2008	18.31	25.42	30.50	32.31	35.37	40.57	40.86	43.17	49.00
2009	19.61	25.98	29.37	31.62	34.08	36.84	37.72	42.99	41.26
2010	17.45	26.82	30.37	31.89	33.58	35.13	38.54	41.49	41.39
2011	18.31	24.52	29.70	31.66	32.62	35.57	40.48	43.02	46.63

Table 14. Observed catch and bycatch by the 4VWX silver hake fishery from the International Observer Database, 2002-2011.

Species	Total Observed (kg)	Total Kept (kg)	Total Discarded (kg)	Percent of total weight caught
Silver hake	7803.11	7793.21	9.90	95.00
Atlantic herring	89.02	81.23	7.79	1.08
Red hake	69.63	68.78	0.85	0.85
Redfish unspecified	32.62	32.52	0.09	0.40
Spiny dogfish	32.49	0.11	32.38	0.40
Atlantic mackerel	25.39	24.87	0.52	0.31
Short-fin squid	22.31	21.59	0.72	0.27
Hake unspecified	21.46	21.46	0.00	0.26
Haddock	18.06	18.03	0.04	0.22
White hake	14.64	14.56	0.08	0.18
Witch flounder	14.43	14.31	0.13	0.18
Alewife	13.84	10.34	3.50	0.17
Basking shark	11.40	0.00	11.40	0.14
Butterfish	8.35	8.13	0.21	0.10
Longfin squid	4.34	4.32	0.02	0.05
Pollock	4.02	3.99	0.03	0.05
Argentine	3.91	3.78	0.13	0.05
Blackbelly rosefish	2.85	2.63	0.23	0.03
American shad	2.81	2.80	0.01	0.03
Squid unidentified	2.45	0.34	2.10	0.03
American plaice	2.32	2.30	0.02	0.03
Yellowtail flounder	2.19	2.19	0.00	0.03
Off-shore hake	1.93	1.93	0.00	0.02
Monkfish	1.54	1.40	0.14	0.02
Winter skate	1.37	0.15	1.22	0.02
Atlantic cod	1.08	1.04	0.03	0.01
Winter flounder	1.01	1.01	0.00	0.01
American lobster	0.90	0.13	0.77	0.01
Thorny skate	0.82	0.10	0.73	0.01
Ocean sunfish	0.65	0.00	0.65	0.01
Atlantic halibut	0.61	0.25	0.36	0.01
Smooth skate	0.40	0.05	0.35	0.00
Cusk	0.16	0.16	0.00	0.00

Table 15. Population abundance (in thousands) estimated for 4VWX silver hake from the short-term (1993-2012) high natural mortality VPA model formulation.

Age/Year	1	2	3	4	5	6	7	8	9
1993	45499	36213	19653	11107	2241	296	147	82	15
1994	38260	27938	17584	5054	3159	516	75	50	28
1995	52611	25512	17651	6342	1909	1088	181	27	18
1996	30226	34982	14198	5692	1110	413	374	63	7
1997	33975	17550	16057	4125	1292	144	102	129	19
1998	23964	21465	9021	5441	437	276	34	36	46
1999	64163	14909	10842	1833	1927	69	88	11	13
2000	59709	36703	6399	3452	298	673	15	31	4
2001	37566	32706	20163	2244	1560	88	246	5	11
2002	36493	21074	11499	8514	818	549	25	89	1
2003	43944	20977	7802	2393	3912	269	194	8	33
2004	29190	25047	10507	2503	922	1413	96	68	3
2005	28143	17836	10208	3470	896	300	503	34	24
2006	38908	17370	7750	3302	1493	255	95	176	12
2007	34229	21574	8707	2592	1174	470	85	33	63
2008	59893	16464	9447	3415	1051	404	164	30	12
2009	34580	35256	7016	3529	1393	355	141	58	11
2010	105466	20389	20292	1882	1486	468	119	48	22
2011	28474	69690	10835	8813	569	490	149	43	16
2012	50000	17608	42523	4899	4231	195	175	55	16

Table 16. Estimated fishing mortality (F) at age for 4VWX silver hake from the short-term (1993-2012) high-natural mortality VPA model formulation (0.00 indicates no catch for that age).

Age/Year	1	2	3	4	5	6	7	8	9
1993	0.09	0.32	0.66	0.56	0.47	0.37	0.08	0.06	0.03
1994	0.01	0.06	0.32	0.27	0.07	0.05	0.04	0.03	0.00
1995	0.01	0.19	0.43	1.04	0.53	0.07	0.05	0.27	0.03
1996	0.14	0.38	0.54	0.78	1.04	0.40	0.06	0.20	0.00
1997	0.06	0.27	0.38	1.55	0.54	0.45	0.05	0.03	0.02
1998	0.07	0.28	0.89	0.34	0.85	0.14	0.11	0.02	0.00
1999	0.16	0.45	0.44	1.12	0.05	0.49	0.05	0.00	0.00
2000	0.20	0.20	0.35	0.09	0.22	0.01	0.04	0.01	0.00
2001	0.18	0.65	0.16	0.31	0.04	0.24	0.02	0.29	0.00
2002	0.15	0.59	0.87	0.08	0.11	0.04	0.10	0.00	0.00
2003	0.16	0.29	0.44	0.25	0.02	0.03	0.05	0.14	0.00
2004	0.09	0.50	0.41	0.33	0.12	0.03	0.05	0.06	0.06
2005	0.08	0.43	0.43	0.14	0.26	0.15	0.05	0.01	0.01
2006	0.19	0.29	0.40	0.33	0.16	0.10	0.05	0.02	0.00
2007	0.33	0.43	0.24	0.20	0.07	0.05	0.03	0.04	0.00
2008	0.13	0.45	0.28	0.20	0.09	0.05	0.03	0.00	0.01
2009	0.13	0.15	0.62	0.16	0.09	0.09	0.07	0.00	0.00
2010	0.01	0.23	0.13	0.50	0.11	0.14	0.02	0.09	0.00
2011	0.08	0.09	0.09	0.03	0.07	0.03	0.00	0.00	0.00

Table 17. Parameter estimates from the short-term high natural mortality VPA model formulation.

Parameter	Parameter est.	Standard Error	Bias
N[2011; 7]	160,883	65,181	11,843
N[2012; 2]	27,874,805	23,909,730	10,267,175
N[2012; 3]	52,900,352	33,275,410	10,377,155
N[2012; 4]	5,787,621	3,329,482	889,110
N[2012; 5]	4,495,912	1,567,718	265,299
N[2012; 6]	219,549	118,520	24,960
N[2012; 7]	187,721	74,529	12,993
q Age 1	0.33	0.07	0.0036
q Age 2	0.45	0.09	0.0051
q Age 3	0.51	0.10	0.0063
q Age 4-7	0.47	0.06	0.0006

Table 18. Output from various iSCAM formulations (No. par –number of parameters; Obj. fn – objective function value; bo – initial biomass; bMSY, MSY in metric tons, q – survey catchability; steepness – initial slope of stock-recruitment curve).

Model	No. par.	obj fn	bo	bMSY	MSY	FMSY	q	Steepness
Basic all	166	-210	269	35	33	0.36	10.4, 0.9, 1.5	0.98
Basic M=.4	129	-458	510	37.5	30	0.42	1.16	0.85
Basic M=.45	129	-385	407	33	23	0.47	0.96	0.83
Basic M=.5	no convergence							
Basic M=.6	129	-460	324	38	31	0.45	0.99	0.73
selectivity survey=6	120	-265	567	36.5	33		0.74	0.86
random walk M	141	-546	156.2	8.5	15.9	0.95	1.7	0.92
short series	81	-207	135	7.7	7.9	0.39	1.8	0.89
SS M=0.45	no convergence							
SS w cpue	81	-194	127	7.4	7.4	0.37	1.7, 2.3	0.89
SS w sel 6	74	-161	106.7	2.8	8.6	0.41	3.4	0.97
two surveys	136	-494	406	33	23	0.35	0.59, 2.1	0.81
Ssmart M=.4	361	-585	685	73	29.7	0.4	1.5	0.71
smart M=.5	361	-582	464	62	25	0.4	1.2	0.63

First column indicates model variations: Basic all – all landings and survey data 1971-2011; Basic model with increasing M from 0.4-0.6; selectivity survey= 6 used a fixed logistic curve for the survey; random M allowed natural mortality to vary; short series - only data from 1993-2011; SS w CPUE included the commercial catch rate series 1999-2011; two surveys – RV survey split at 1993; Ssmart – time varying selectivity option used for RV survey.

Table 19. Summary of 4VWX silver hake ASAP model (v 2.0.20) configurations including the best model run (Run 12) and various sensitivity models.

Run #	Years	Catch	Fishery Selectivity Time Blocks	Natural Mortality	Stock-Recruit Function	Survey Indices	Survey Selectivity Time Block	Plus Age Group Formulation
1	1977-2011	Single Fleet (1977-2011)	None	Const = 0.4	None	Summer Index (1977-2011)	None	1-9+
2	1977-2011	Single Fleet (1977-2011)	Two (1977-1992 and 1993-2011)	Const = 0.4	None	Summer Index (1977-2011)	None	1-9+
3	1977-2011	Single Fleet (1977-2011)	Two (1977-1992 and 1993-2011)	Const = 0.4	None	Summer Index (1977-2011)	None	1-9+
4	1977-2011	Single Fleet (1977-2011)	Two (1977-1992 and 1993-2011)	Const = 0.4	None	Summer Index (1977-2011)	None	1-9+
5	1977-2011	Single Fleet (1977-2011)	Two (1977-1992 and 1993-2011)	Const = 0.2	None	Summer Index (1977-2011)	Split Survey (1977-1992 and 1993-2011)	1-9+
6	1977-2011	Single Fleet (1977-2011)	Two (1977-1992 and 1993-2011)	Const = 0.2	None	Summer Index (1977-2011)	Split Survey (1977-1992 and 1993-2011)	1-9+
7	1993-2011	Single Fleet (1993-2011)	None	Const = 0.4	None	Summer Index (1993-2011)	None	1-9+
8	1993-2011	Single Fleet (1993-2011)	None	Const = 0.4	None	Summer Index (1993-2011)	None	1-9+
9	1993-2011	Single Fleet (1993-2011)	None	Const = 0.4	YES (Beverton-holt)	Summer Index (1993-2011)	None	1-9+
10	1993-2011	Single Fleet (1993-2011)	Two (1993-1998 and 1999-2011)	Const = 0.4	None	Summer Index (1993-2011)	None	1-9+
11	1993-2011	Single Fleet (1993-2011)	Three (1993-1996; 1997-2000; 2001-2011)	Const = 0.4	None	Summer Index (1993-2011)	None	1-9+
12	1993-2011	Single Fleet (1993-2011)	Two (1993-1998 and 1999-2011)	Const = 0.4	None	Summer Index (1993-2011)	None	1-9+

Note: Assumed 100% discard mortality.

Table 20a. Summary of 4VWX silver hake model fit from the ASAP runs and various sensitivity analyses (runs 1-4).

Run #		1	2	3	4
Model Description		Start year in 1977; 9+ age group, NO fishery selectivity time block; assumed flattop for fishery and survey selectivity for ages 2+; recruitment (geometric mean); Constant natural mortality (M = 0.4)	Start year in 1977; 9+ age group; 2 fishery Selectivity time blocks (1977-1992 and 1993-2011); assumed flattop for survry and both fishery selectivity time blocks; recruitment (geometric mean); Constant natural mortality (M = 0.4)	Start year in 1977; 9+ age group; 2 fishery Selectivity time blocks (1977-1992 and 1993-2011); assumed flattop for fishery selectivity time block 1 (ages 2+)and allowed a dome to be estimated in time block 2 (fixed at age 2); maintained flattop selectivity for survey selectivity; recruitment (geometric mean); Constant natural mortality (M = 0.4)	Start year in 1977; 9+ age group ; split survey (1973-1992; 1993-2011); 2 fishery Selectivity time blocks (1977-1992 and 1993-2011); assumed flattop for fishery and survery selectivity time block 1 (ages 2+)and allowed a dome to be estimated in time block 2 for both fishery and survey (fixed at age 2); maintained flattop selectivity for survey selectivity; recruitment (geometric mean); Constant natural mortality (M = 0.4)
# of Parameters		82	83	90	98
Objective Function		1695	1639	1443	1426
Components of Objective Function	Survey Age Comp.	210	214	247	207
	Catch age Comp.	488	471	394	387
	index fit total	657	622	494	484
	catch total	340	332	308	348
	Rec Devs.	NA	NA		
RMSE	Catch total	1.36	1.2	0.14	0.4
	Survey Index	3.7	3.42	1.1	2.0
	Recr. Devs.	NA	NA		
Biomass (mt) 2011		271,110	270,402	918757	375990
SSB (mt) 2011		136,534	163,104	683,969	284,521
F Avg, 2011		0.06	0.05	0.003	0.007

Table 20b. Summary of 4VWX silver hake model fit from the ASAP runs and various sensitivity analyses (runs 5-8).

Run #		5	6	7	8
Model Description		Start year in 1977; 9+ age group; split survey (1973-1992; 1993-2011); 2 fishery Selectivity time blocks (1977-1992 and 1993-2011); assumed flattop for fishery and survery selectivity time block 1 (ages 2+)and allowed a dome to be estimated in time block 2 for both fishery and survey (fixed at age 2 Only); maintained flattop selectivity for survey selectivity; recruitment (geometric mean); Constant natural mortality (M = 0.2)	Start year in 1977; 9+ age group; split survey (1973-1992; 1993-2011); 2 fishery Selectivity time blocks (1977-1992 and 1993-2011); assumed flattop for fishery and survery selectivity time block 1 (ages 2+)and allowed a dome to be estimated in time block 2 for both fishery and survey (fixed at age 2-5); maintained flattop selectivity for survey selectivity; recruitment (geometric mean); Constant natural mortality (M = 0.2)	Short time series; Start year in 1993; 9+ age group; No Fishery or survey Selectivity time blocks ; allowed a dome to be estimated for both the fishery and survey selectivity (fixed ages 2-5); recruitment (geometric mean); Constant natural mortality (M = 0.4)	Short time series; Start year in 1993; 9+ age group; No Fishery or survey Selectivity time blocks ; allowed a dome to be estimated for the fishery (fixed ages 2-5); assumed flattop selectivity for the survey (ages 2+); recruitment (geometric mean); Constant natural mortality (M = 0.4)
# of Parameters		-	95	58	54
Objective Function		MODEL DID NOT CONVERGE	1437	667	669
Components of Objective Function	Survey Age Comp.	-	206	85	87
	Catch age Comp.	-	382	165	166
	index fit total	-	489	239	238
	catch total	-	361	178	178
	Rec Devs.	-	-	-	-
RMSE	Catch total	-	0.95	0.6	0.6
	Survey Index	-	2.0	1.1	1.0
	Recr. Devs.	-	-	-	-
Biomass (mt) 2011		-	49,943	59,174	59,510
SSB (mt) 2011		-	23,320	31,727	31,844
F Avg, 2011		-	0.30	0.24	0.24

Table 20c. Summary of 4VWX silver hake model fit from the ASAP runs and various sensitivity analyses (runs 9-12).

Run #		9	10	11	12
Model Description		Short time series; Start year in 1993; 9+ age group; No Fishery or survey Selectivity time blocks ; allowed a dome to be estimated for the fishery (fixed ages 2-5); assumed flattop selectivity for the survey (ages 2+); allowed a stock recruit function; Constant natural mortality (M = 0.4)	Short time series; Start year in 1993; 9+ age group; No survey Selectivity time blocks ; 2 fishery selectivity time blocks (1993-1998; 1999-2011); allowed a dome to be estimated for the fishery (fixed ages 2-3); assumed flattop selectivity for the survey (ages 2+); allowed a stock recruit function; Constant natural mortality (M = 0.4)	Short time series; Start year in 1993; 9+ age group; No survey Selectivity time blocks ; 3 fishery selectivity time blocks (1993-1996; 1997-2000, 2001-2011); allowed a dome to be estimated for the fishery (fixed ages 2-3); assumed flattop selectivity for the survey (ages 2+); allowed a stock recruit function; Constant natural mortality (M = 0.4)	Short time series; Start year in 1993; 9+ age group; No survey Selectivity time blocks ; 2 fishery selectivity time blocks (1993-1996; 1996-2000;2001-2011); allowed a dome to be estimated for the fishery (fixed ages 2-3 in block 1 and for age 5 Only in block 2); assumed flattop selectivity for the survey (ages 2+); allowed a stock recruit function; Constant natural mortality (M = 0.4)
# of Parameters		-	64	71	65
Objective Function		MODEL DID NOT CONVERGE	640	658	660
Components of Objective Function	Survey Age Comp.	-	88	88	87
	Catch age Comp.	-	156	155	158
	index fit total	-	241	237	237
	catch total	-	155	178	178
	Rec Devs.	-	-	-	
RMSE	Catch total	-	0.2	0.5	0.6
	Survey Index	-	1.1	1.0	1.0
	Recr. Devs.	-	-	-	-
Biomass (mt) 2011		-	69,130	66,385	60,688
SSB (mt) 2011		-	41,392	38,363	33,988
F Avg, 2011		-	0.10	0.12	0.18

Table 21. Total biomass (t) and SSB (t) of 4VWX silver hake as of January 1 from 1993 to 2011 as estimated by ASAP model Run 12.

Year	SSB	Biomass
1993	40,720	83,338
1994	35,071	56,495
1995	36,181	62,494
1996	34,123	55,810
1997	29,445	47,904
1998	24,710	45,597
1999	17,201	43,077
2000	15,870	49,676
2001	18,426	46,478
2002	14,620	35,985
2003	13,240	35,646
2004	16,118	35,690
2005	14,749	35,583
2006	10,245	36,336
2007	10,149	31,422
2008	13,336	40,054
2009	17,409	52,866
2010	25,244	62,450
2011	33,988	60,687

Table 22. Fishing mortality at age of 4VWX silver hake from 1993-2011 as estimated by ASAP model Run 12.

Year	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6	Age-7	Age-8	Age-9+	Avg.
1993	0.07006	0.43986	0.58648	0.58648	0.30961	0.06066	0.01147	0.01070	0.00077	0.23068
1994	0.02436	0.15291	0.20389	0.20389	0.10763	0.02109	0.00399	0.00372	0.00027	0.08019
1995	0.05088	0.31942	0.42589	0.42589	0.22483	0.04405	0.00833	0.00777	0.00056	0.16751
1996	0.08128	0.51031	0.68041	0.68041	0.35920	0.07038	0.01331	0.01241	0.00089	0.26762
1997	0.08564	0.53767	0.71690	0.71690	0.37846	0.07415	0.01403	0.01308	0.00094	0.28197
1998	0.14107	0.88563	1.18083	1.18083	0.62337	0.12213	0.02310	0.02155	0.00154	0.46445
1999	0.31720	1.01359	1.23811	1.02294	1.23811	0.34611	0.09410	0.01744	0.00020	0.58753
2000	0.21211	0.67780	0.82794	0.68406	0.82794	0.23145	0.06292	0.01166	0.00013	0.39289
2001	0.29826	0.95309	1.16421	0.96188	1.16421	0.32545	0.08848	0.01640	0.00018	0.55246
2002	0.25503	0.81494	0.99546	0.82246	0.99546	0.27828	0.07566	0.01402	0.00016	0.47238
2003	0.15582	0.49791	0.60820	0.50251	0.60820	0.17002	0.04622	0.00857	0.00010	0.28862
2004	0.22461	0.71774	0.87673	0.72437	0.87673	0.24509	0.06663	0.01235	0.00014	0.41604
2005	0.20836	0.66580	0.81328	0.67194	0.81328	0.22735	0.06181	0.01146	0.00013	0.38593
2006	0.31135	0.99492	1.21531	1.00410	1.21531	0.33973	0.09236	0.01712	0.00019	0.57671
2007	0.28662	0.91589	1.11877	0.92434	1.11877	0.31275	0.08503	0.01576	0.00018	0.53090
2008	0.16302	0.52092	0.63631	0.52573	0.63631	0.17788	0.04836	0.00896	0.00010	0.30195
2009	0.10899	0.34827	0.42542	0.35149	0.42542	0.11892	0.03233	0.00599	0.00007	0.20188
2010	0.06664	0.21296	0.26013	0.21492	0.26013	0.07272	0.01977	0.00366	0.00004	0.12344
2011	0.05832	0.18637	0.22765	0.18809	0.22765	0.06364	0.01730	0.00321	0.00004	0.10803

Table 23. 4VWX silver hake abundance at age from 1993-2011, estimated by ASAP model Run 12.

Year	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9+	Total
1993	287,665	336,763	150,204	64,310	13,522	2,764	907	269	57	856,460
1994	253,865	179,780	145,405	56,009	23,980	6,651	1,744	601	216	668,251
1995	321,111	166,076	103,422	79,490	30,619	14,434	4,365	1,164	546	721,228
1996	279,372	204,570	80,885	45,283	34,805	16,392	9,259	2,902	1,140	674,607
1997	232,340	172,649	82,319	27,457	15,372	16,290	10,241	6,124	2,685	565,477
1998	147,975	142,959	67,599	26,943	8,987	7,057	10,139	6,769	5,850	424,277
1999	289,003	86,140	39,525	13,912	5,545	3,230	4,187	6,641	8,356	456,539
2000	507,488	141,068	20,955	7,682	3,353	1,078	1,531	2,554	9,975	695,684
2001	257,041	275,162	48,012	6,138	2,598	982	573	964	8,378	599,847
2002	209,051	127,865	71,113	10,047	1,572	544	475	352	6,251	427,269
2003	410,115	108,587	37,941	17,616	2,959	389	276	295	4,422	582,600
2004	231,514	235,243	44,240	13,844	7,144	1,080	220	177	3,160	536,622
2005	203,059	123,969	76,928	12,341	4,497	1,993	566	138	2,235	425,727
2006	334,911	110,514	42,701	22,865	4,225	1,337	1,064	357	1,589	519,563
2007	343,294	164,435	27,391	8,490	5,615	840	638	650	1,300	552,654
2008	331,808	172,771	44,107	5,998	2,258	1,230	412	393	1,301	560,277
2009	347,018	188,961	68,789	15,648	2,377	801	690	263	1,133	625,679
2010	617,265	208,593	89,413	30,133	7,380	1,041	477	448	934	955,685
2011	451,841	387,089	113,005	46,207	16,293	3,814	649	313	925	1,020,137

Table 24. Retrospective Rho statistics for 4VWX silver hake for average F, SSB and ages 1-9+.

Year	2006	2007	2008	2009	2010	Min	Max	Mohn's Rho (5 year Peel)
Average F	-0.5911	-0.0319	0.5171	0.0779	-0.0718	-0.5911	0.5171	-0.0200
SSB	0.7557	-0.0255	-0.2581	-0.0478	0.1652	-0.2581	0.7557	0.1179
Biomass	0.6236	0.0433	-0.149	-0.0363	-0.0403	-0.1490	0.6236	0.0883
N at Age1	0.8943	0.1506	-0.1162	-0.0323	-0.3325	-0.3325	0.8943	0.1128
N at Age2	0.3284	0.0285	-0.1713	-0.0494	0.2159	-0.1713	0.3284	0.0704
N at Age3	0.4295	-0.0676	-0.1812	-0.0138	0.1492	-0.1812	0.4295	0.0632
N at Age4	0.5177	-0.1647	-0.2850	-0.0376	0.1351	-0.2850	0.5177	0.0331
N at Age5	0.5425	-0.2064	-0.3604	-0.0935	0.0692	-0.3604	0.5425	-0.0097
N at Age6	0.6049	-0.2804	-0.4033	-0.1529	-0.0078	-0.4033	0.6049	-0.0479
N at Age7	0.4404	-0.1016	-0.1933	-0.1171	-0.1566	-0.1933	0.4404	-0.0256
N at Age8	0.3560	-0.1193	-0.0735	-0.0606	-0.2348	-0.2348	0.3560	-0.0264
N at Age9+	0.2903	0.0011	-0.0297	-0.0122	-0.1948	-0.1948	0.2903	0.0109

Table 25. Inputs to the 4VWX silver hake YPR analyses.

Age	Selectivity on Fishing Mortality	Natural Mortality	Stock Weights	Catch Weights	Spawning Stock Weights	Fraction Mature
1	0.2562	0.4000	0.0493	0.0578	0.0560	0.0100
2	0.8187	0.4000	0.0761	0.0908	0.0889	0.6220
3	1.0000	0.4000	0.1144	0.1350	0.1320	0.9190
4	1.0000	0.4000	0.1539	0.1738	0.1721	0.9690
5	1.0000	0.4000	0.2142	0.2606	0.2534	1.0000
6	0.2795	0.4000	0.2904	0.3298	0.3209	1.0000
7	0.0760	0.4000	0.3977	0.4952	0.4766	1.0000
8	0.0141	0.4000	0.5405	0.5776	0.5679	1.0000
9+	0.0002	0.4000	0.6500	0.6612	0.6600	1.0000

Table 26. Biological reference points for 4VWX silver hake based on the 100 year long-term projections.

Fishing Reference Points	
FMSY (F40%)	0.31

	Biomass Reference Points		
Units (mt)	5% CI	Median	95%CI
SSBMSY	35.11	41.89	50.84
BMSY	58.06	69.67	85.17
MSY	8.82	11.02	14.08

FIGURES

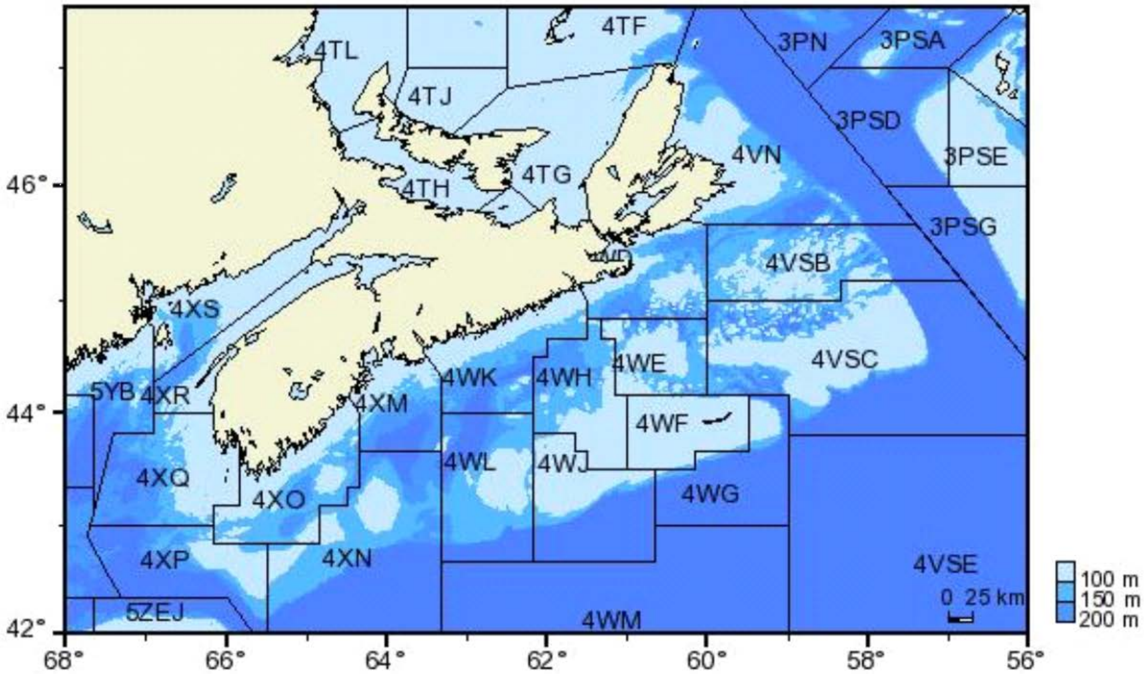


Figure 1. Map of statistical unit areas comprising NAFO 4VWX.

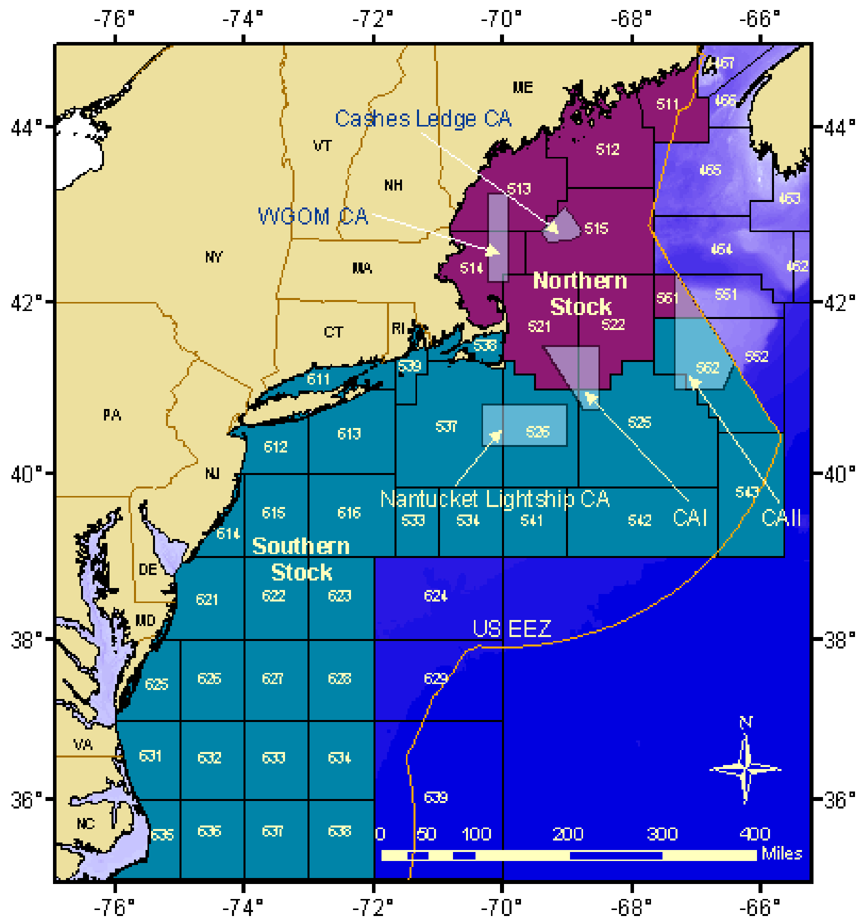


Figure 2. Commercial fishery statistical areas (SA) for northern (SA 511-515, 521, 522, 551 and 561) and southern (SA 525, 526, 533-539, 541-543, 552, 562 and 611-639) USA silver hake stocks in the northwest Atlantic.

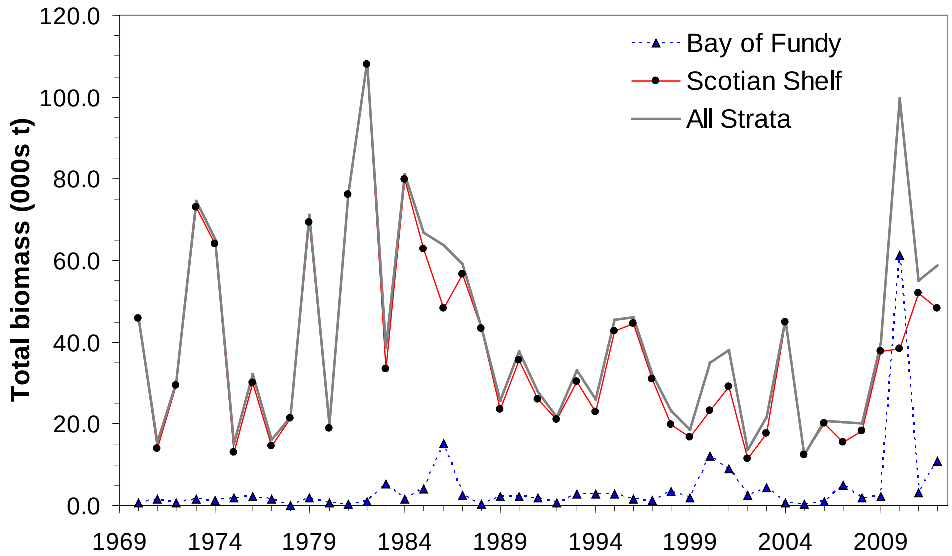


Figure 3. Trends in total biomass for silver hake from the DFO summer RV survey for Scotian Shelf strata (440-483), Bay of Fundy strata (484-495) and all strata combined, 1970-2012.

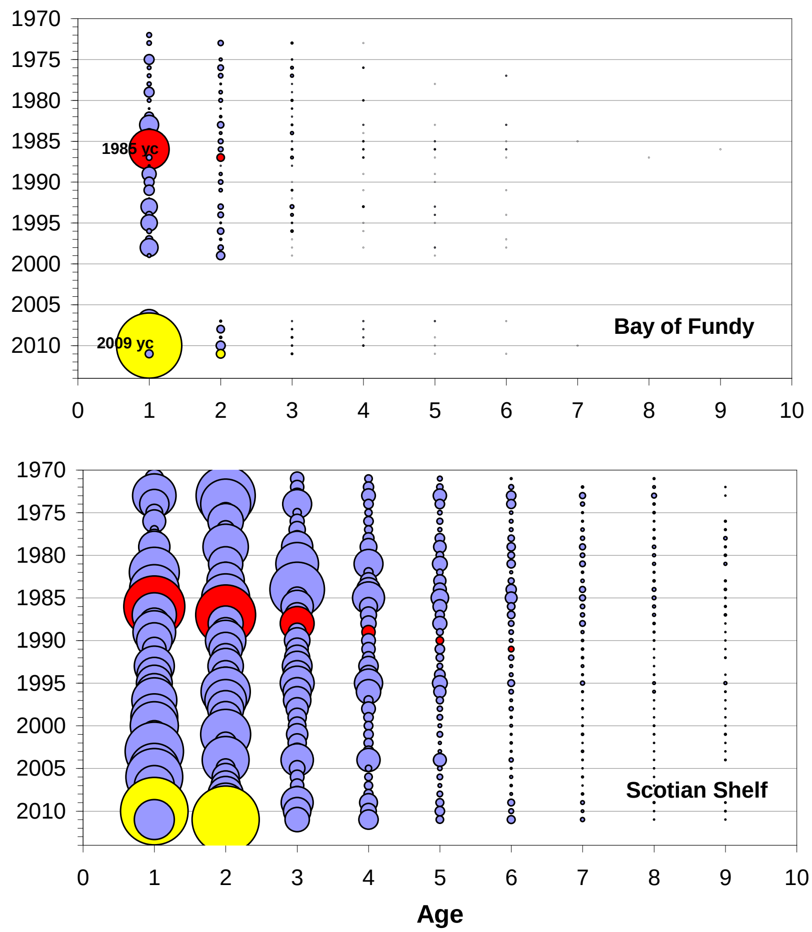


Figure 4. Trends in stratified total abundance at age for silver hake from the DFO summer RV survey for Scotian Shelf strata (440-483) and Bay of Fundy strata (484-495), 1970-2012.

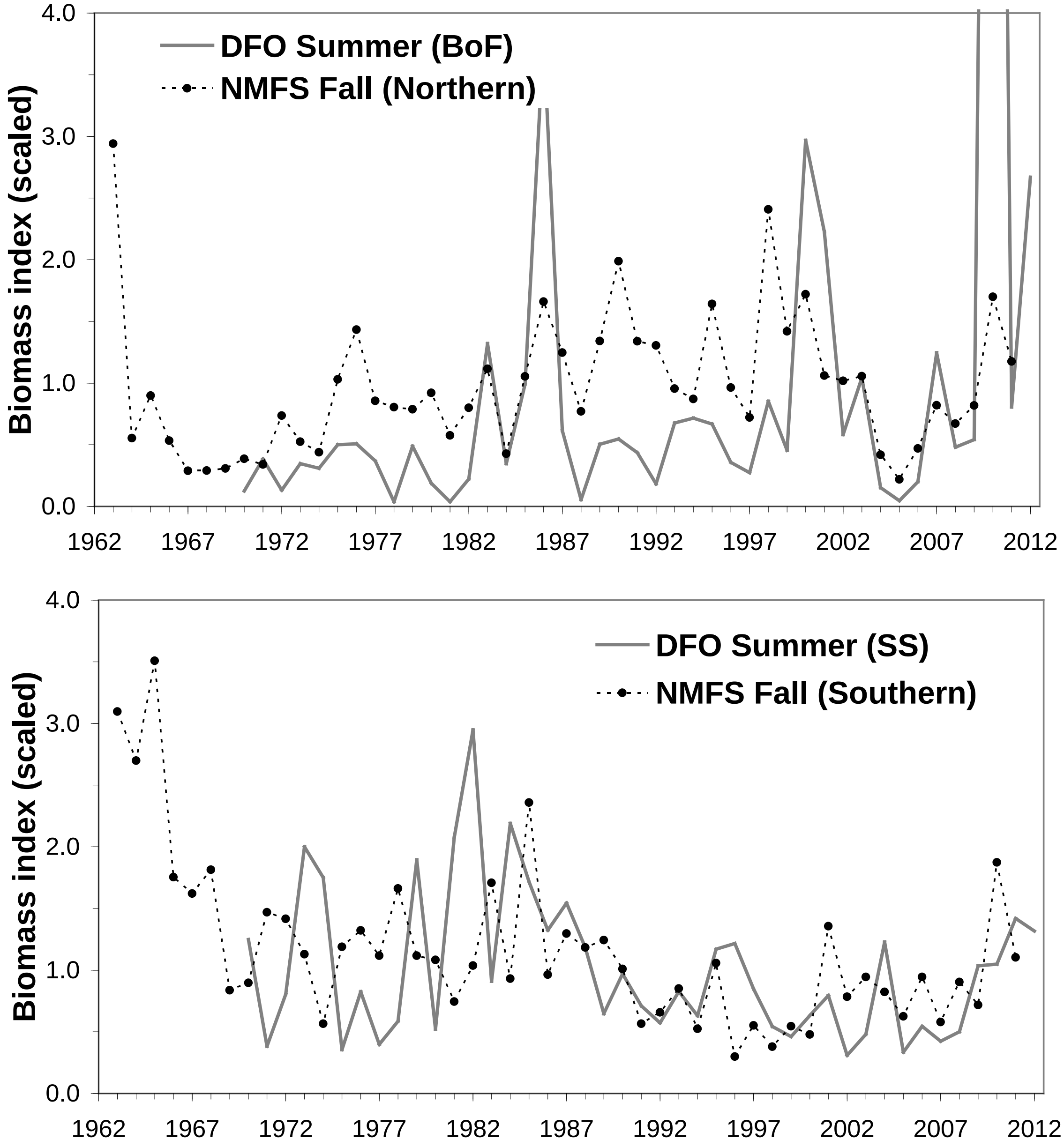


Figure 5. Upper panel: Scaled biomass index (kg/tow) for silver hake from the DFO summer RV survey for the Bay of Fundy (1970-2012) and the NMFS fall survey for the Northern stock (Gulf of Maine, 1963-2011). Lower panel: Scaled biomass index (kg/tow) for silver hake from the DFO summer RV survey for the Scotian Shelf (1970-2012) and the NMFS fall survey for the Southern Stock (Georges Bank-Mid Atlantic Bight, 1963-2011).

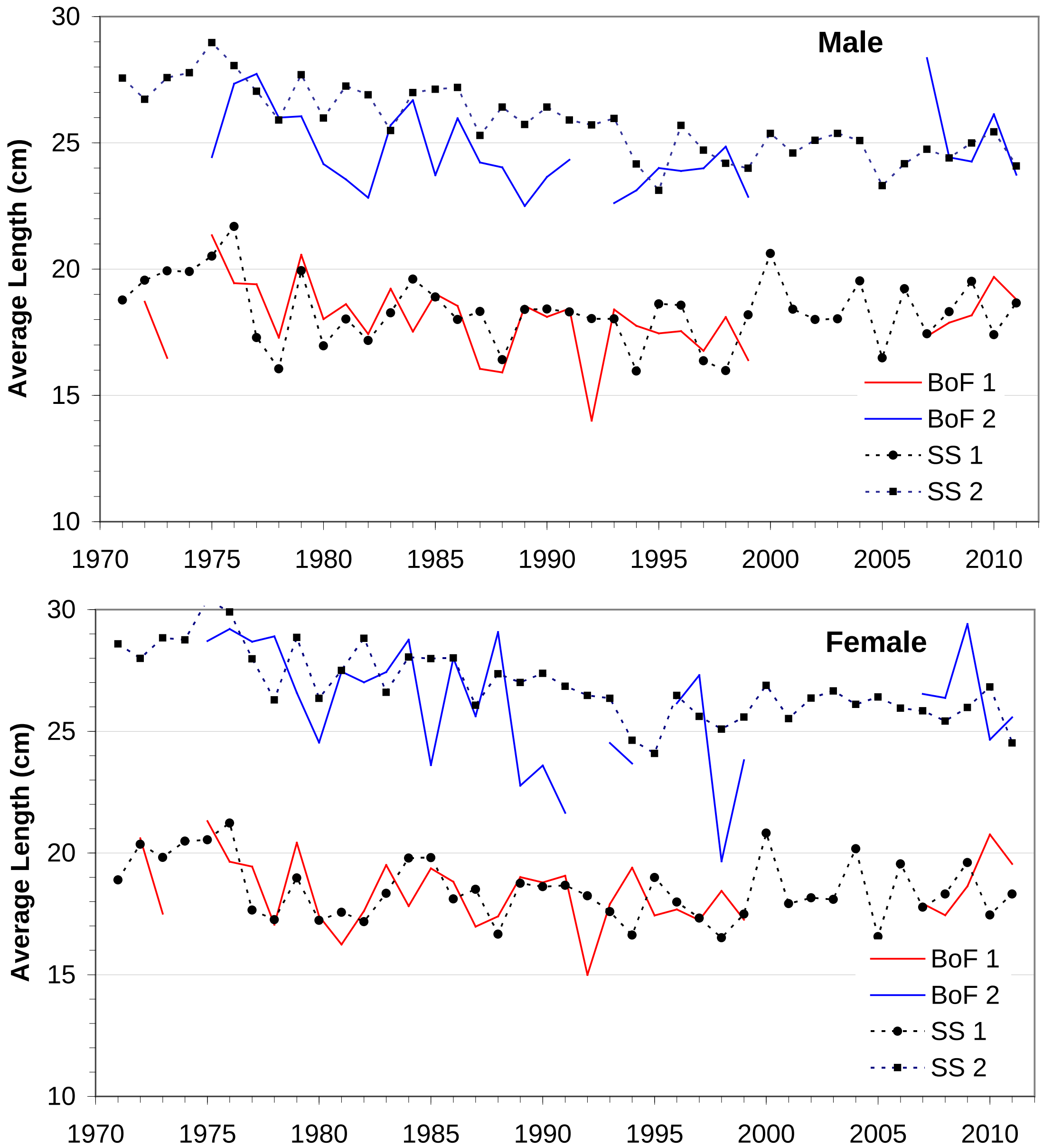


Figure 6. Mean length-at-age for age 1 and 2 silver hake captured during the DFO summer RV survey in the Bay of Fundy (BoF) and on the Scotian Shelf (SS). Upper panel: males; lower panel: females.

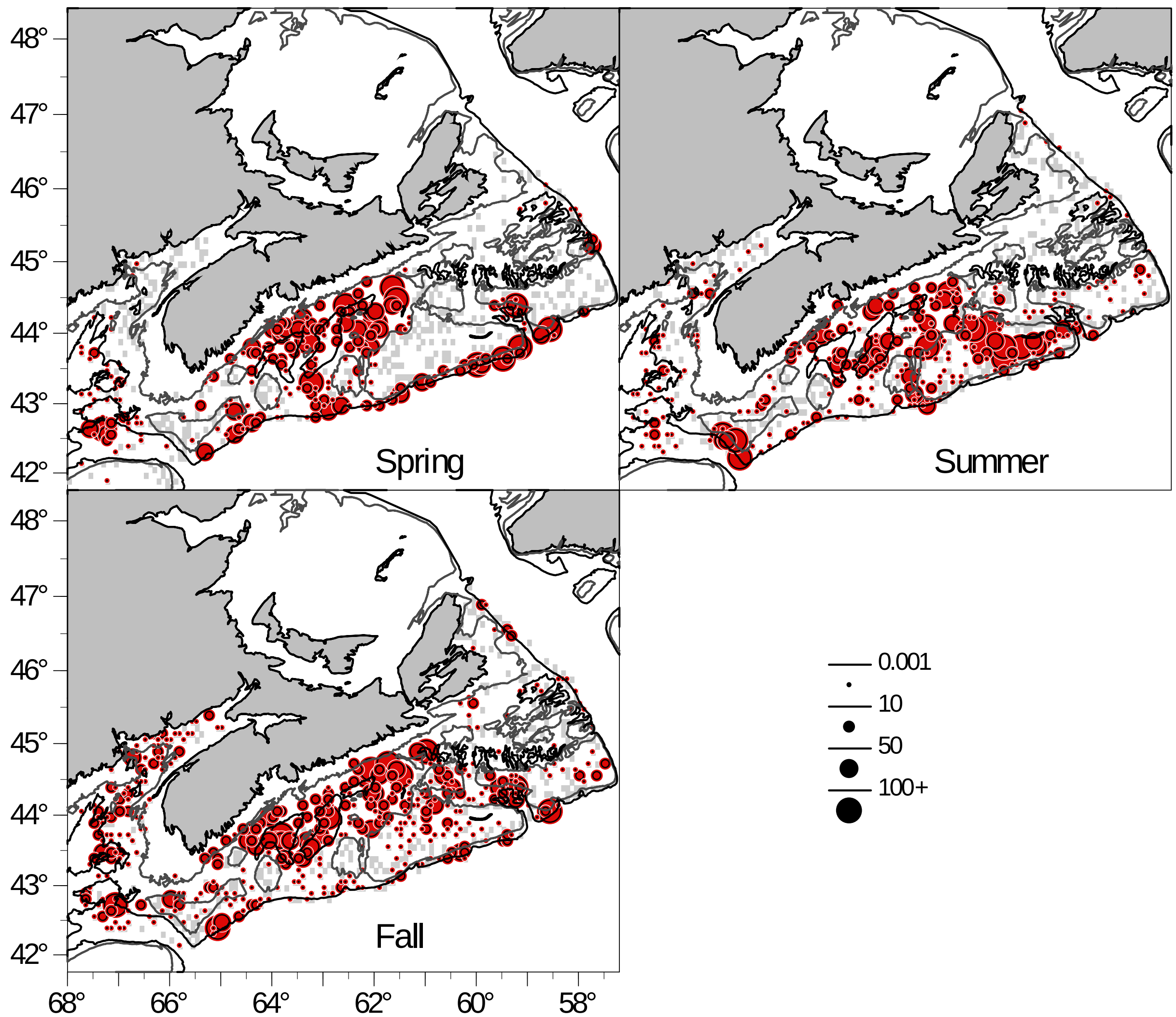


Figure 7. Distribution of silver hake catches (six-year average weight (kg)/tow aggregated by 10 minute squares) from DFO summer RV survey strata 440-495, from a six-year period (1979-1984) when spring, summer and fall surveys were conducted annually. Grey shading indicates extent of area surveyed.

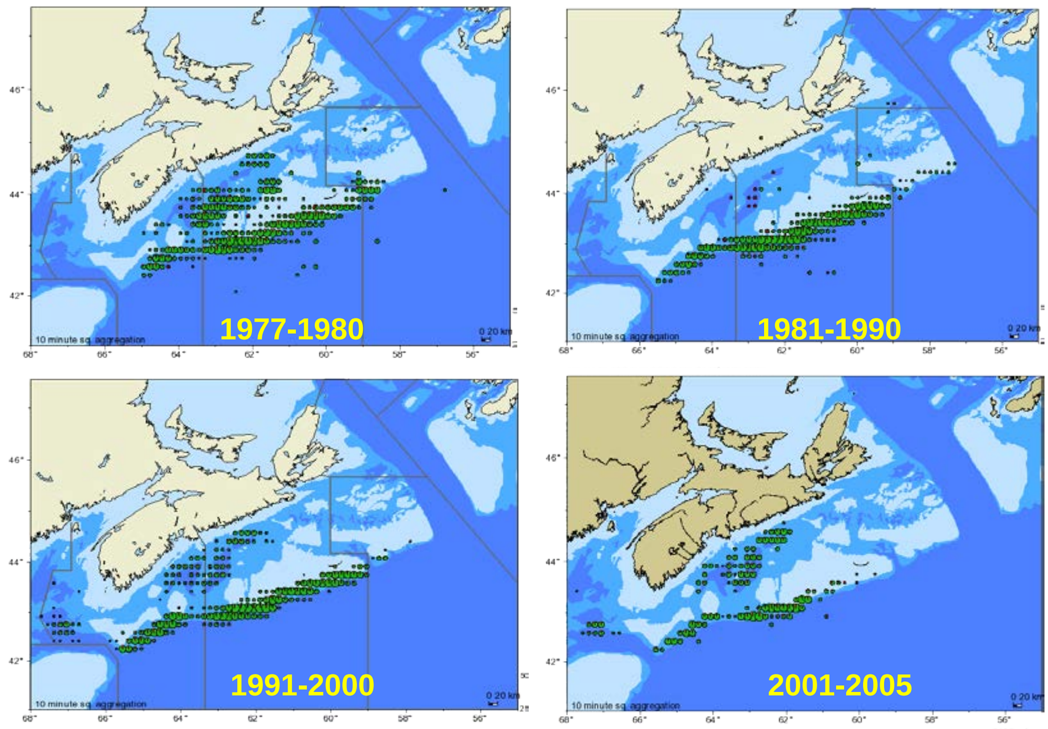


Figure 8. Distribution of mobile gear silver hake catches (t per 10 minute square) from foreign and domestic fishing operations reported by Canadian at-sea observers, 1977-2005.

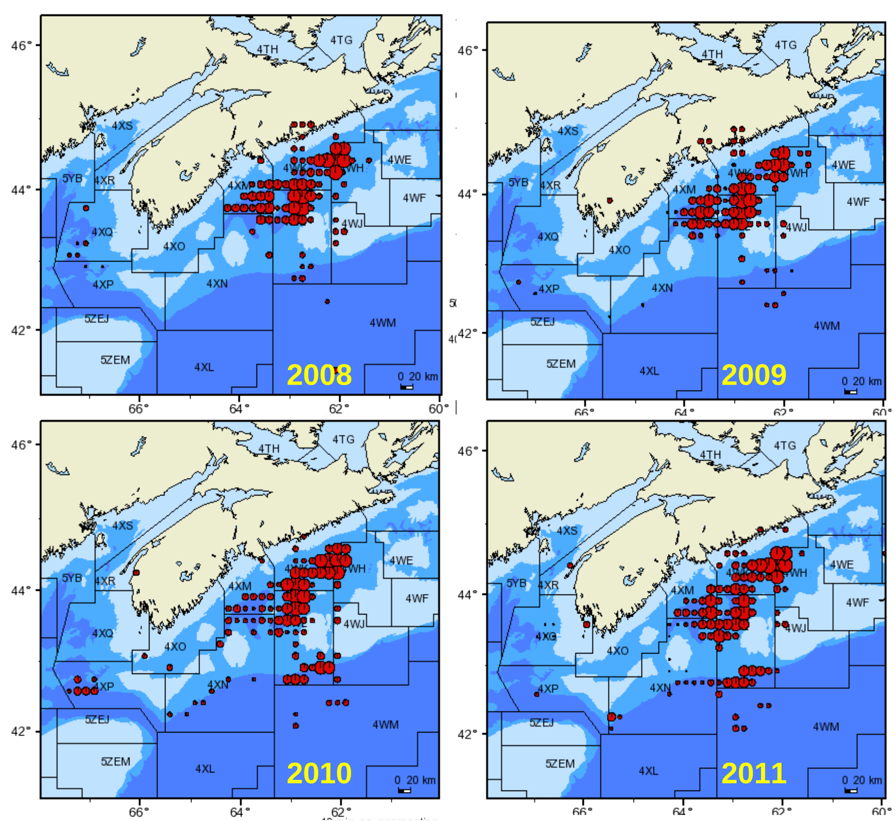


Figure 9. Distribution of silver hake catches (t per 10 minute square) from Canadian mobile gear log record data, 2008-2011.

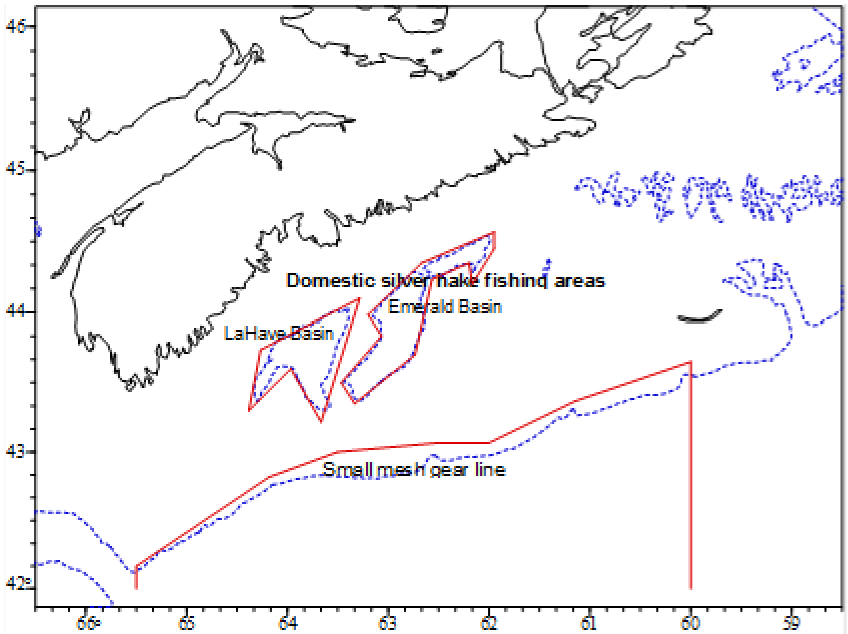


Figure 10. Scotian Shelf silver hake fishing areas showing the locations of Emerald and LaHave basins and the small mesh gear line.

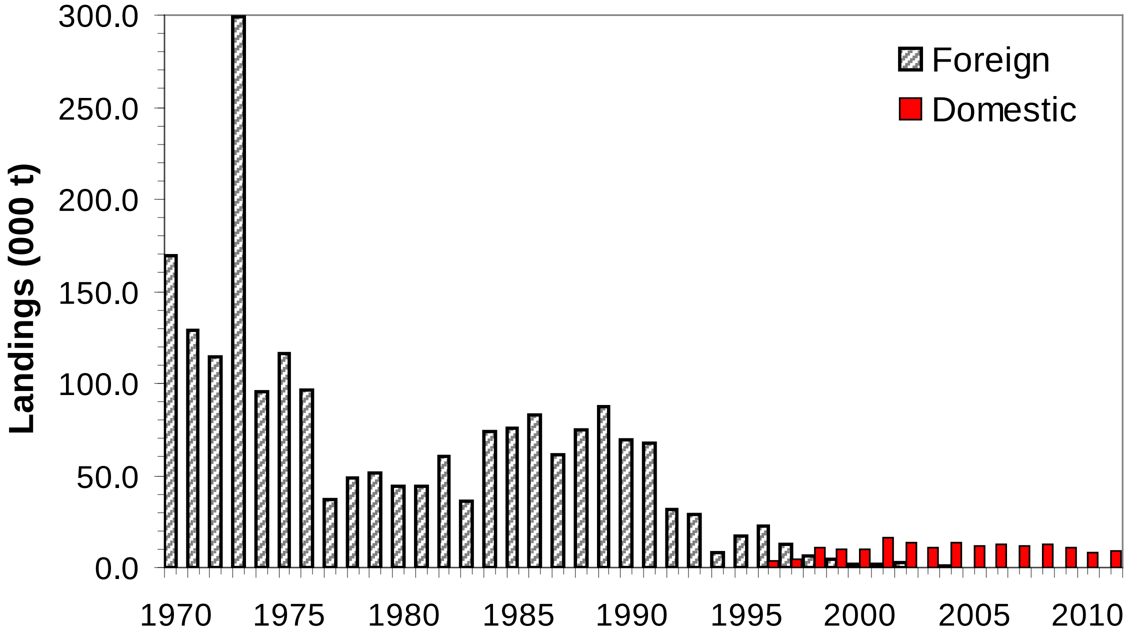


Figure 11. Landings (000 t) of Scotian Shelf silver hake by foreign (Russia, Cuba) (hatched bars) and domestic (Canada) (red bars) fleets, 1970-2011.

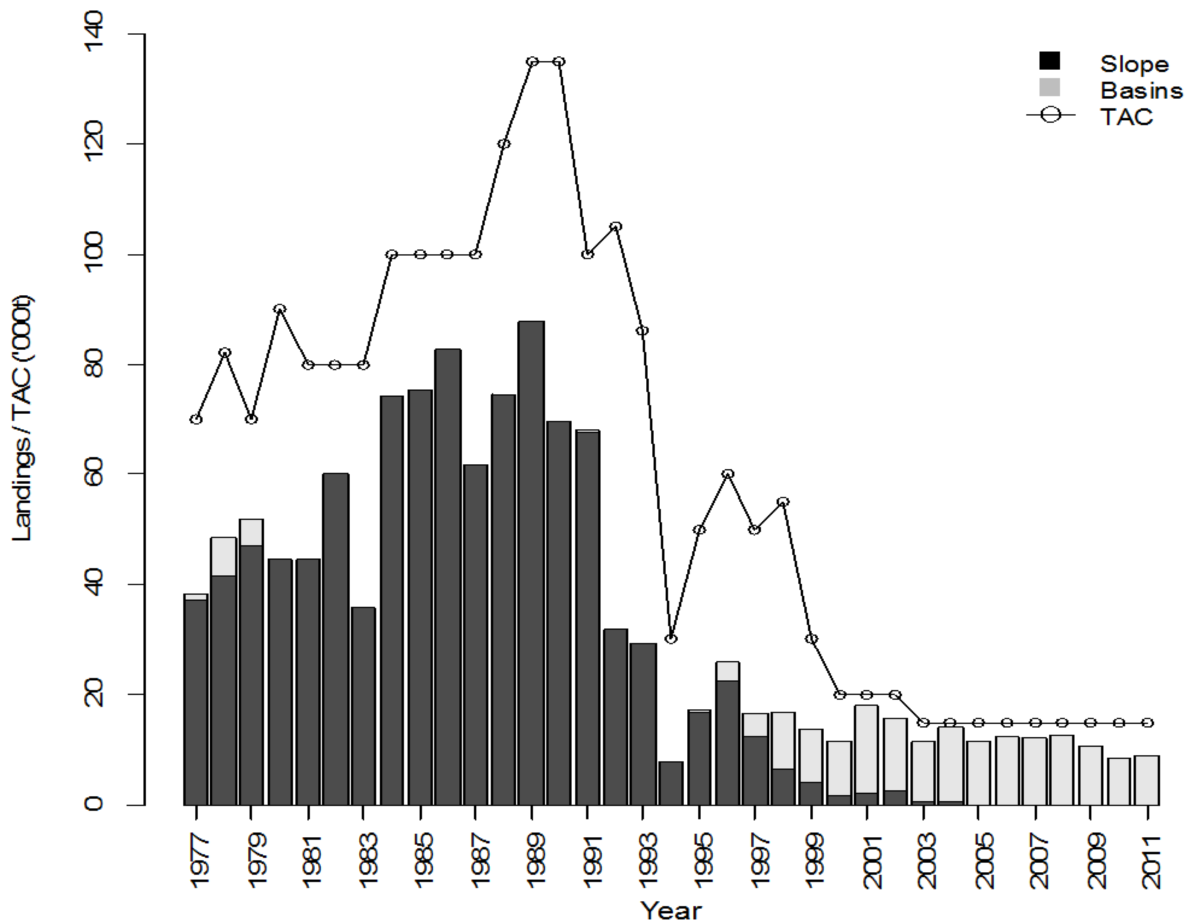


Figure 12. Silver hake TAC and catches (000 t) by fishing area, 1977-2011. Basin: landings from Emerald and LaHave basins. Slope: landings from the edge of the Scotian Shelf.

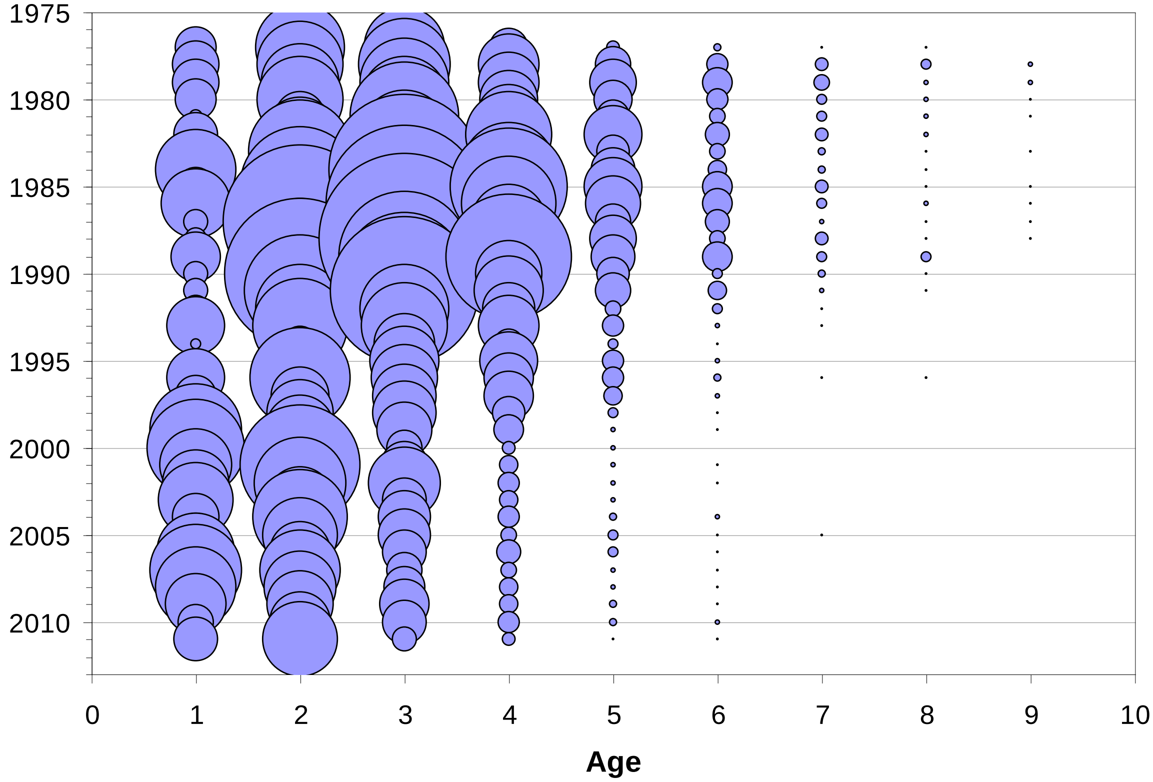


Figure 13. Fishery catch-at-age for silver hake from 4VWX, 1977-2011. The area of the circle is proportional to the catch at that age and year.

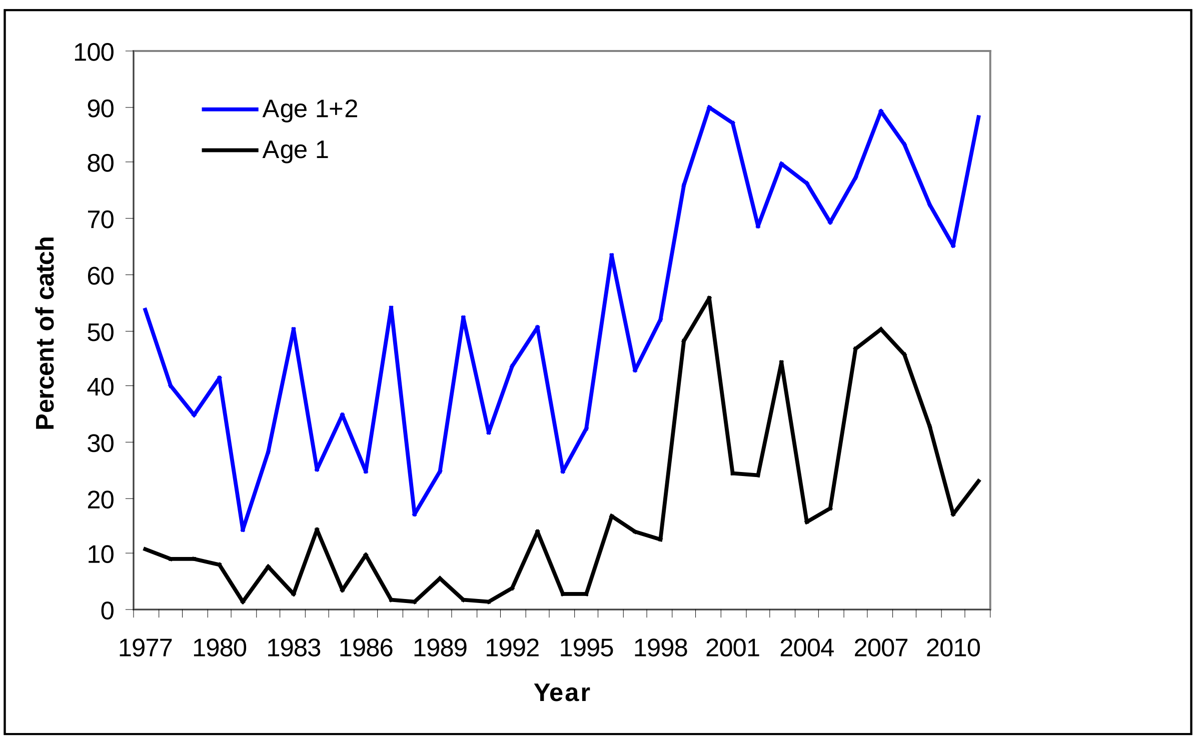


Figure 14. Silver hake catch-at-ages 1 and 1+2 combined as a proportion of total catch, 1977-2011.

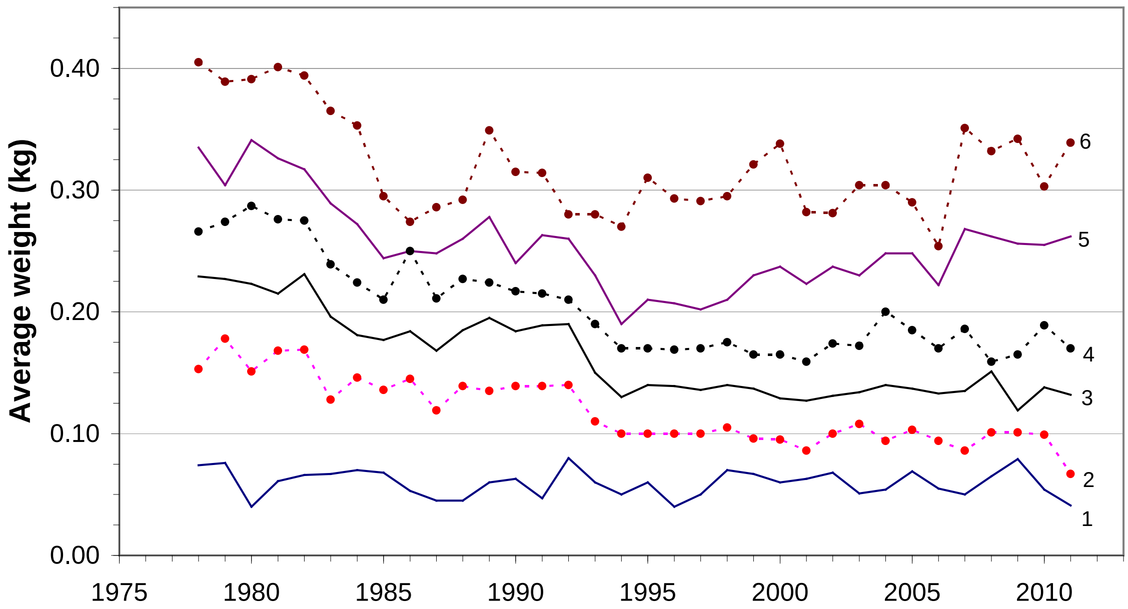


Figure 15. Trends in fishery weights-at-age (kg) for silver hake aged 1-6 from the 4VWX silver hake fishery, 1977-2011.

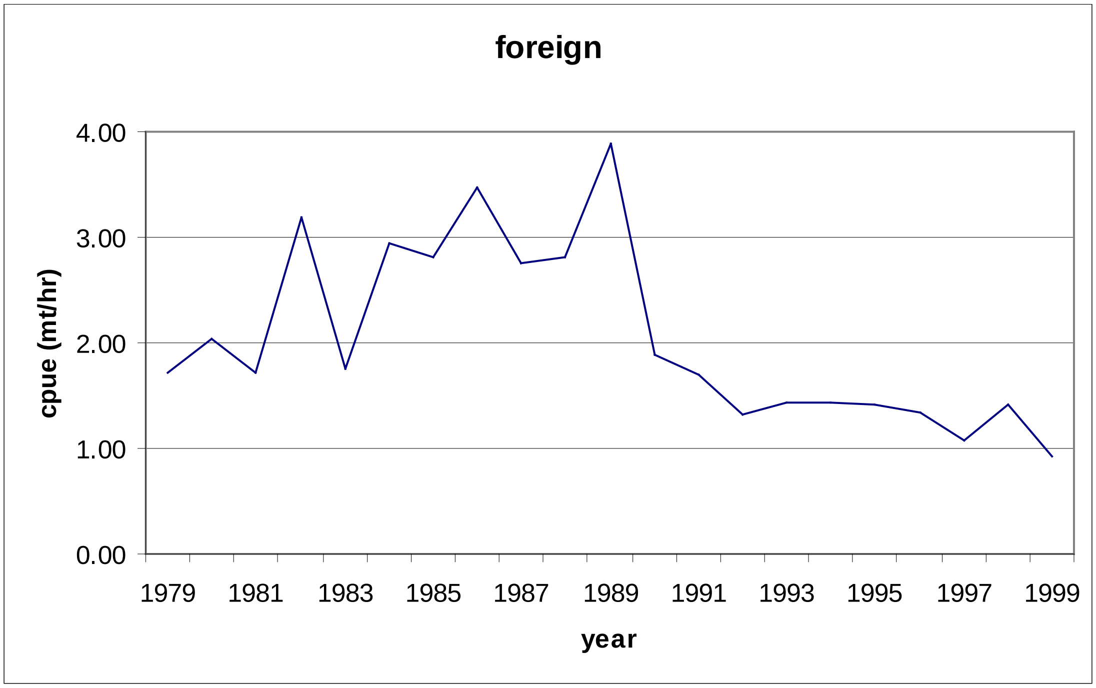


Figure 16. Predicted catch rates from the foreign fleet (t/hr) for silver hake in NAFO Div. 4W, in July, 1979-1999.

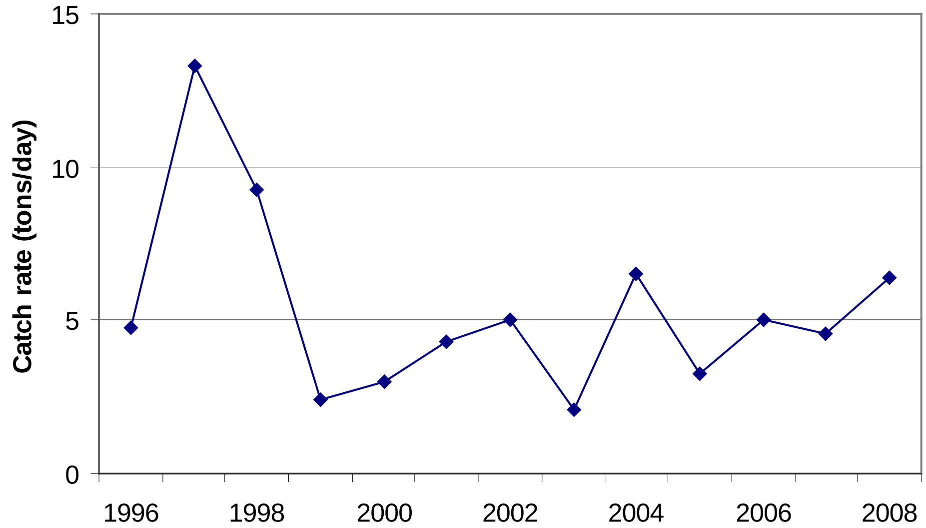


Figure 17. Predicted catch rates (t/day) for silver hake in NAFO Div. 4W, in July, 1996-2008.

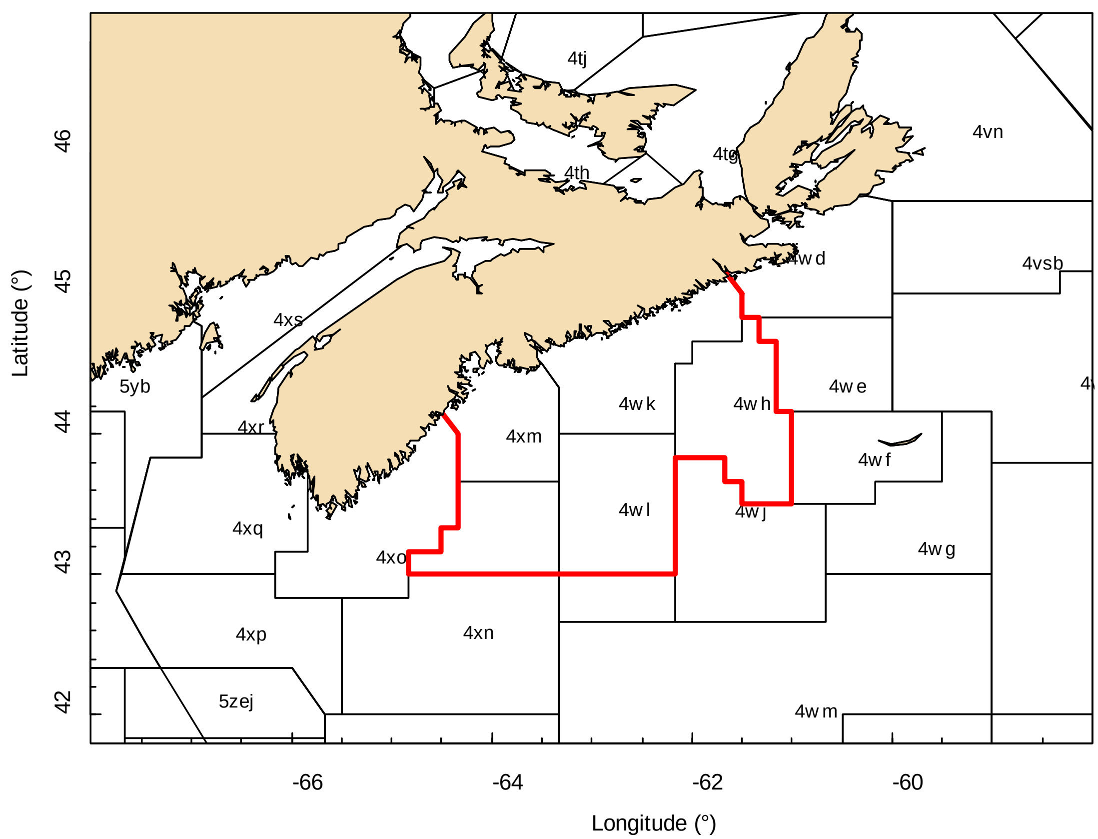


Figure 18. Map of area used in standardized catch rate series for 4VWX silver hake.

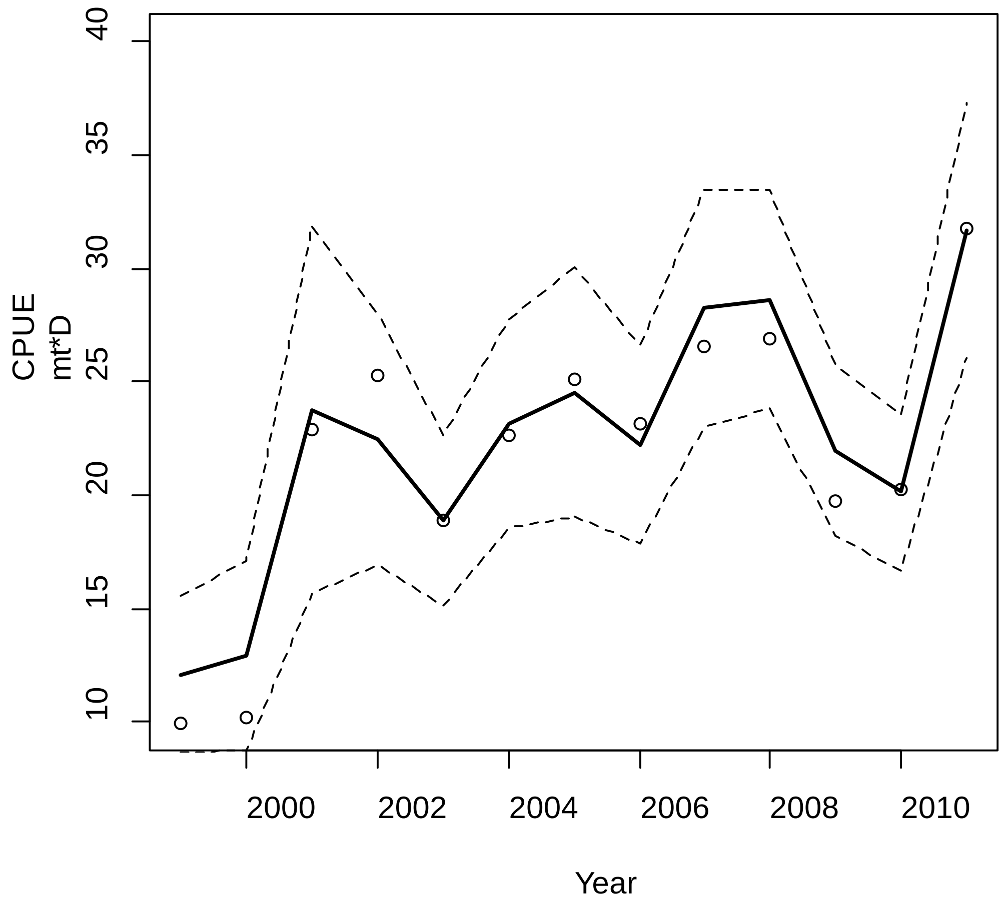


Figure 19. Standardized catch rate series (t/day) from landings and effort data from the basins region of the Scotian Shelf since 1999. A multiplicative model using the catch series from vessels were included in the model with the main effects of vessel, year, quarter and area and the interactive effect of year and period.

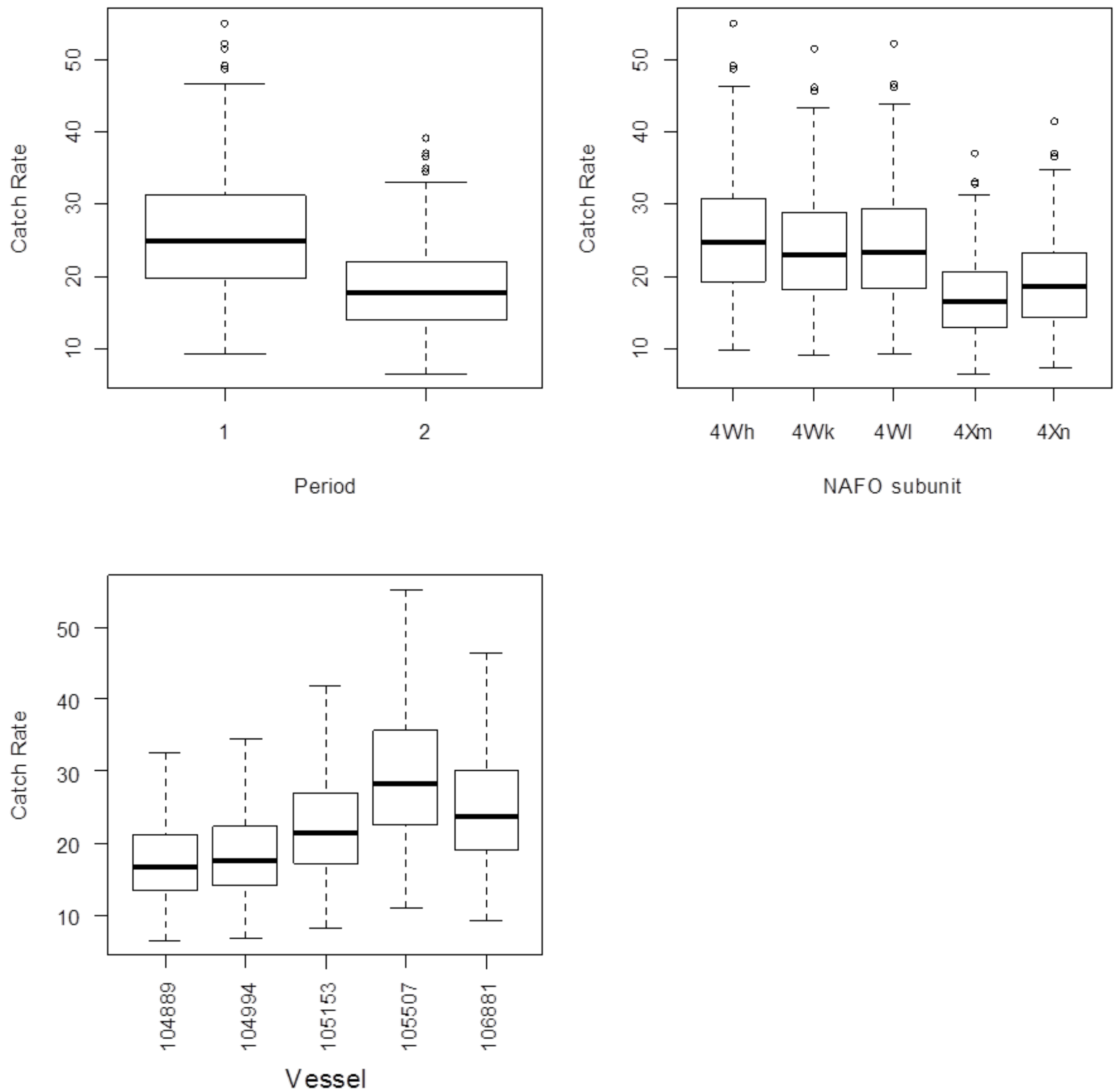


Figure 20. Main effects from the multiplicative standardized catch rate model for silver hake in 4VWX.

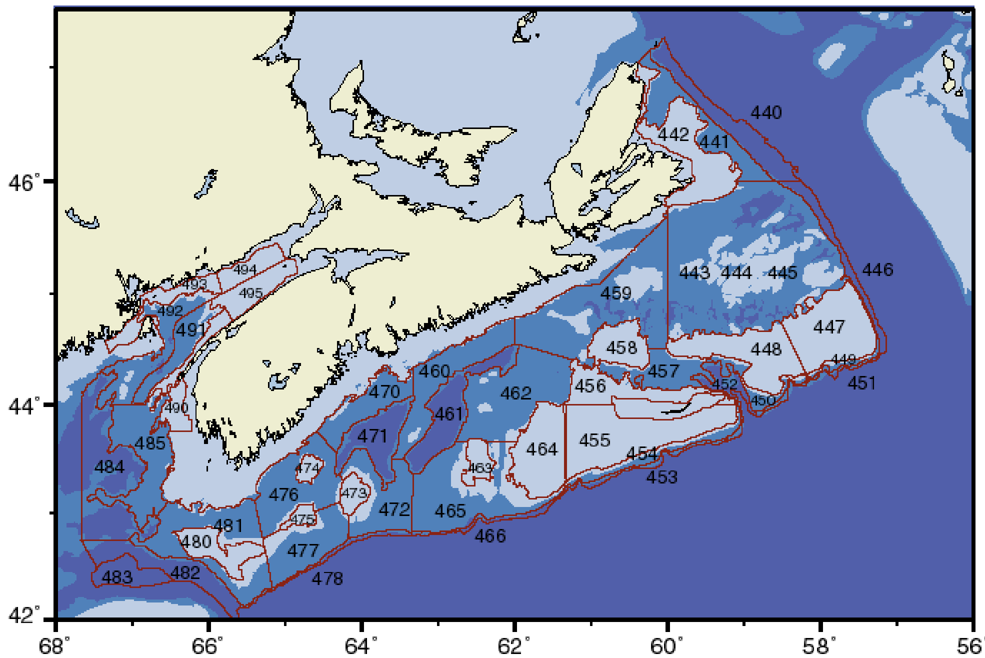


Figure 21. DFO bottom trawl survey strata and area of coverage (4VWX) for the summer RV survey series (1970-2012) and spring and fall survey series (1979-1984).

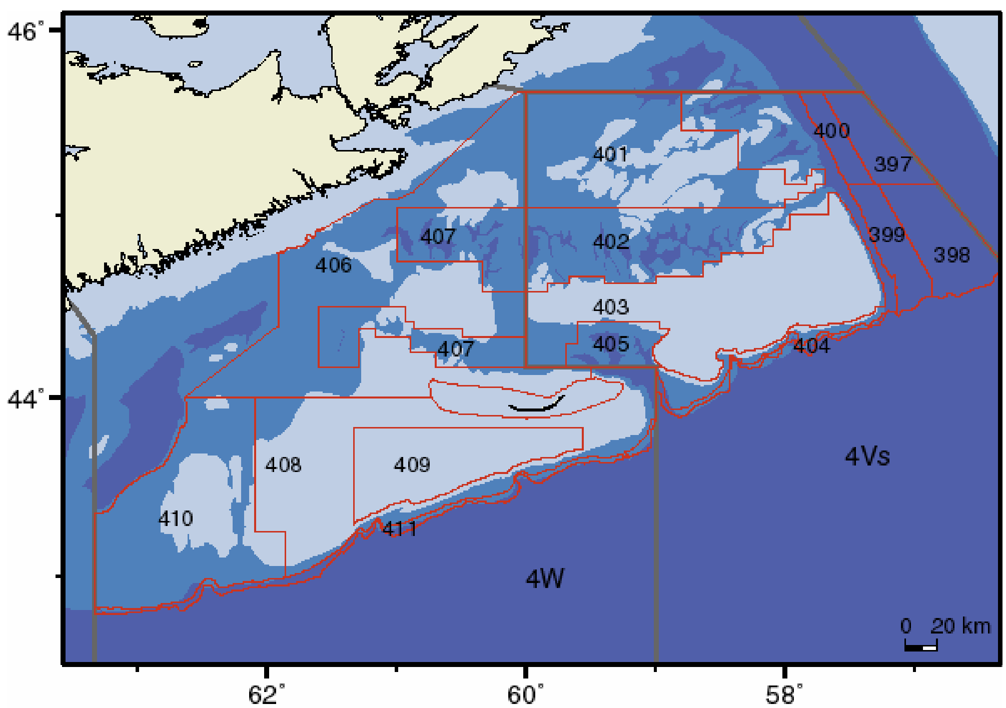


Figure 22. DFO eastern Scotian Shelf (4VsW) spring survey strata and area of coverage.

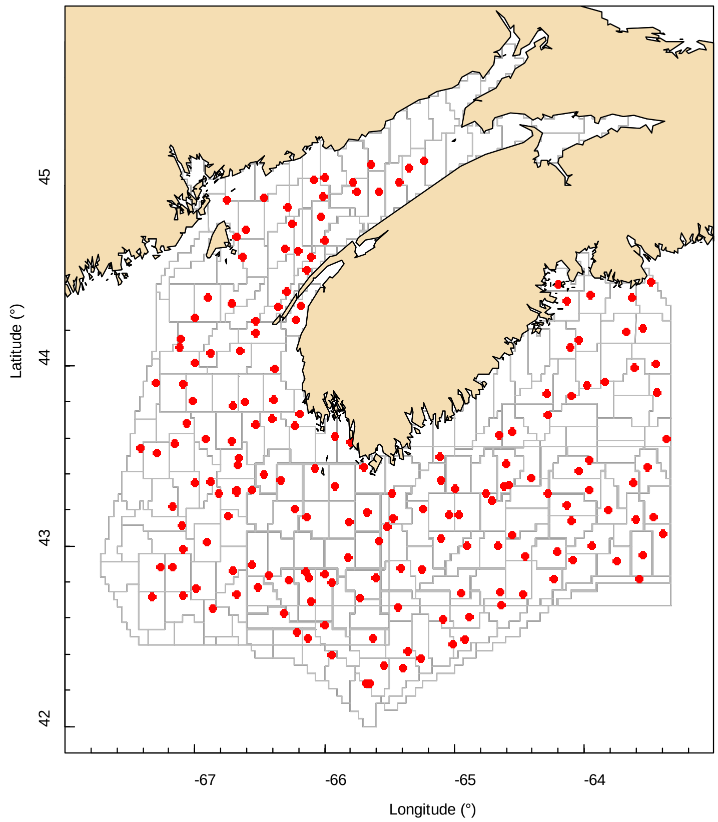


Figure 23. Location of grid blocks and fixed set locations within each used for the 4X ITQ fixed station industry survey.

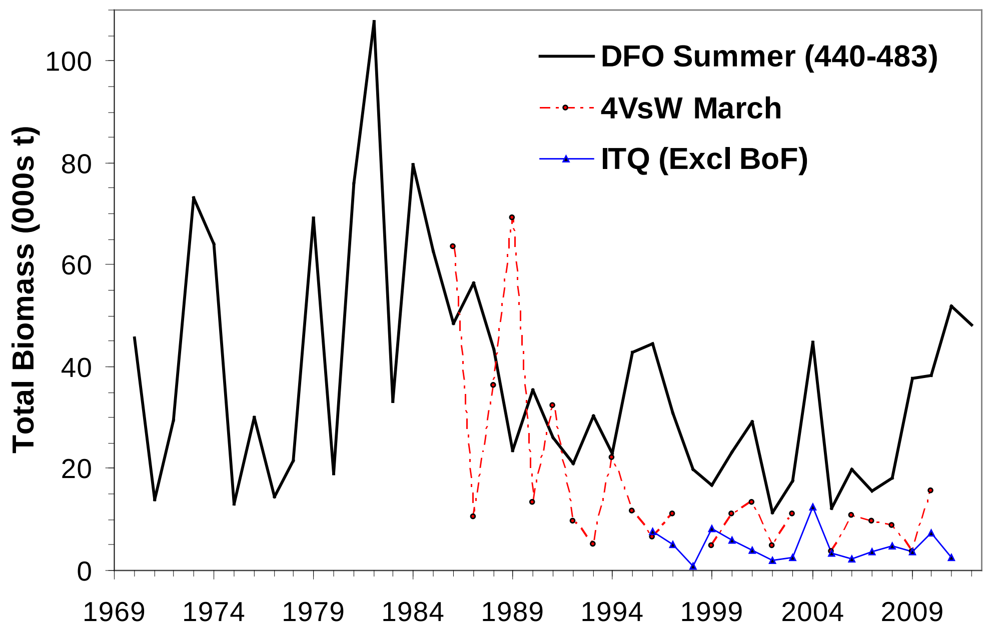


Figure 24a. Trends in total biomass (000 t) from the DFO summer RV survey (strata 440-483; 1970-2012), the 4VsW March survey (1986-2010) and the ITQ survey excluding Bay of Fundy stations (1995-2011).

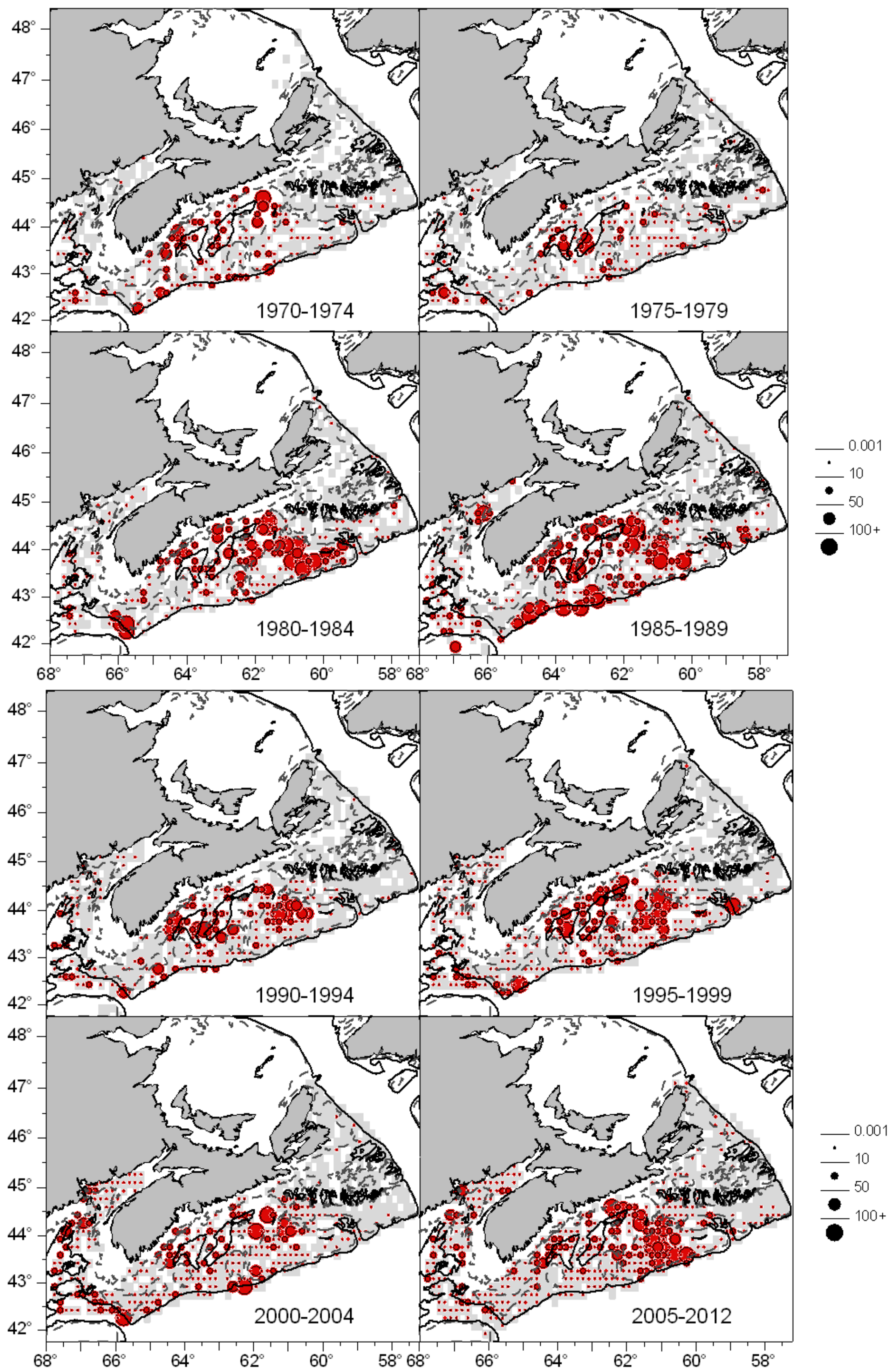


Figure 24b. Distribution of silver hake catches (five-year average weight (kg)/tow aggregated by 10 minute squares) from the DFO summer RV survey 1970-2012. Grey shading indicates extent of area surveyed.

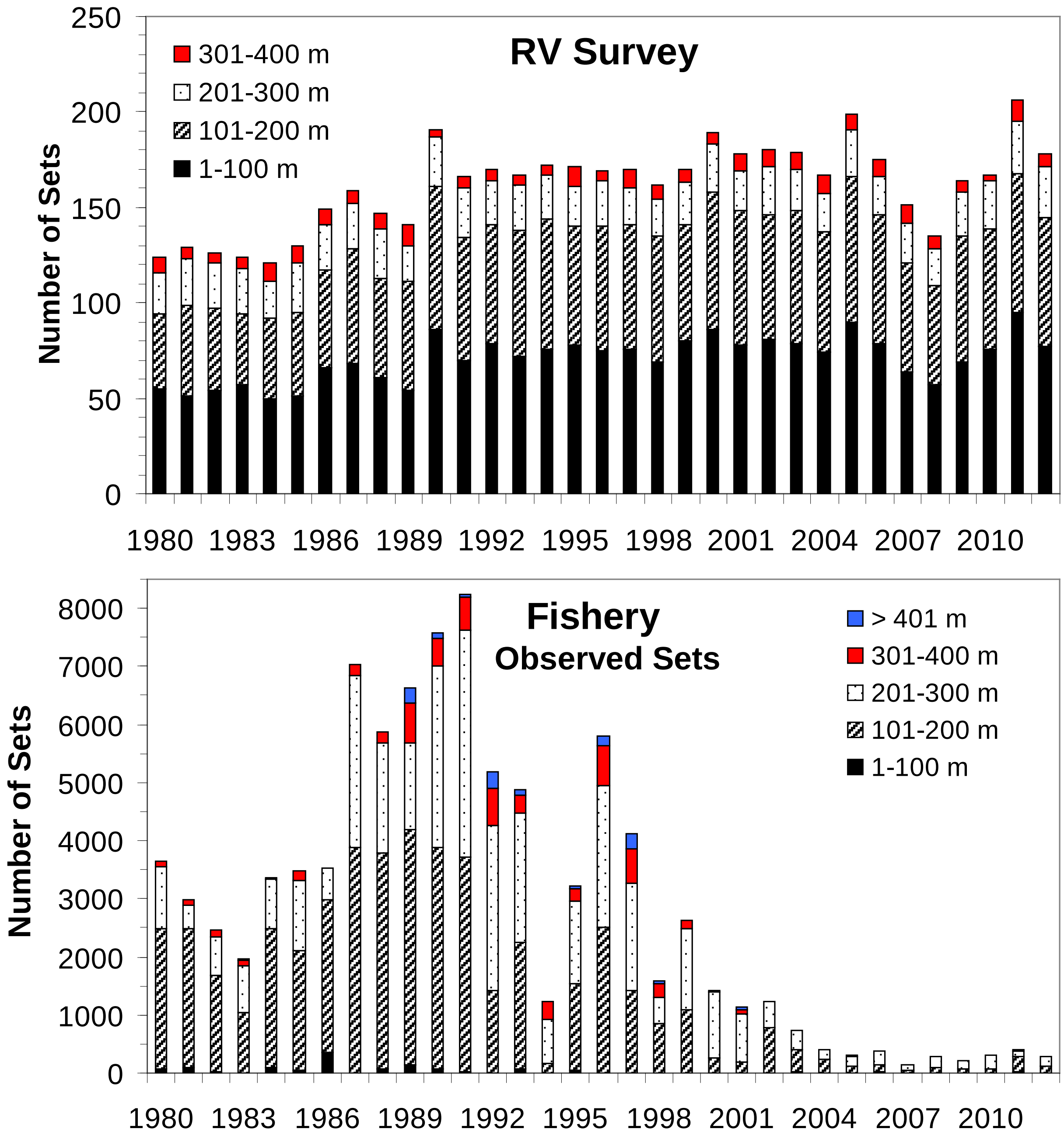


Figure 25. Number of sets by depth range (m) from the DFO summer RV survey (1980-2012; top panel) compared to the number of observed sets from the commercial fishery (1980-2012; lower panel).

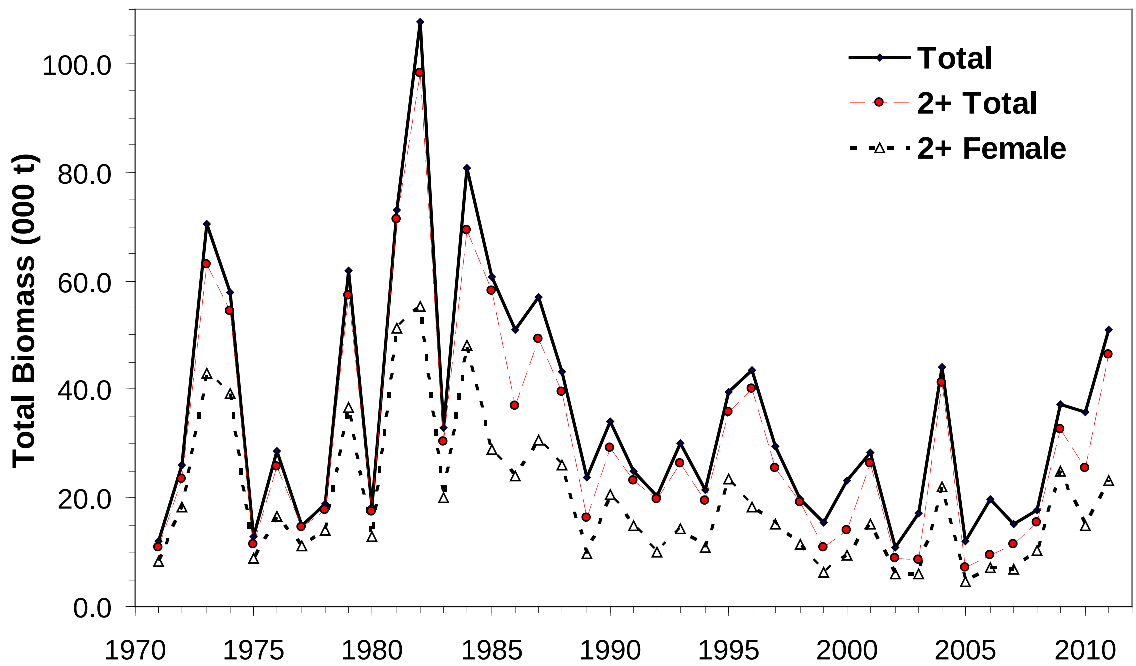


Figure 26. Stratified total biomass indices from the DFO summer RV survey for strata 440-483, 1970-2012. Total: ages 1-9, sexes combined; 2+ total: ages 2+, sexes combined; 2+ female: ages 2+ females only.

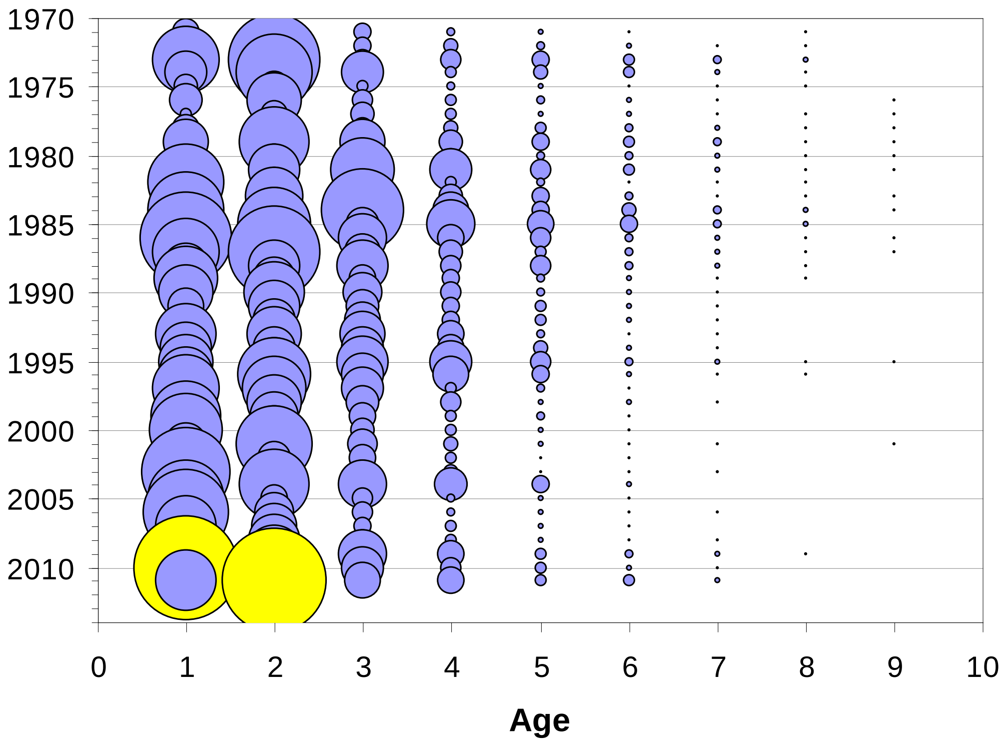


Figure 27. Stratified total number per tow at age (1-9) for silver hake from the DFO summer RV survey, strata 440-483, 1971-2011. The recent strong 2009 year class is indicated by the yellow circles.

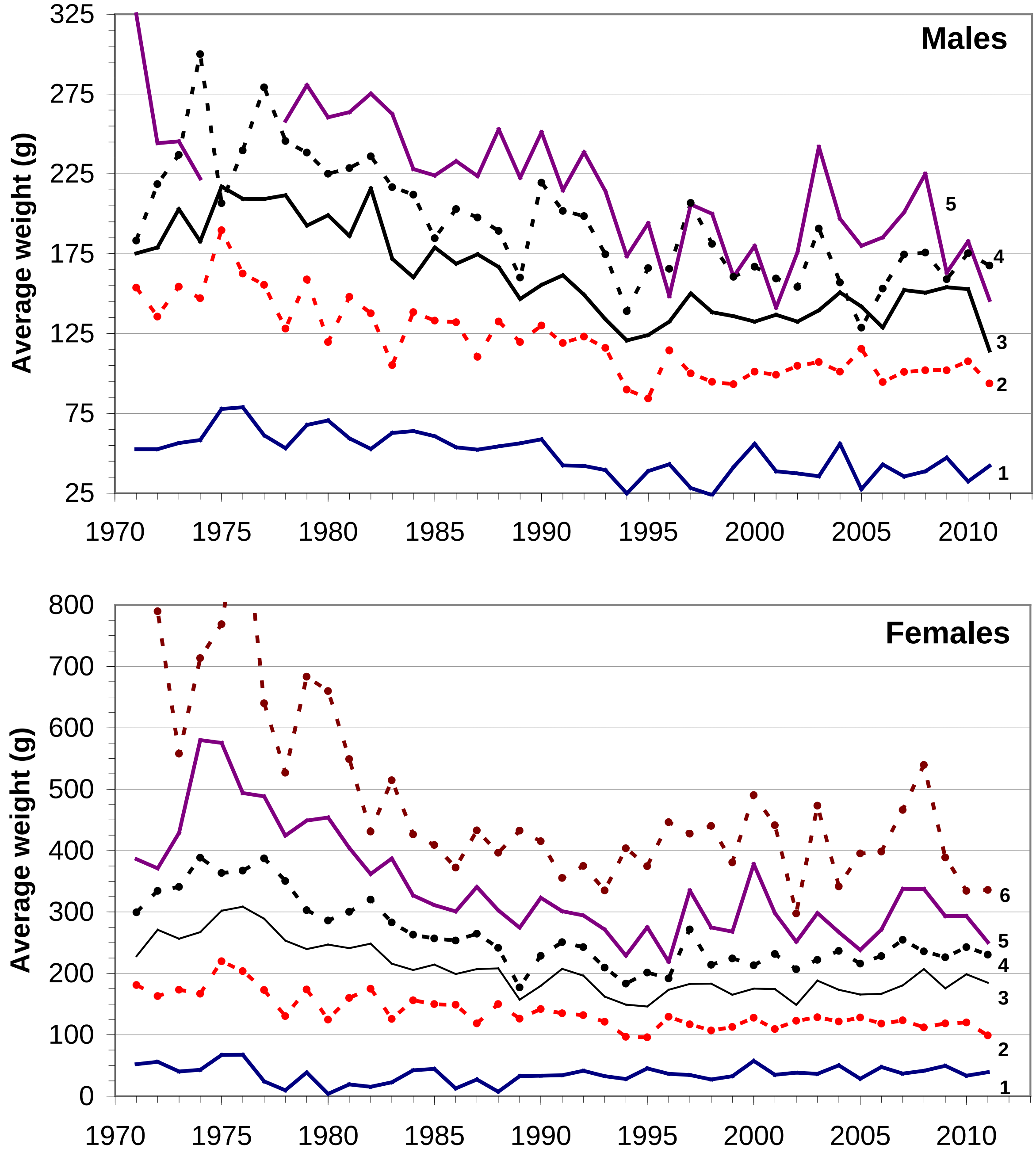


Figure 28. Annual mean weight-at-age (g) for male (ages 1-5; upper panel) and female (ages 1-6; lower panel) from the DFO summer RV survey for strata 440-483, 1971-2011.

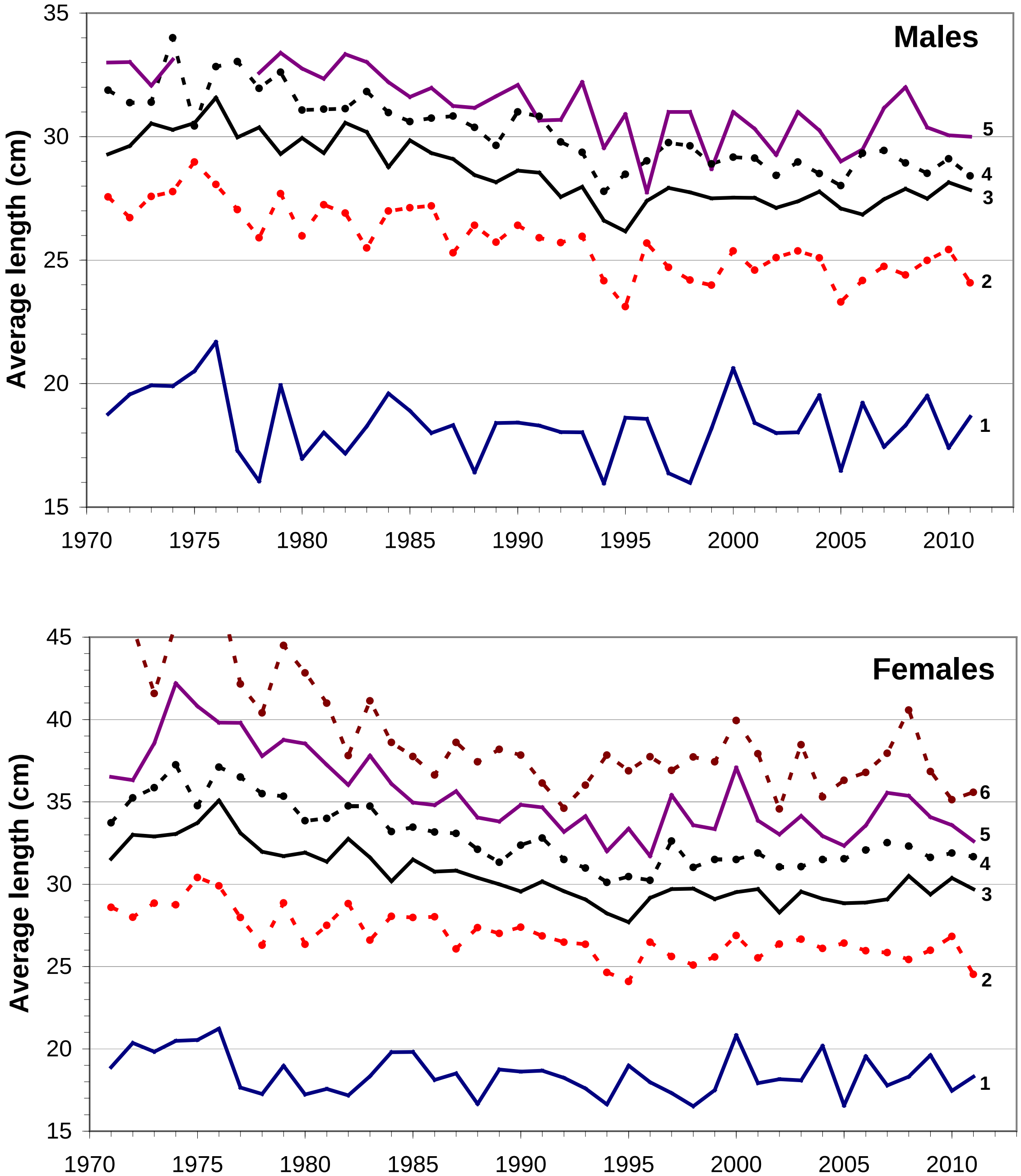


Figure 29. Annual mean length-at-age (cm) for male (ages 1-5; upper panel) and female (ages 1-6; lower panel) from the DFO summer RV survey for strata 440-483, 1971-2011.

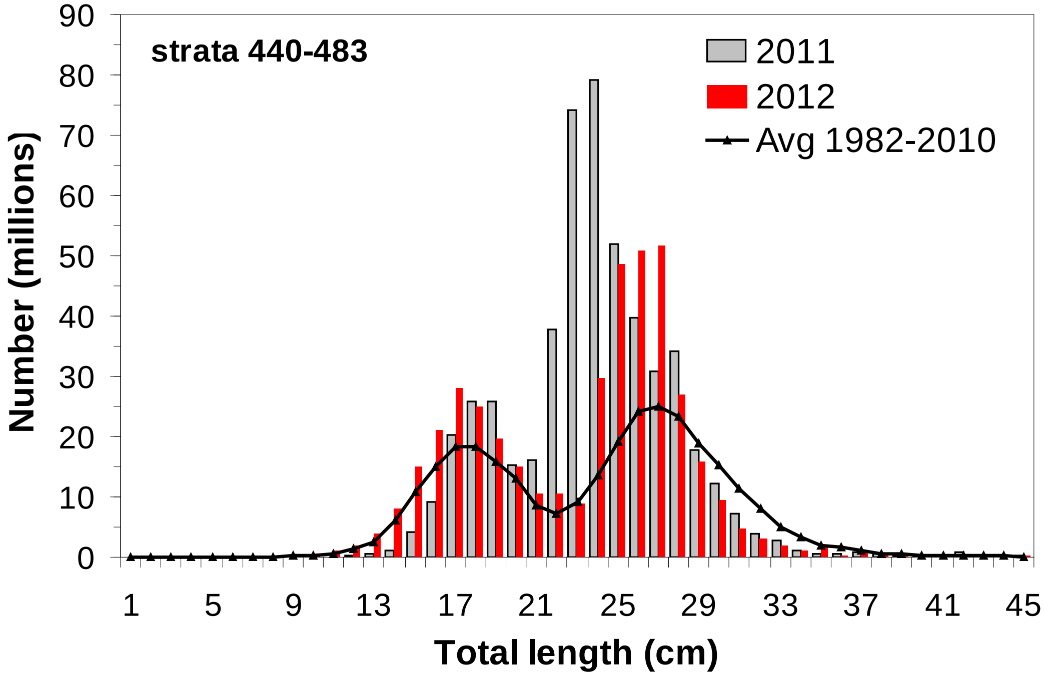


Figure 30. Length stratified total number (millions) for silver hake from DFO summer RV survey strata 440-483 for 2011 and 2012 compared to the average for 1982-2010 (Western IIA time series).

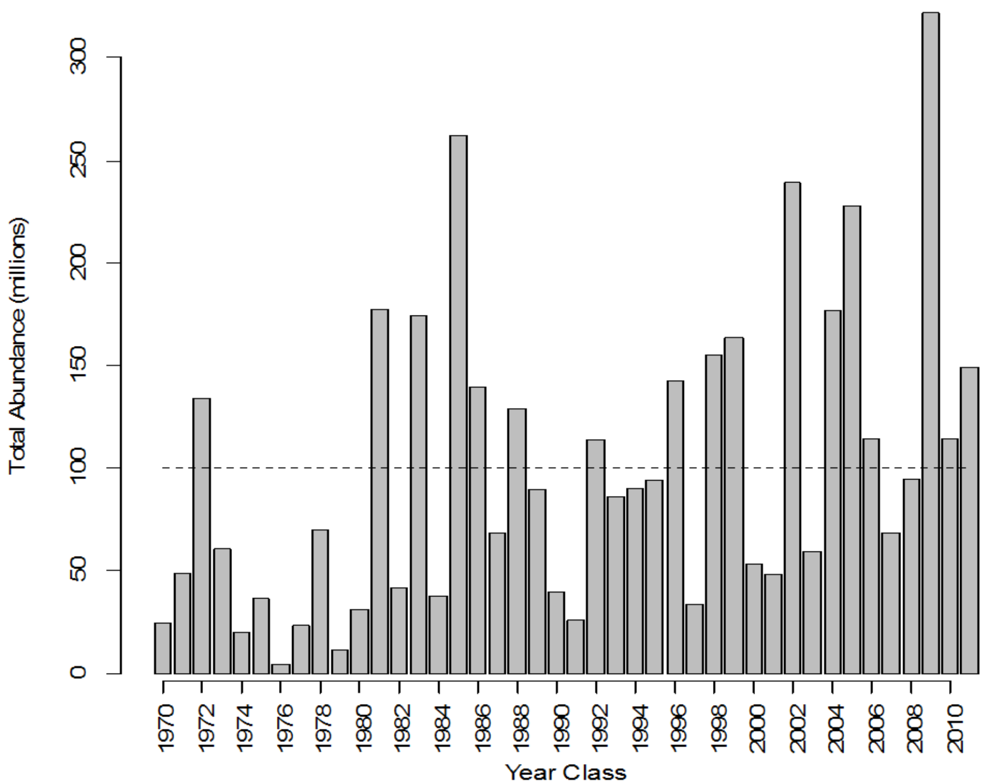


Figure 31. Recruitment estimates for Scotian Shelf silver hake from age 1 summer RV survey abundance. Long-term average indicated by dashed line (2011 value estimated from 2012 RV length data).

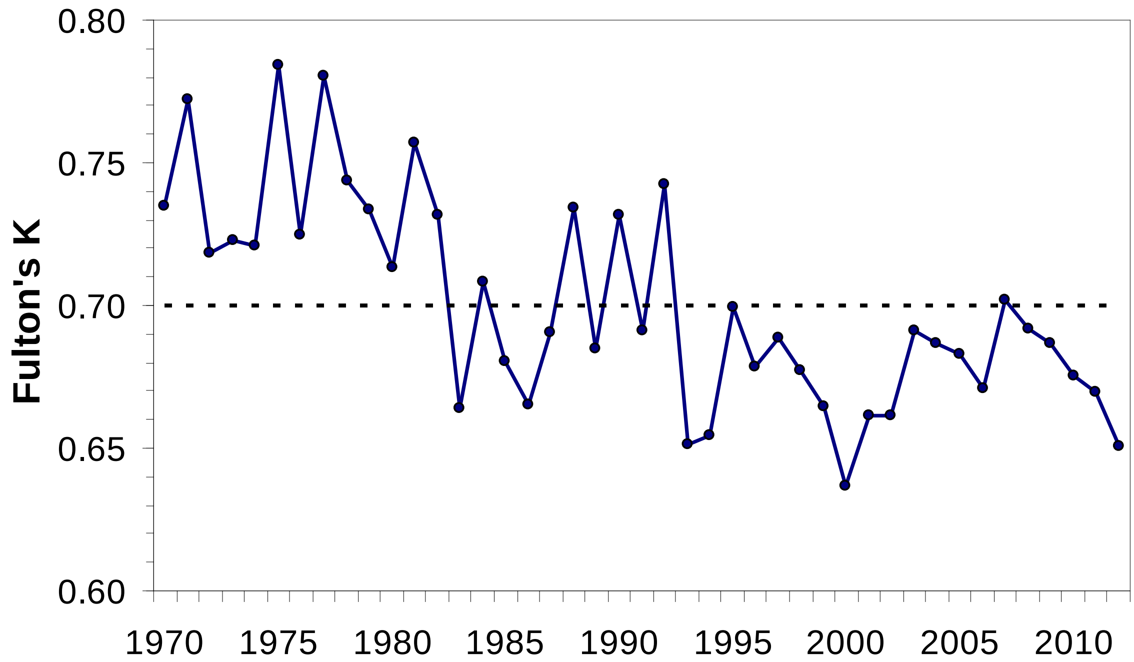


Figure 32. Annual mean condition factor (Fulton's K) for silver hake (combined sexes, 21-44 cm total length) compared to the long-term mean from DFO summer RV survey strata 440-483, 1970-2012.

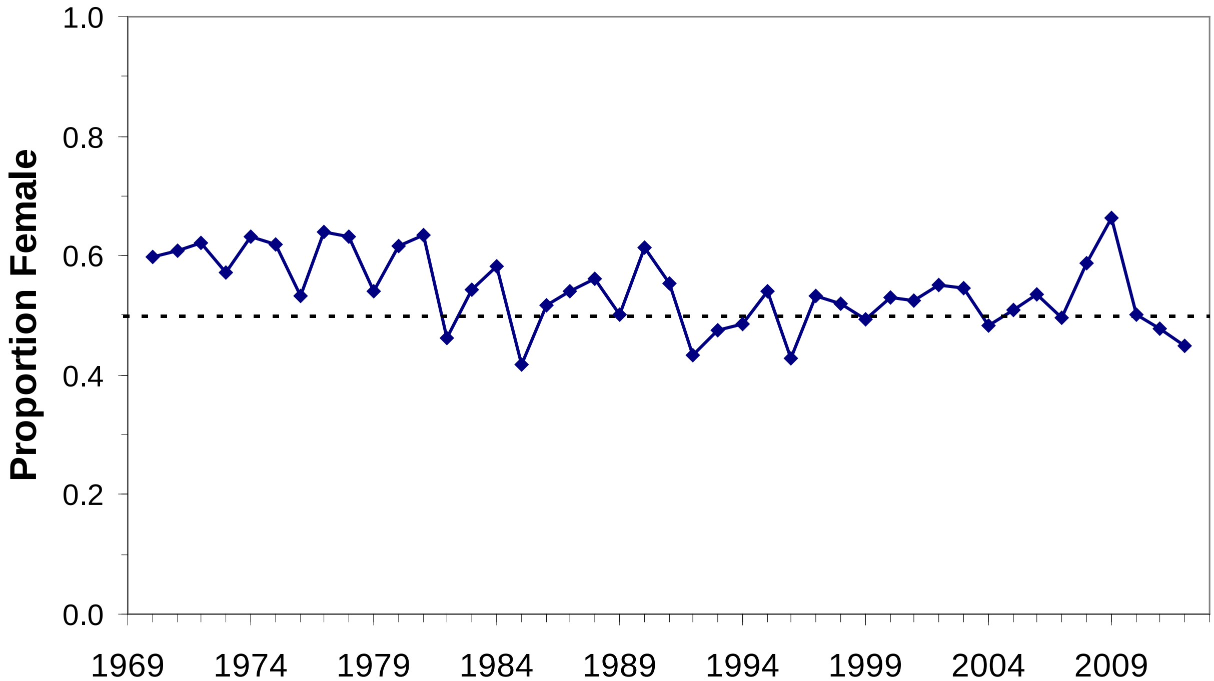


Figure 33. Annual trends in the proportion of female silver hake based on DFO summer RV survey total stratified abundance by sex estimated for 1970-2012.

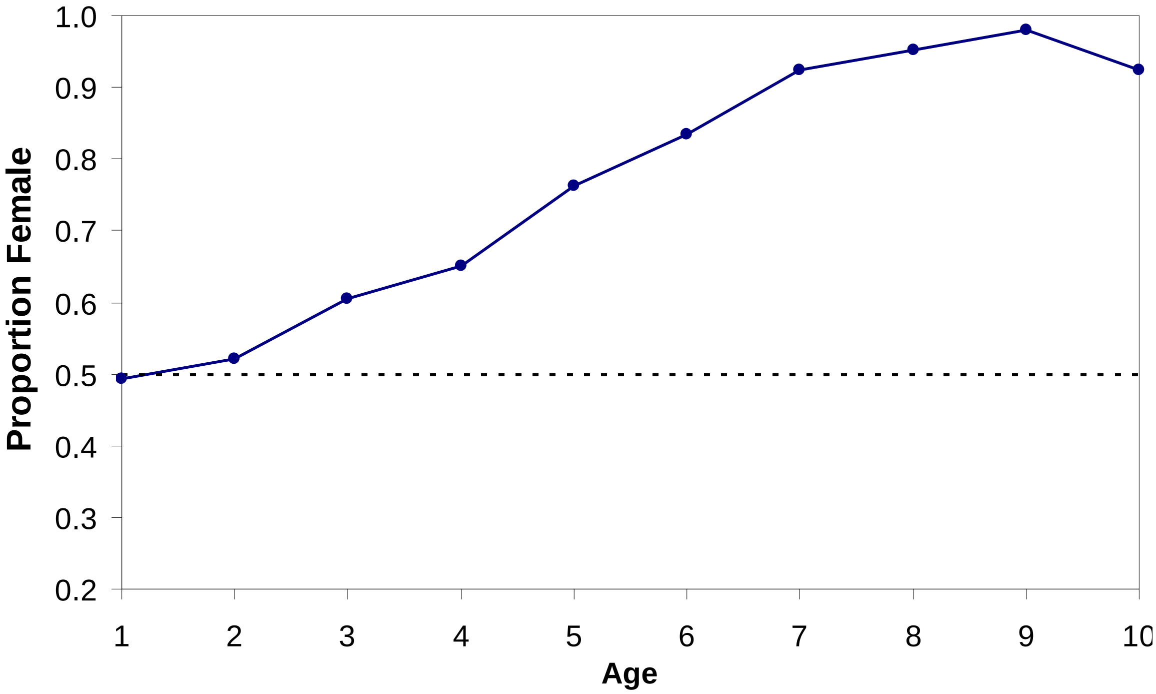


Figure 34. Annual trends in the proportion of female silver hake at age based on DFO summer RV survey total stratified abundance at age by sex for 1970-2012.

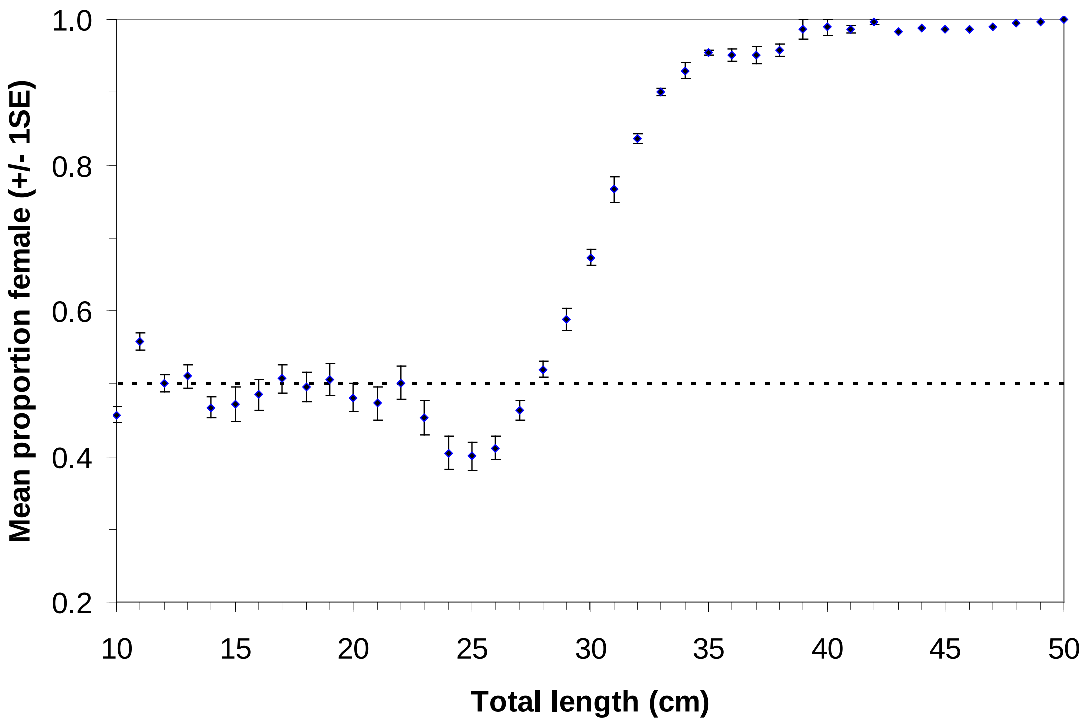


Figure 35. Annual trends in the proportion of female silver hake at length based on DFO summer RV survey total stratified abundance at length by sex for 1970-2012.

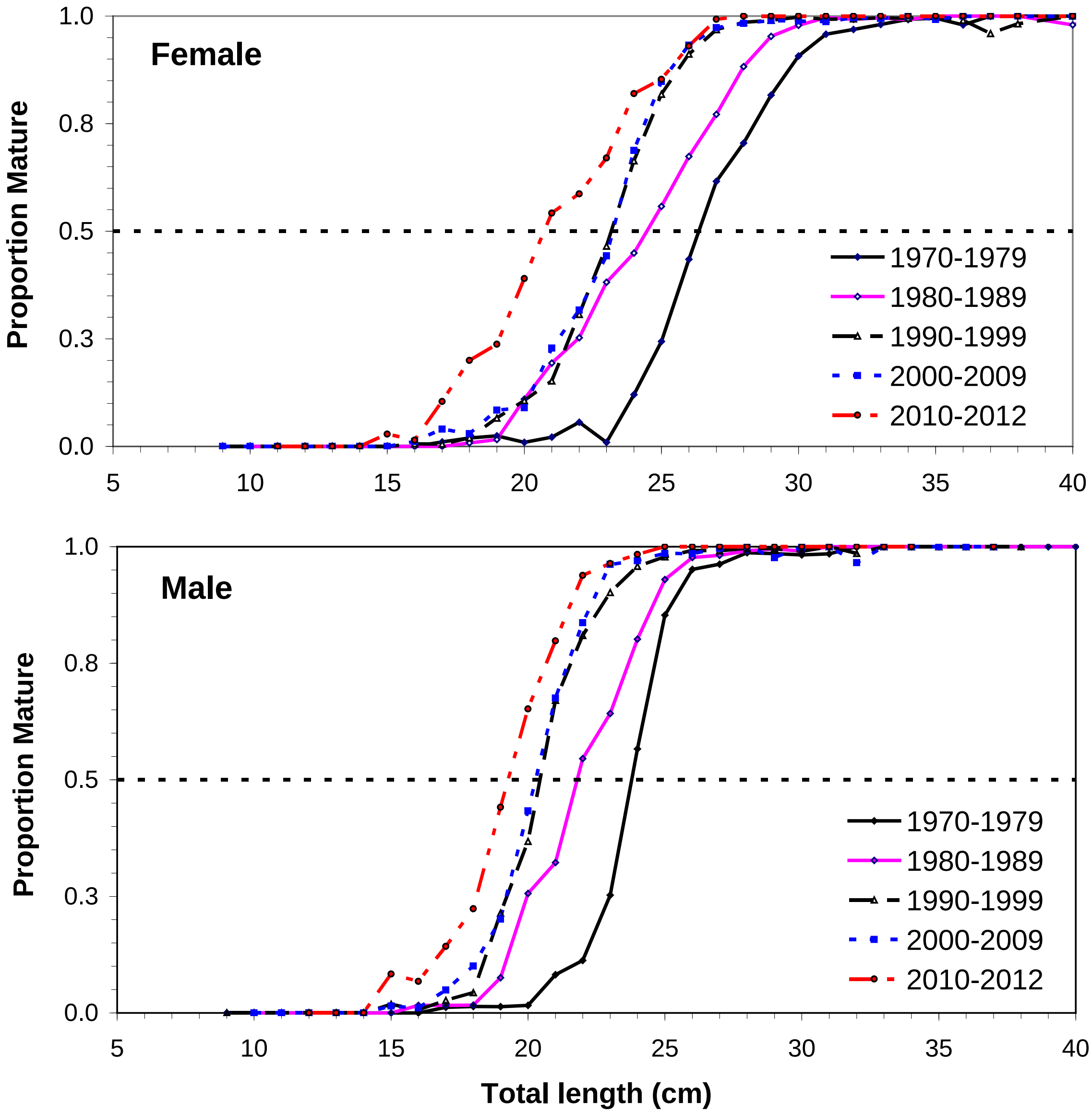


Figure 36. Proportion mature (stages 2-8) at length for silver hake from DFO summer RV survey strata 440-483. Maturity data has been aggregated into 10-year blocks. This analysis was based on sampled fish and was not scaled to population level.

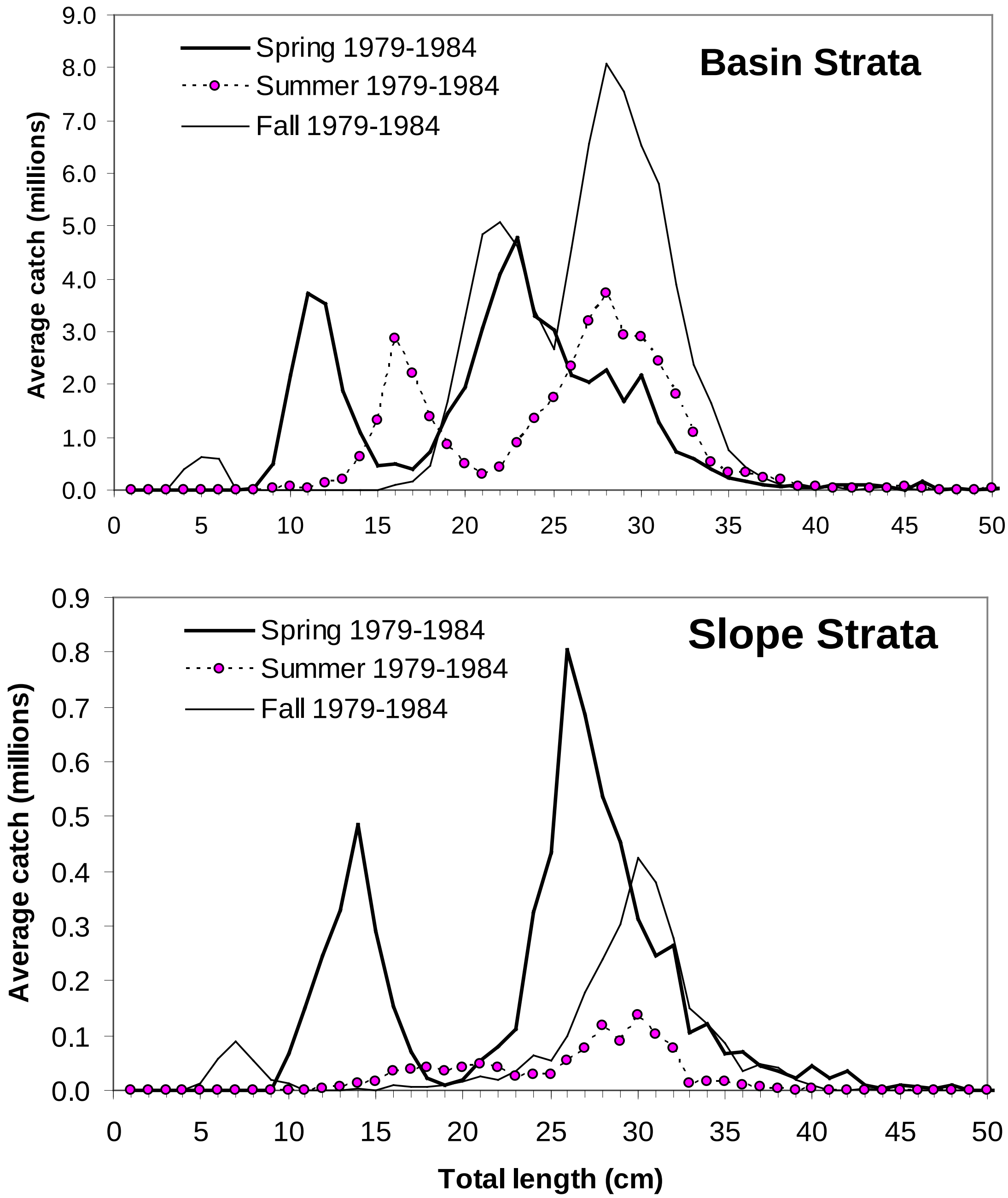


Figure 37. Average size composition of silver hake from a six-year period (1979-1984) when spring, summer and fall RV surveys were conducted annually on the Scotian Shelf. Upper panel: basin strata (461 and 471); lower panel: slope strata (466 and 478).

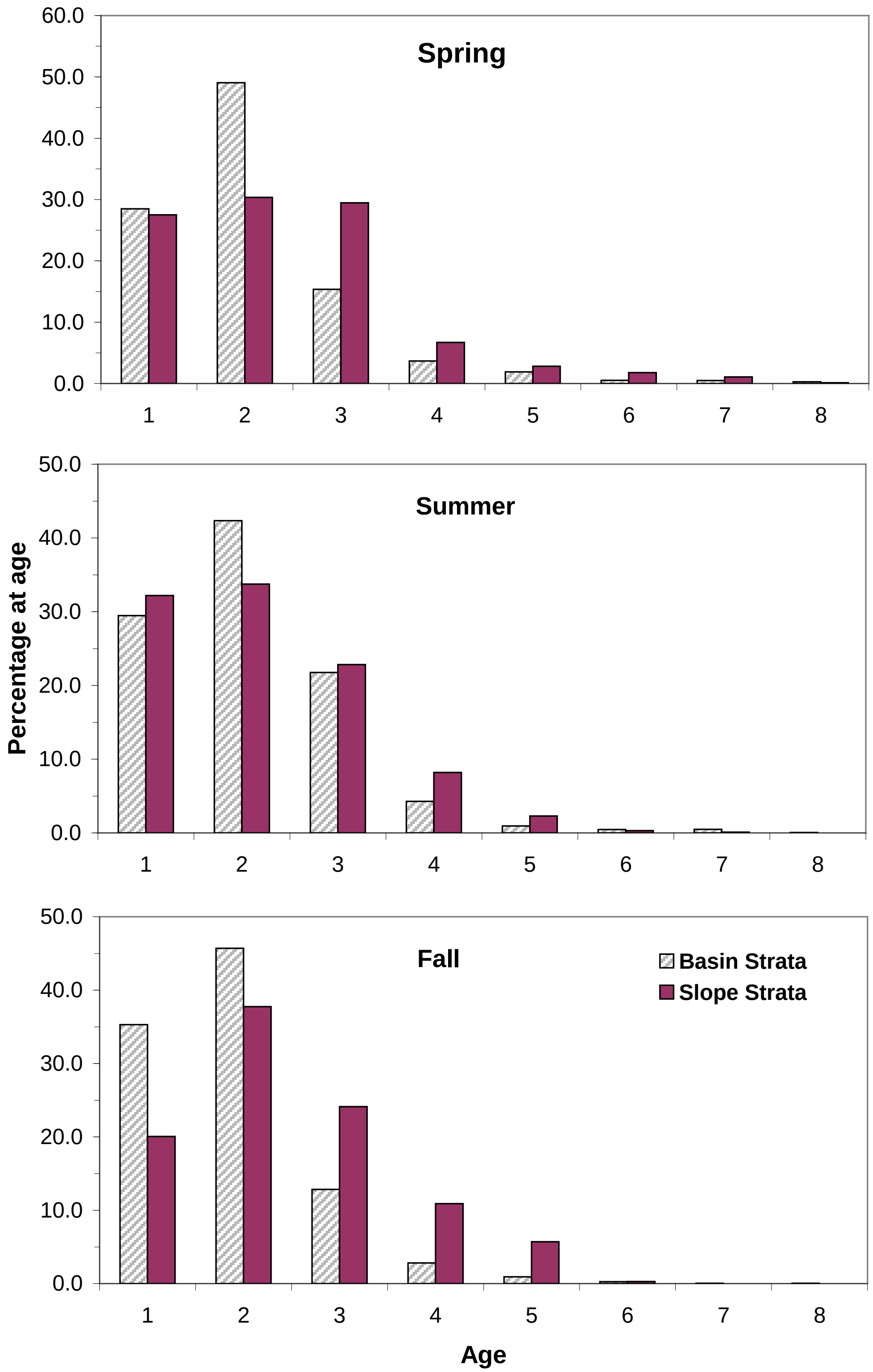


Figure 38. Average age composition (%) of silver hake in basin strata (461, 471) and slope strata (466, 478) from a six-year period (1979-1984) when spring, summer and fall RV surveys were conducted annually on the Scotian Shelf.

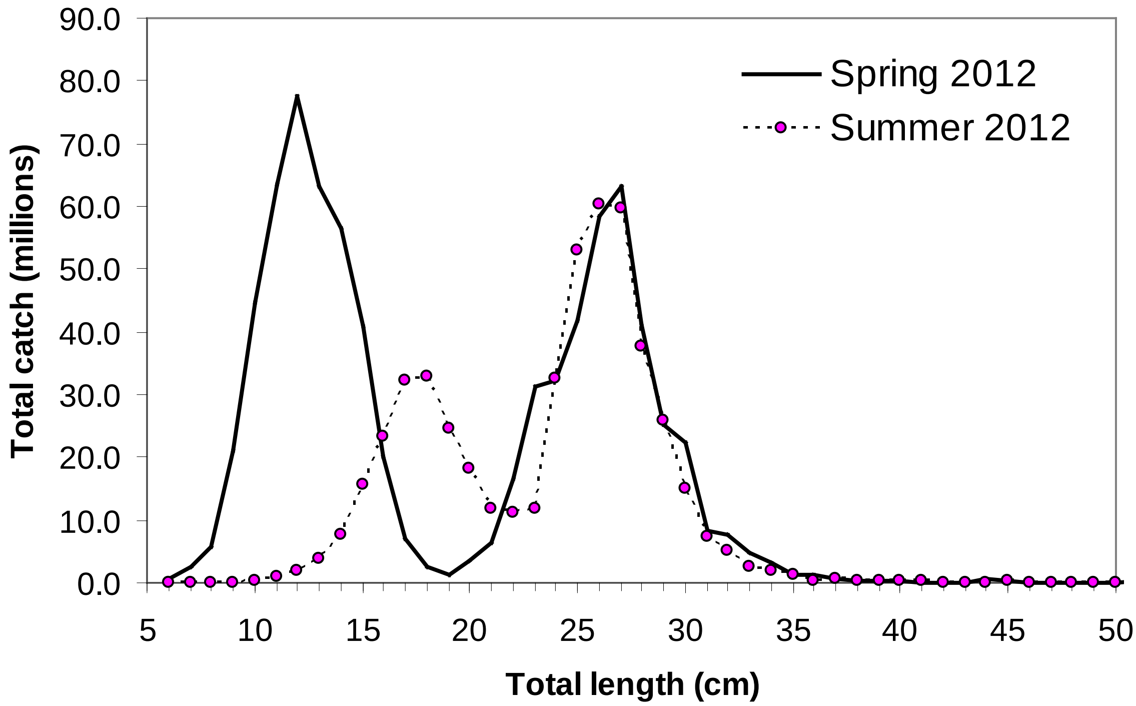


Figure 39. Total abundance at-size of silver hake captured during DFO spring and summer RV surveys on the Scotian Shelf in 2012.

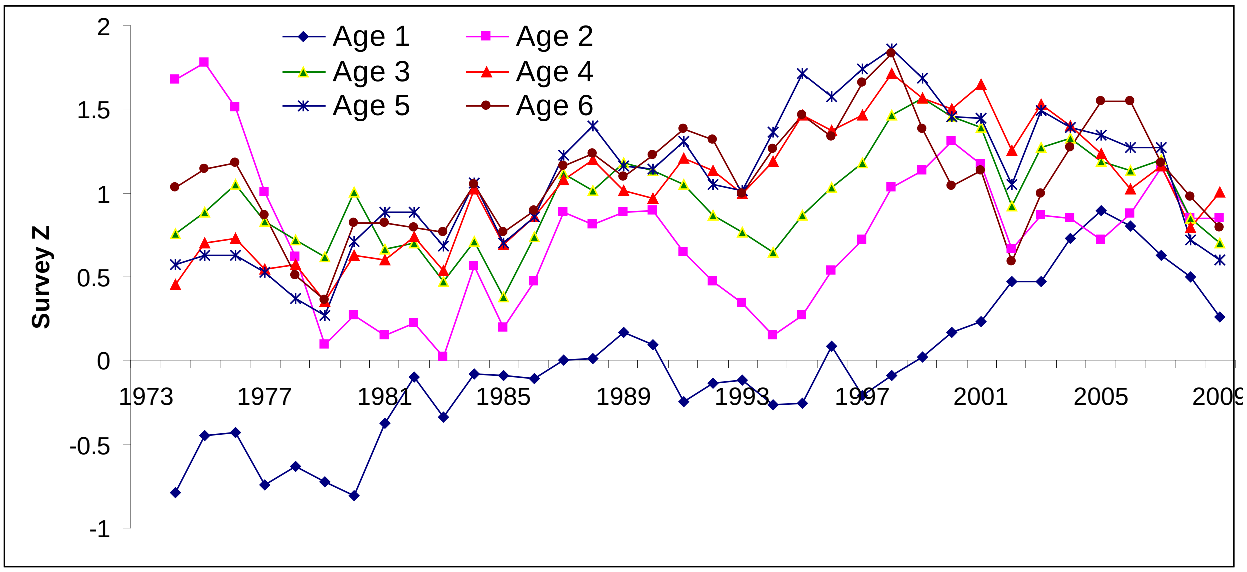


Figure 40. Total mortality (Survey Z) (five-year running mean Z for 1971-2011) for silver hake estimated from DFO summer survey abundance data, ages 1-6.

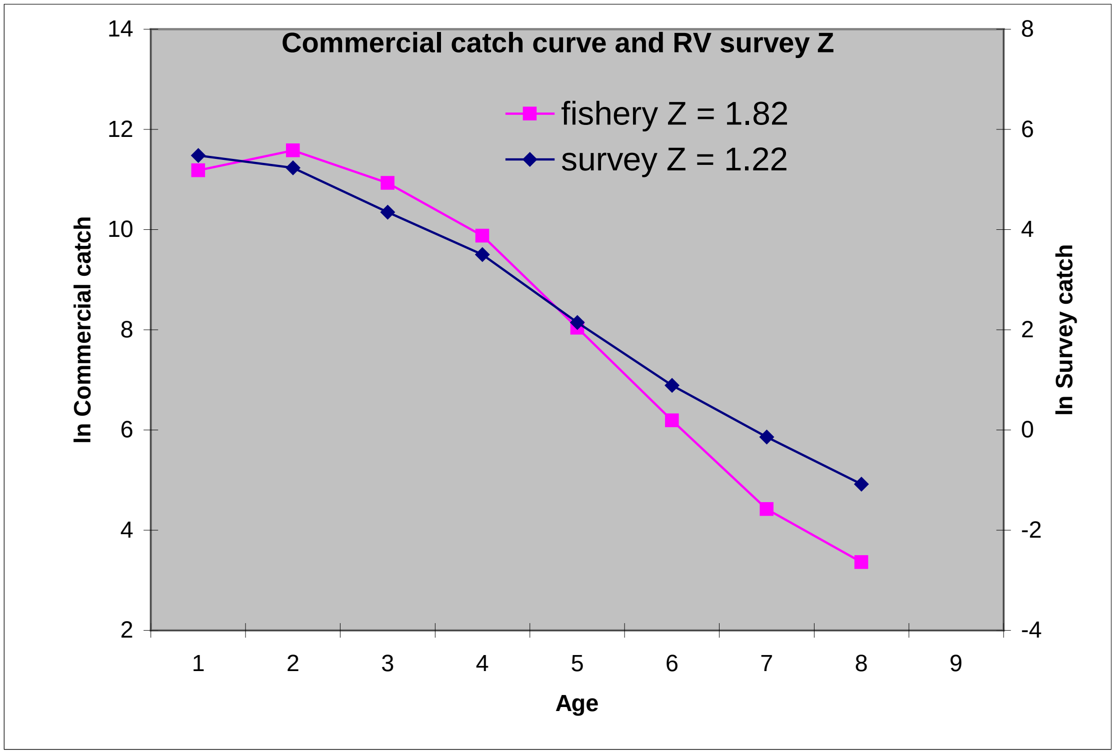


Figure 41. Comparison of catch-curve Z from commercial fishery and summer RV survey data.

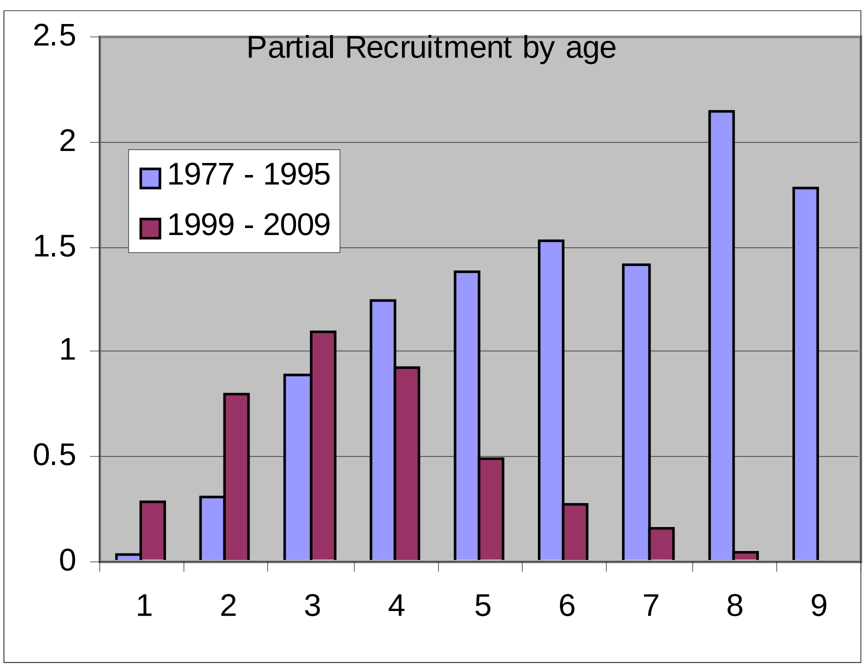


Figure 42. Partial recruitment (PR) pattern in the commercial fishery calculated from Relative F at age.

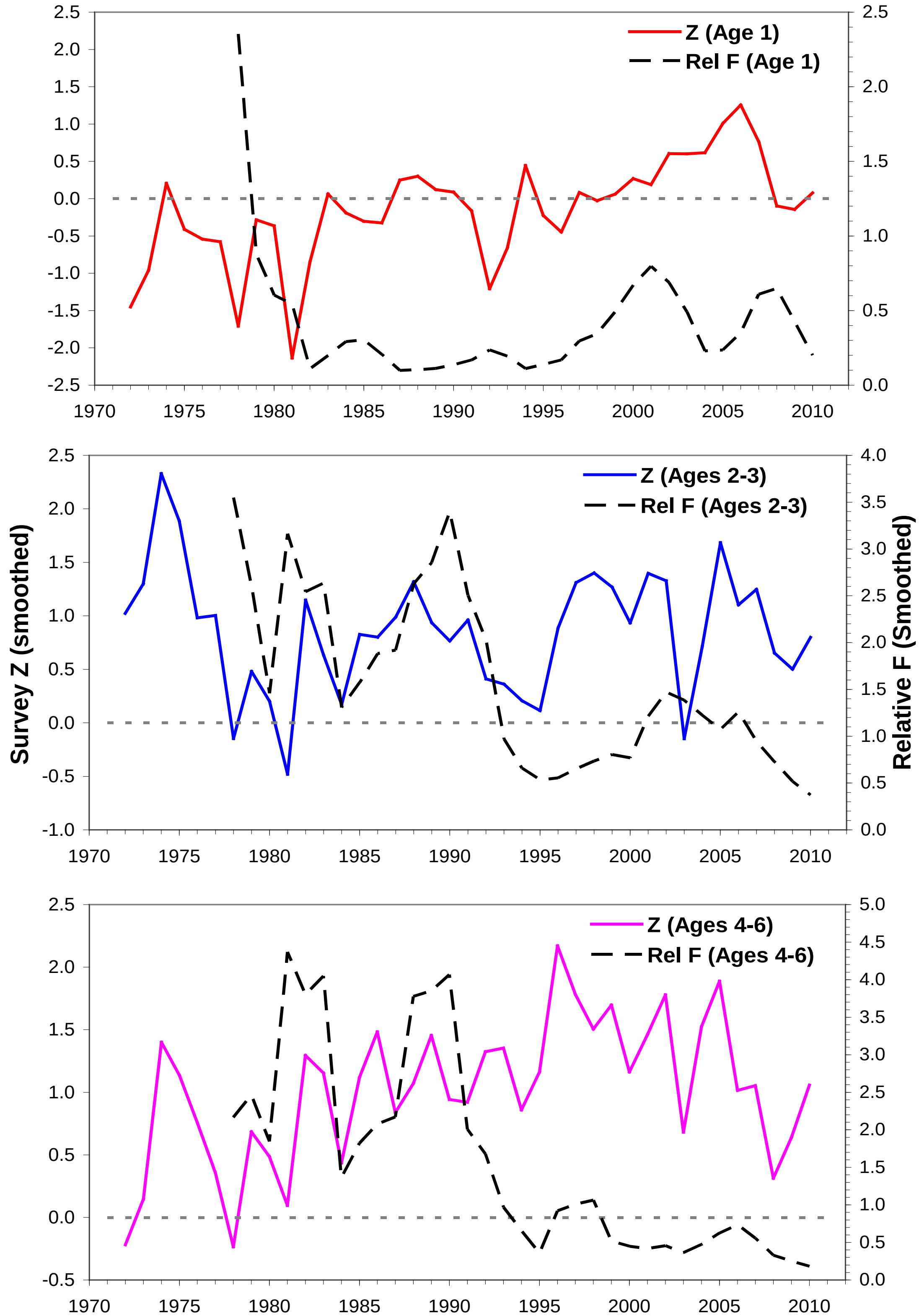


Figure 43. Total mortality (Survey Z) and relative fishing mortality (Rel F) for age 1 (top panel) ages 2-3 (middle panel) and ages 4-6 (lower panel). Survey Z was calculated from summer RV survey catch-at-age data while Relative F was based on fishery catch-at-age/survey catch-at-age for each age group.

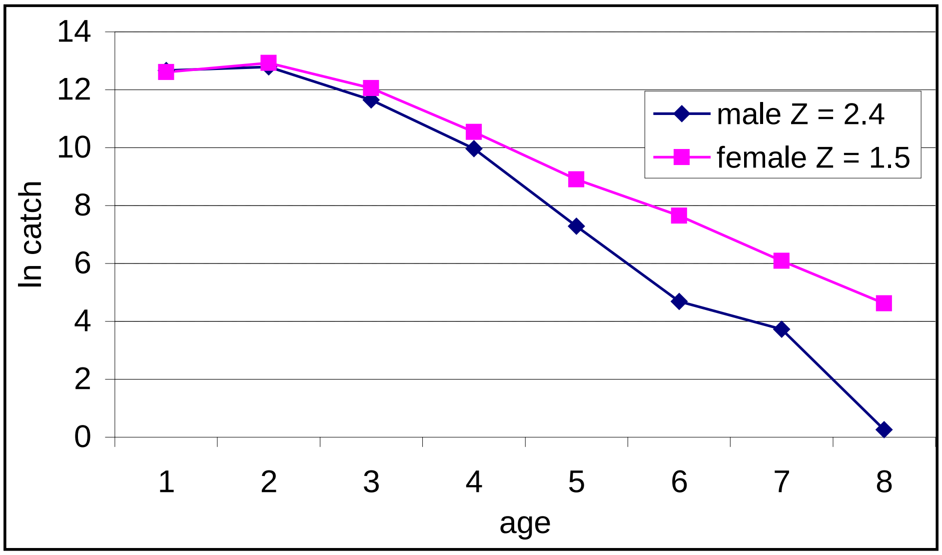


Figure 44. Total mortality Z by sex estimated from commercial catches for silver hake.

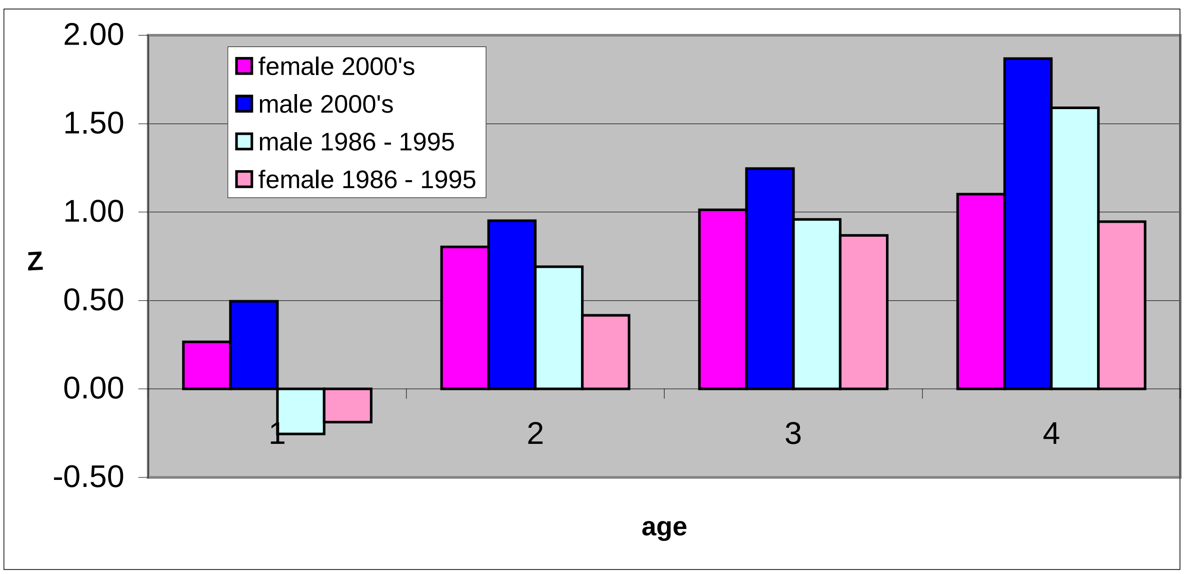


Figure 45. Estimates of total mortality Z for silver hake by sex for two time periods.

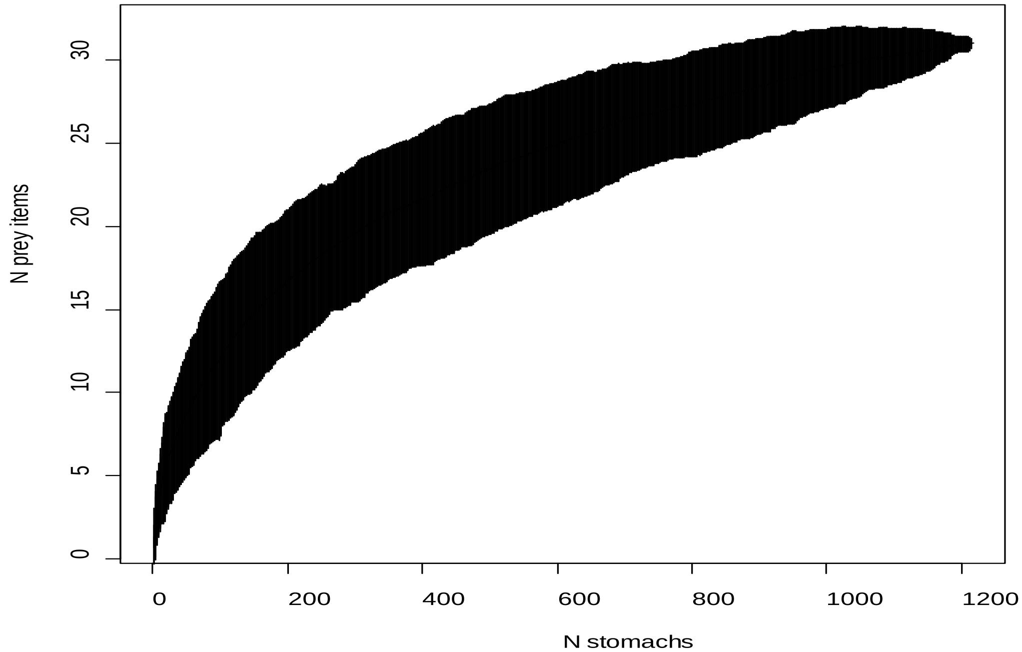


Figure 46. Species accumulation curve for prey items found in silver hake stomachs compared to the number of stomachs sampled from the summer RV survey (strata 440-483) between 1999 and 2009.

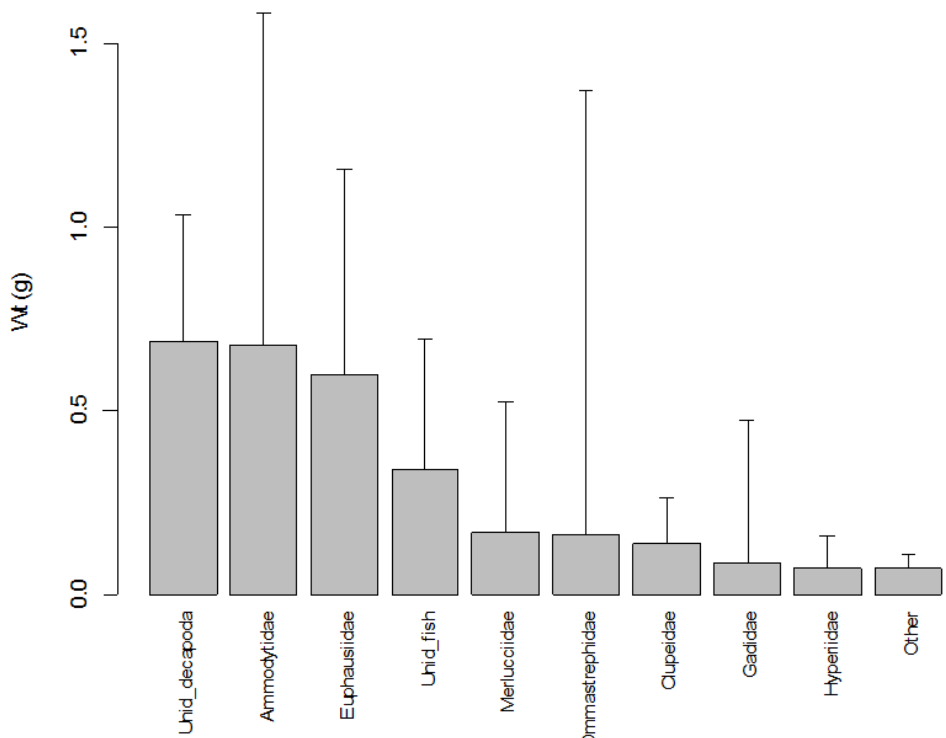


Figure 47. Mean diet composition for silver hake of all size classes from the summer RV survey (strata 440-483) between 1999 and 2009. Standard error bars are shown. Prey names with "Unid" represent unidentified species with broader groups. All other prey items are grouped into an "Other" category.

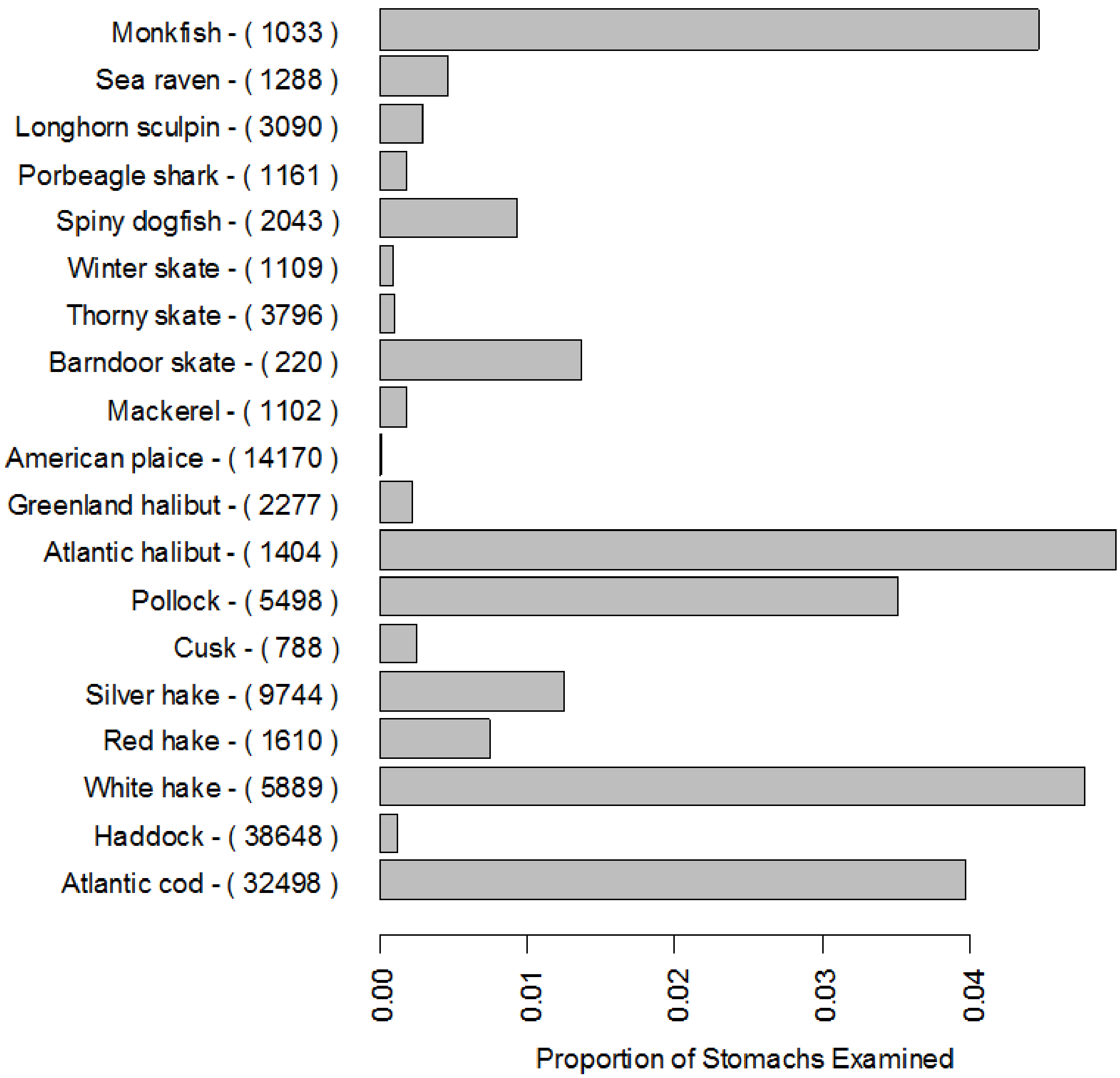


Figure 48. Proportion of predator stomachs examined containing silver hake. The number of stomachs examined are shown in brackets after the predator name. The entire suite of samples from PED food habits database for the Scotian Shelf (as described in Cook and Bundy 2010) was used in this analysis.

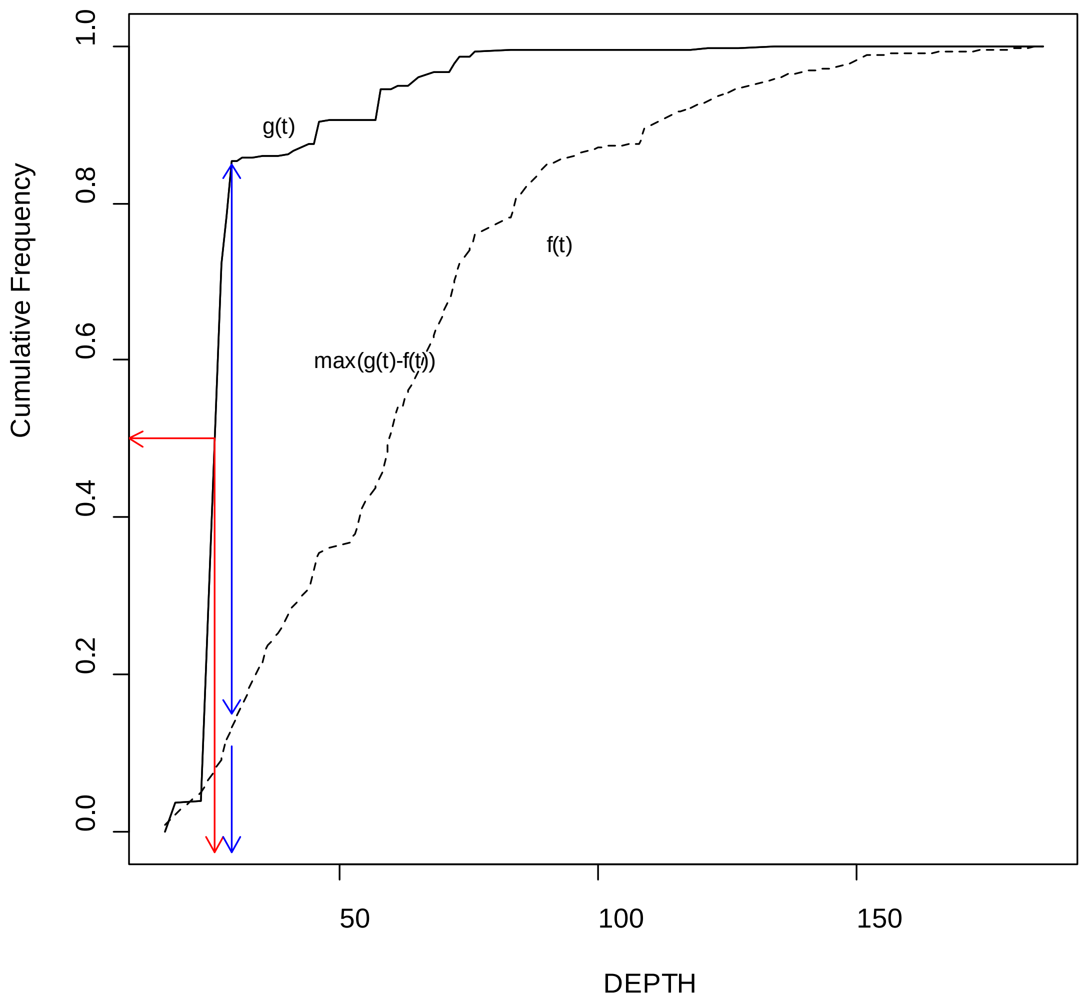


Figure 49. An example of the cumulative distribution functions of effort and catch weighted effort for silver hake from the DFO summer RV Survey. Red arrow indicates median depth of silver hake, blue arrows indicate the location of the maximum difference between the distribution of survey effort and catch weighted curves.

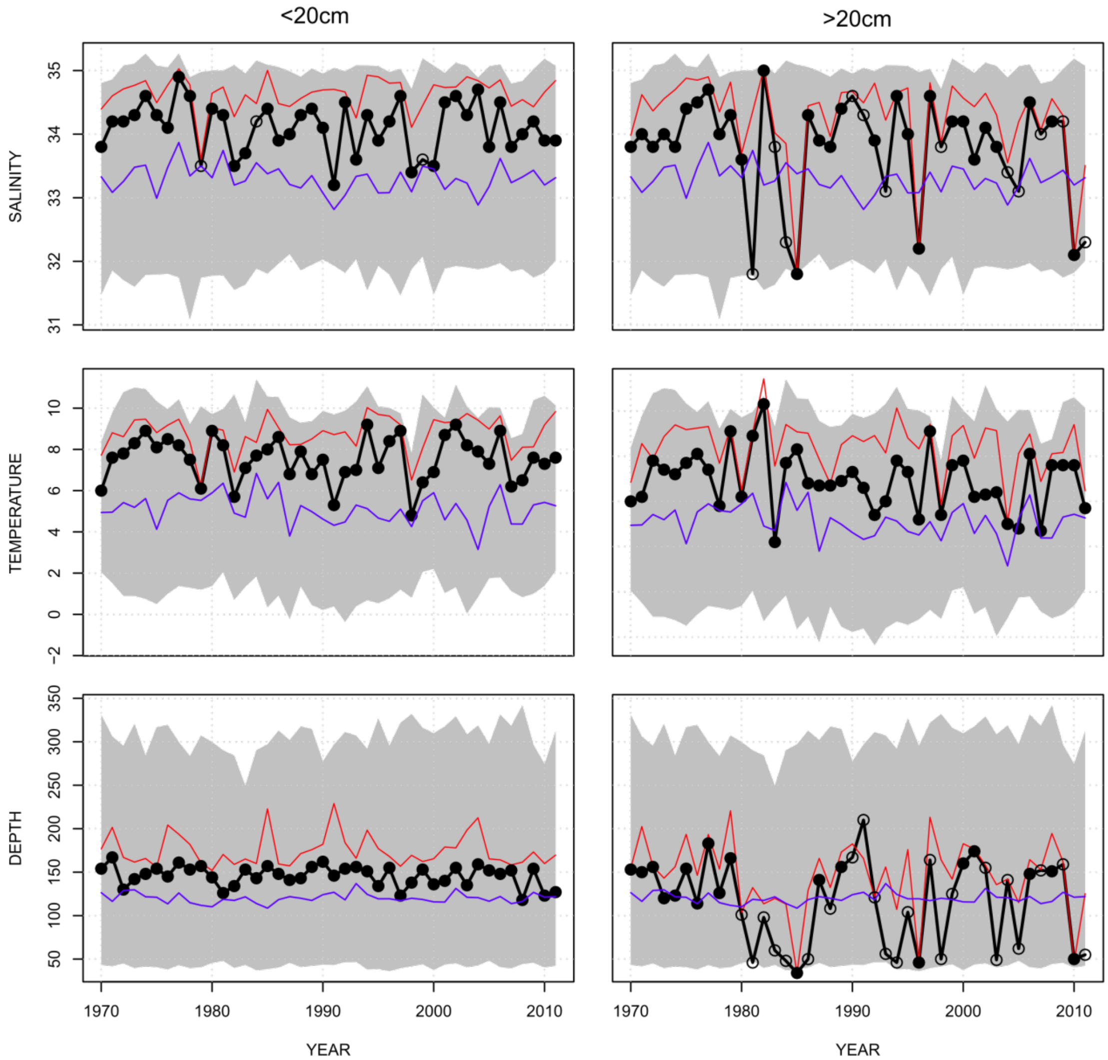


Figure 50. Time series of habitat preferences of silver hake as obtained from the summer RV survey series between 1970 and 2011. Circles represent the location of maximum deviation of cumulative distributions from catch weighted effort and effort. Filled circles represent statistically significant habitat associations and open circles represent non significant associations. Red line indicates the median habitat occupied by silver hake. Purple line is the median sampled habitat. Shaded polygon in background is the 95th percentile for range of sampled habitat.

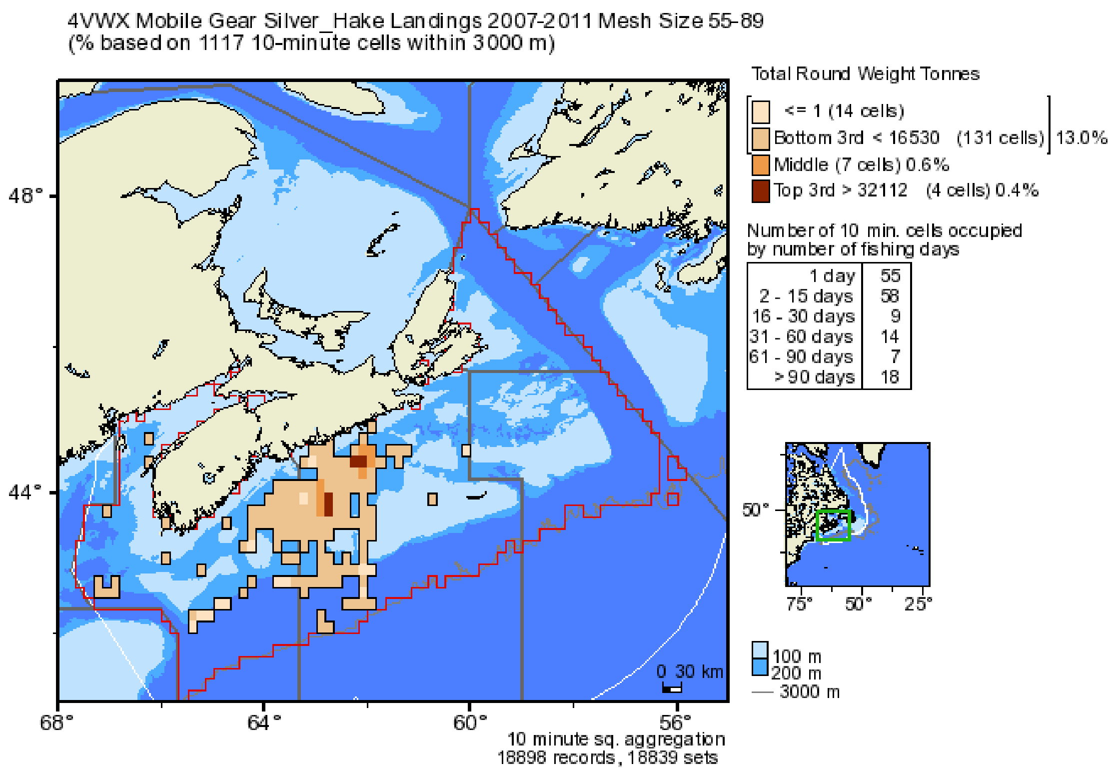


Figure 51. Distribution of silver hake landings using mesh size of 55-89 mm (2007-2011).

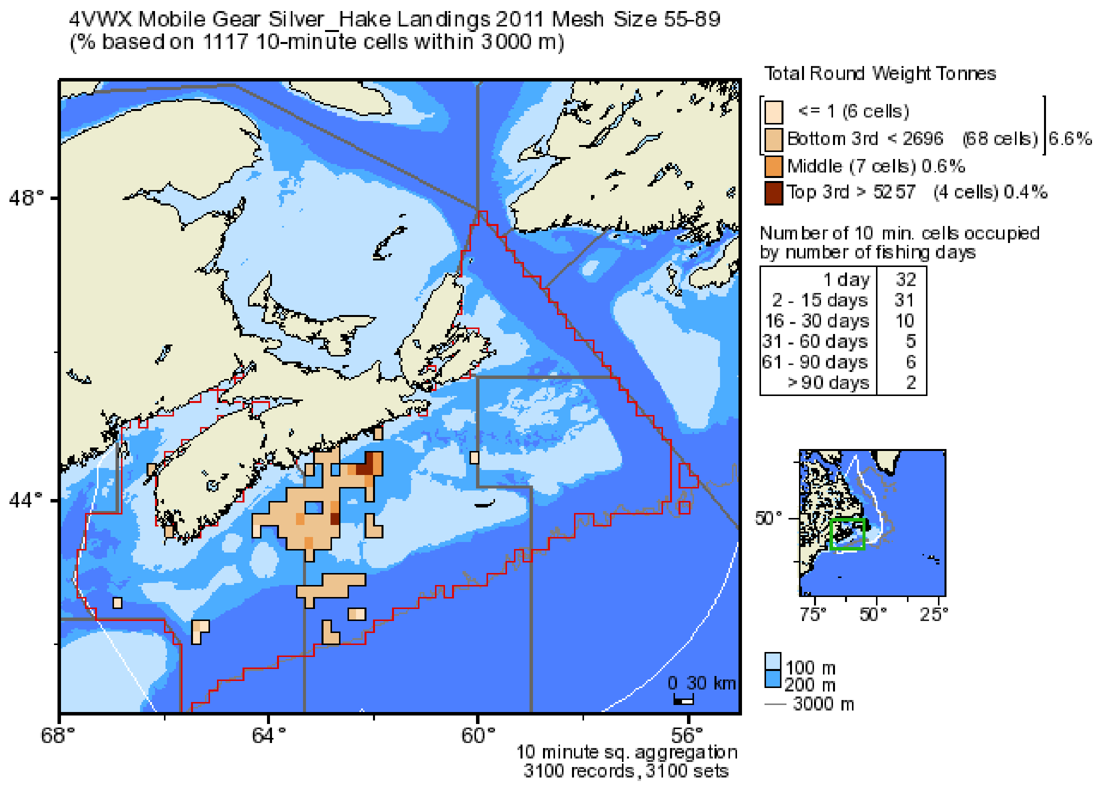


Figure 52. Distribution of silver hake landings using mesh size of 55-89 mm (2011).

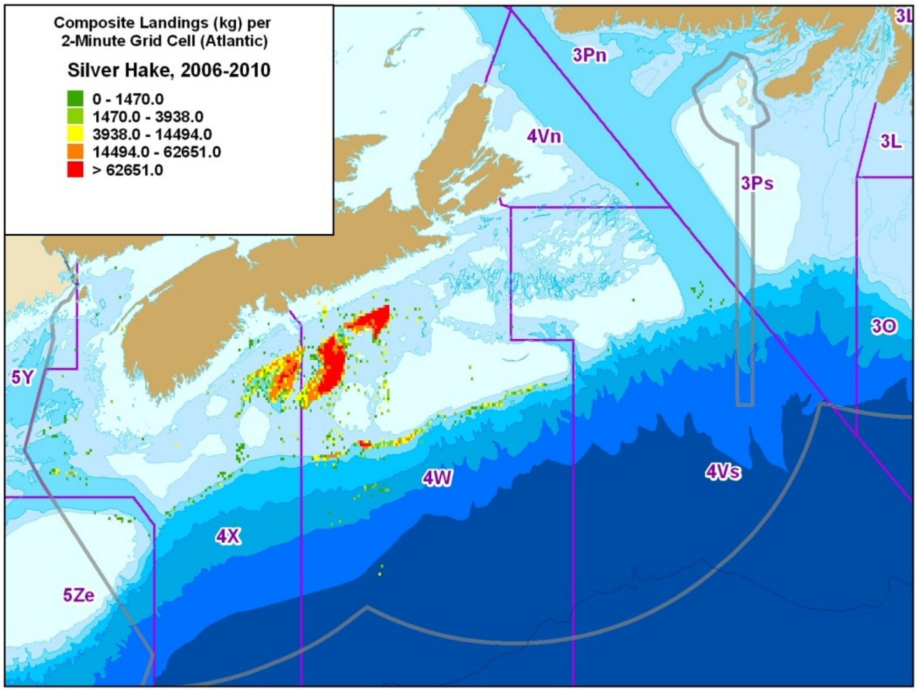


Figure 53. Fishery footprint for 4VWX silver hake fishery derived from targeted and bycatch landings from 2006-2010. Colour scale represents fishing intensity as total weight of fish (kg) landed per two minute cell from lowest (green) to highest (red).

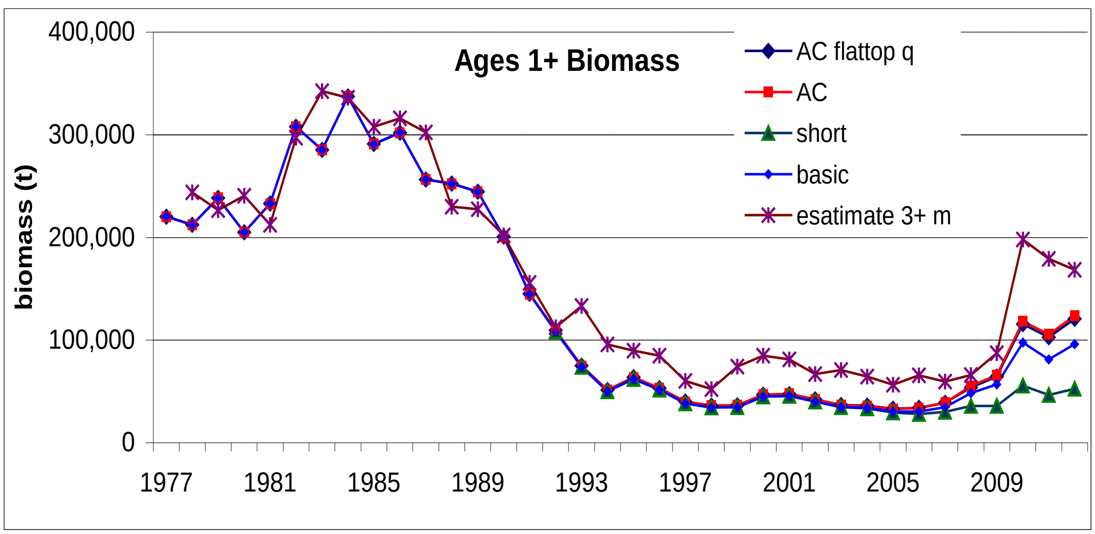


Figure 54. Population biomass estimates (t) for Scotian Shelf silver hake from a series of VPA formulations.

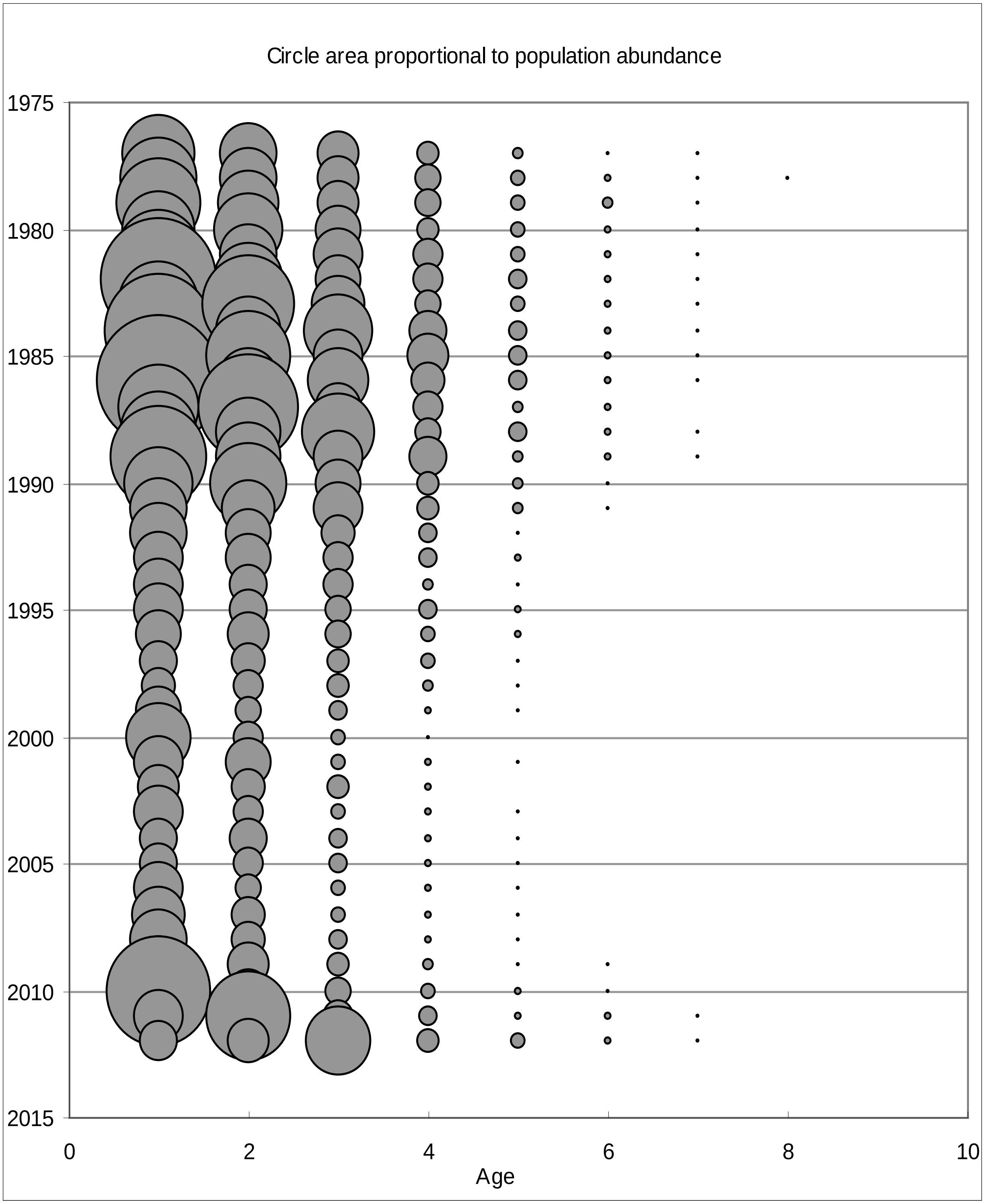


Figure 55. Estimated population abundance at age for Scotian Shelf silver hake from the AC flattop VPA formulation. Circle size is proportional to abundance.

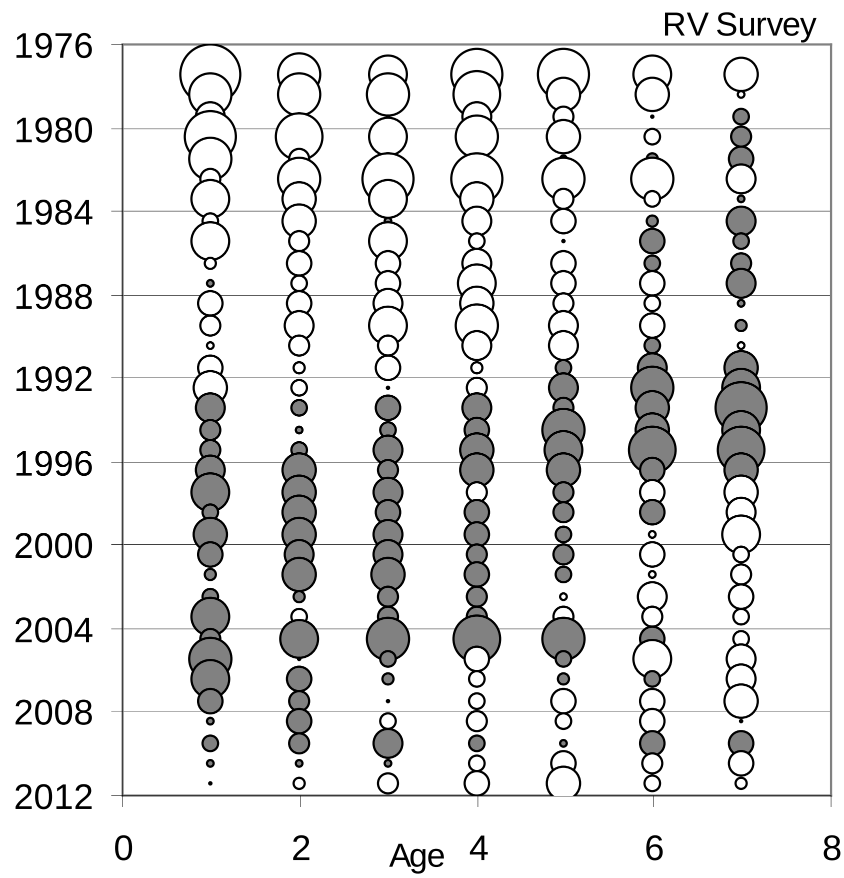


Figure 56. Residuals by year and age for the RV survey from the AC flattop VPA formulation. Solid symbols indicate positive values. Circle size is proportional to magnitude.

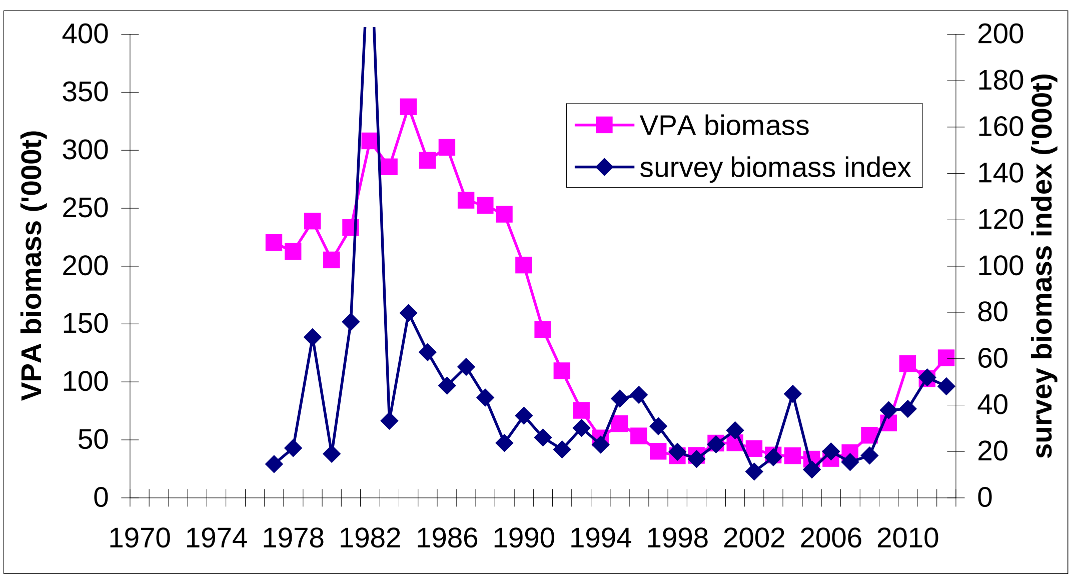


Figure 57. Comparison of VPA biomass estimate with the RV survey biomass index from the AC flattop formulation.

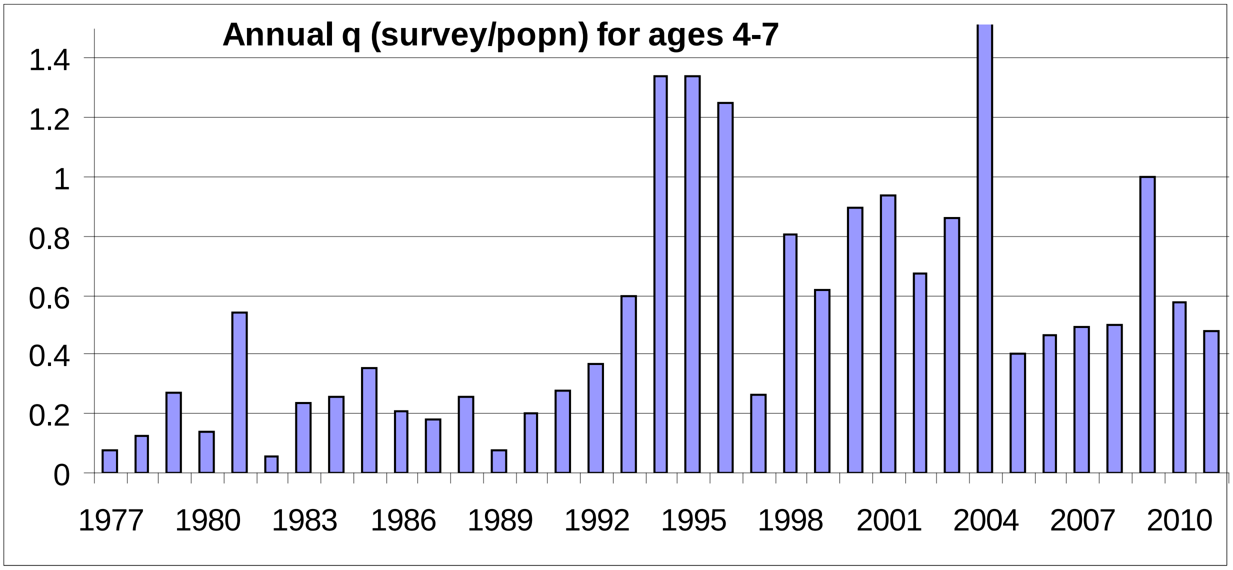


Figure 58. Annual estimates of q for silver hake in the RV survey (survey population index/VPA population estimate).

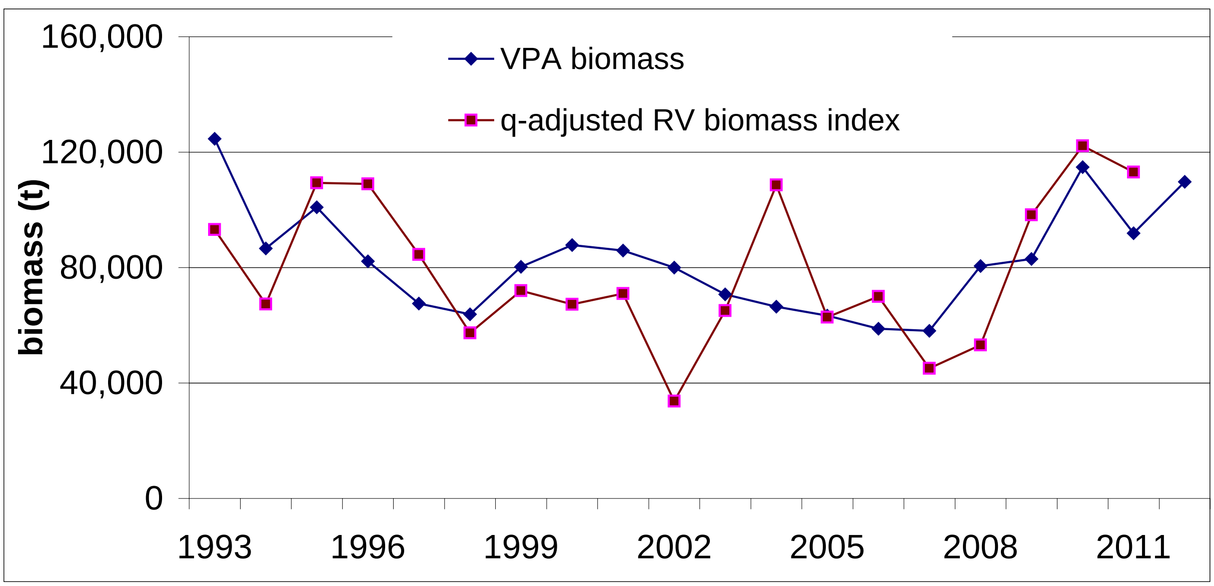


Figure 59. A comparison of the VPA biomass estimate from the short-term high natural mortality formulation with the q-adjusted biomass index from the RV survey.

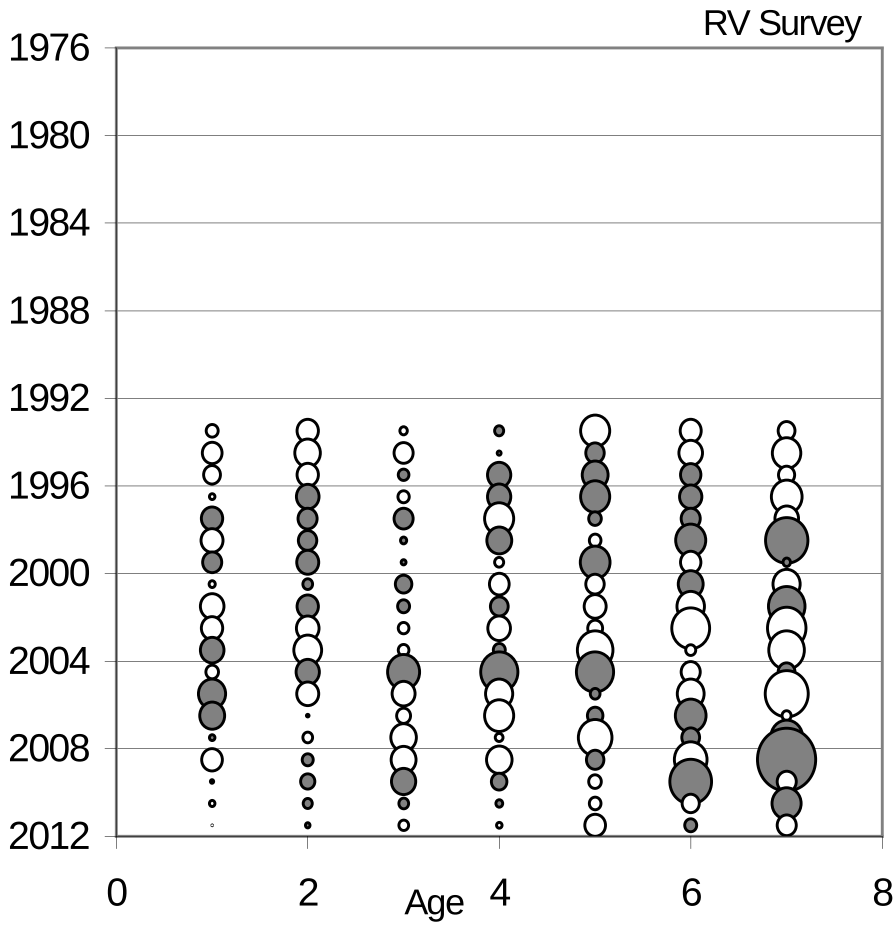


Figure 60. Residuals by year and age for the RV survey from the short-term high natural mortality VPA formulation. Solid symbols indicate positive values. Circle size is proportional to magnitude.

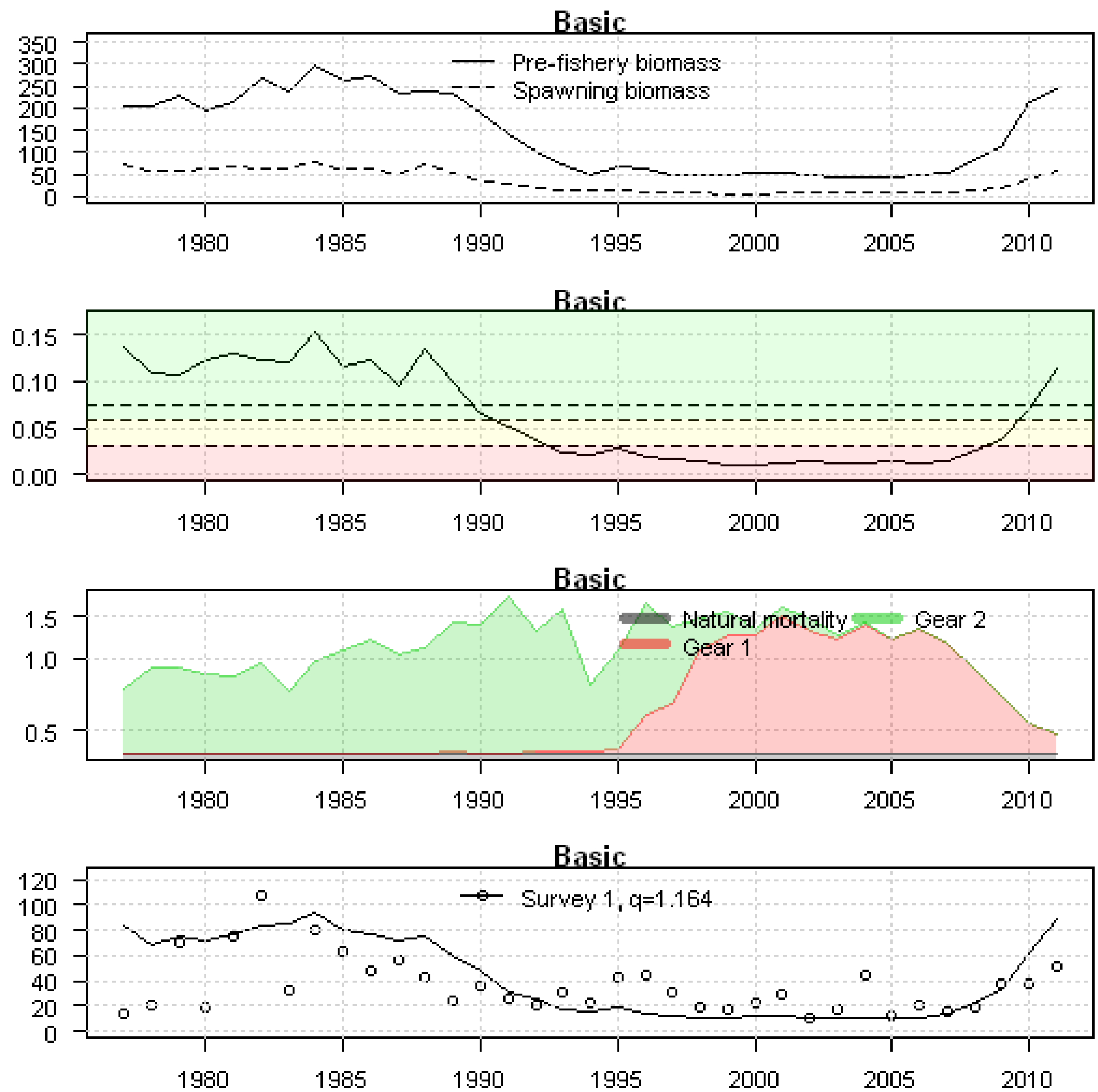


Figure 61. Output from the basic(fixed M = 0.4) statistical catch-at-age model. From top to bottom: estimated total biomass, depletion (SSB/initial biomass), Z and survey abundance. Green, yellow and red zones in depletion graph correspond to > 80% B_{MSY}, 40-80% B_{MSY} and < 40% of B_{MSY}, respectively. Open circles in survey graph indicate the observed survey indices.

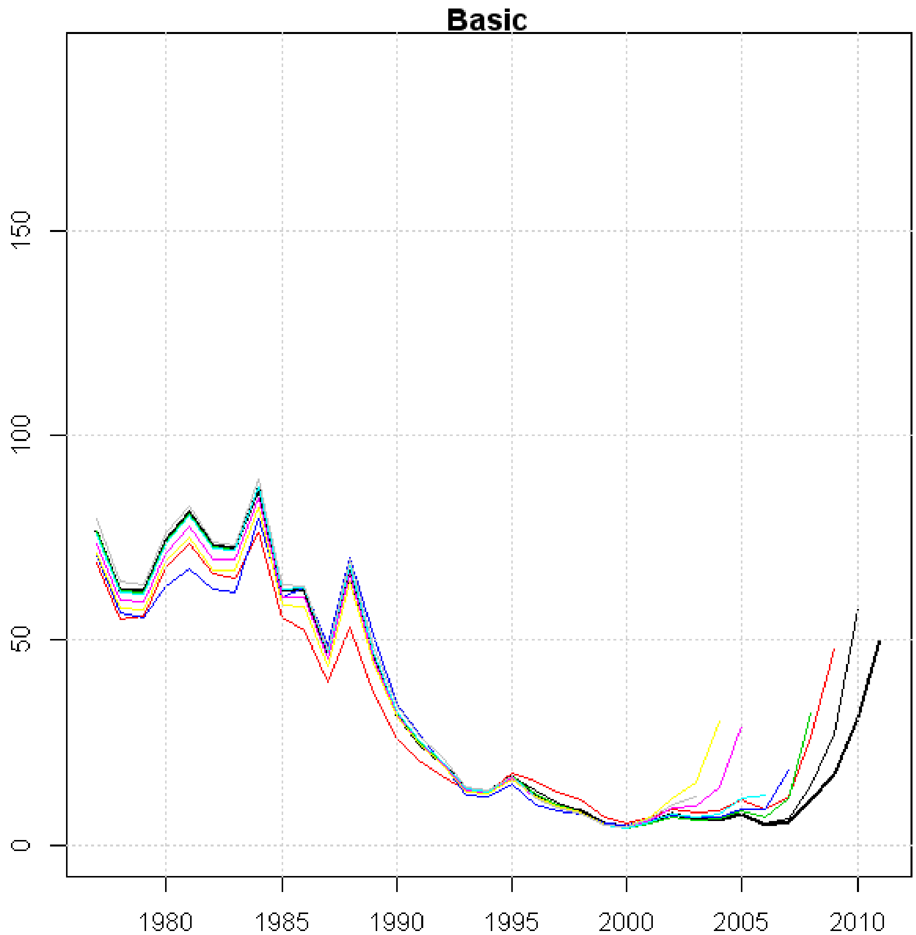


Figure 62. Retrospective pattern in SSB displayed by the basic statistical catch-at-age model as the terminal year is removed.

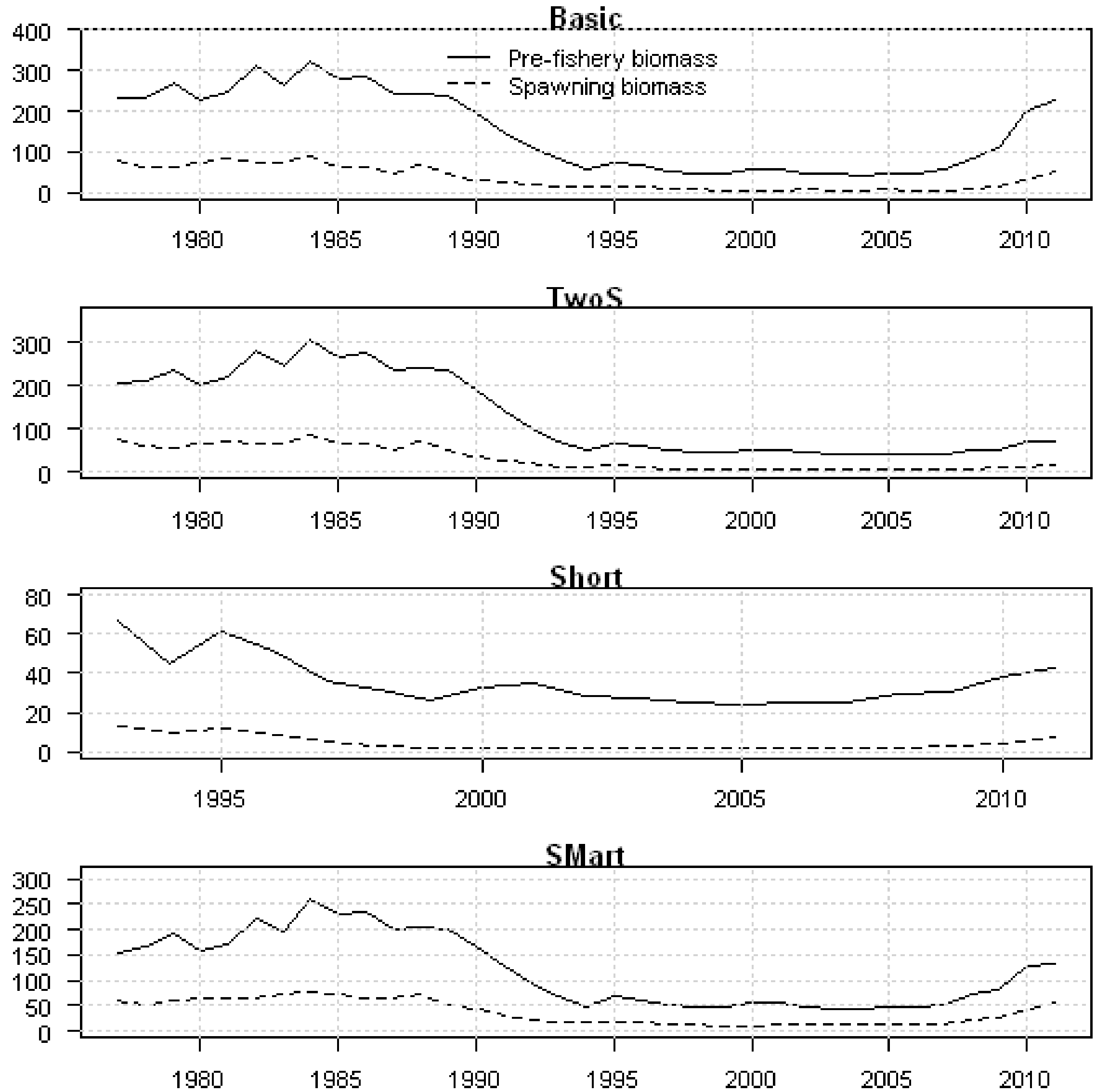


Figure 63. Total biomass and SSB estimated by the four statistical catch-at-age models.

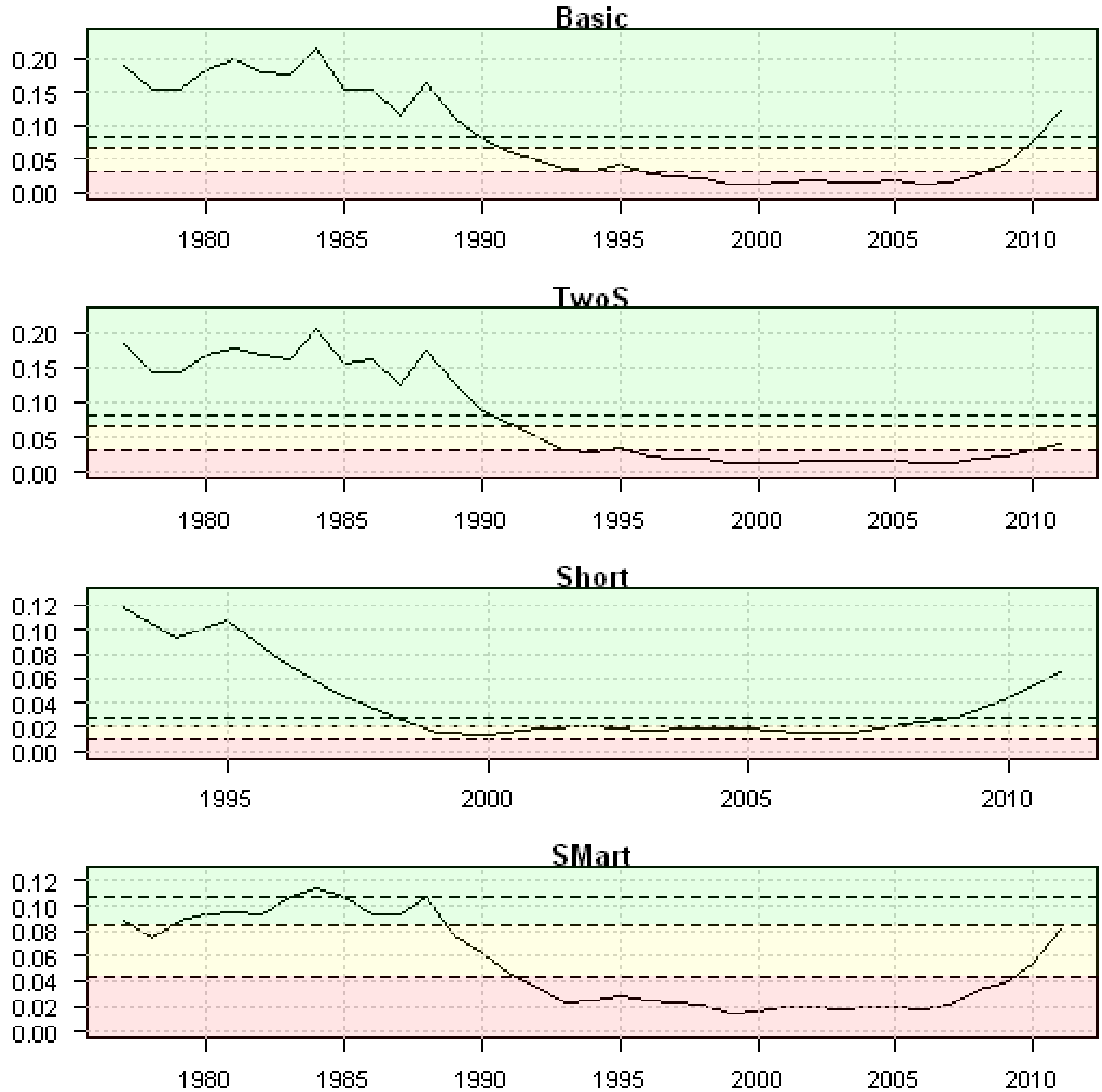


Figure 64. Depletion estimates (SSB ratio to total initial biomass) from the four statistical catch-at-age models. Green, yellow and red zones correspond to > 80% B_{MSY}, 40-80% B_{MSY} and < 40% of B_{MSY}, respectively.

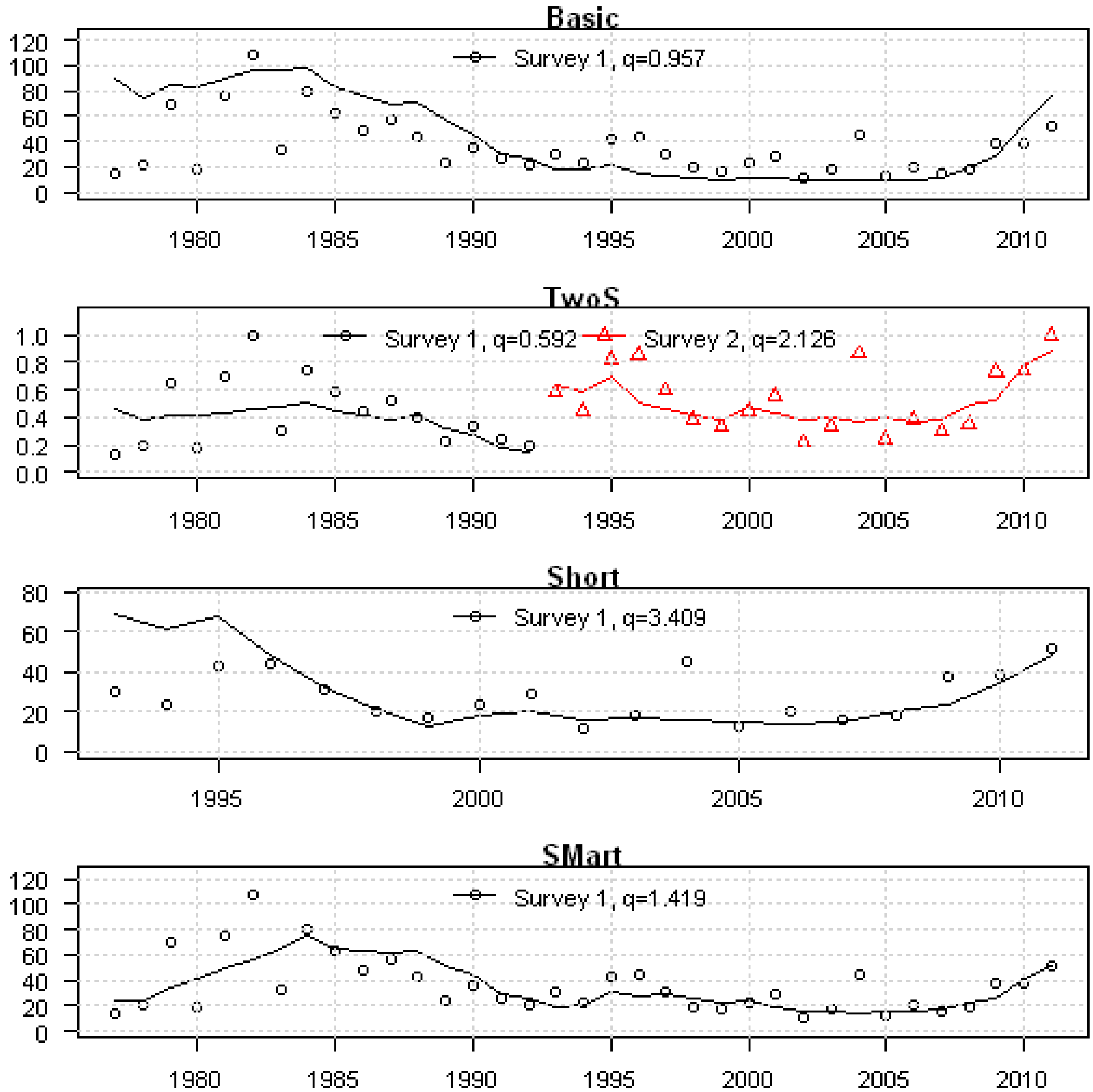


Figure 65. Estimates of survey abundance by the four statistical catch-at-age models. Survey estimates for the split survey model (TwoS) are shown in proportion to the highest observed values.

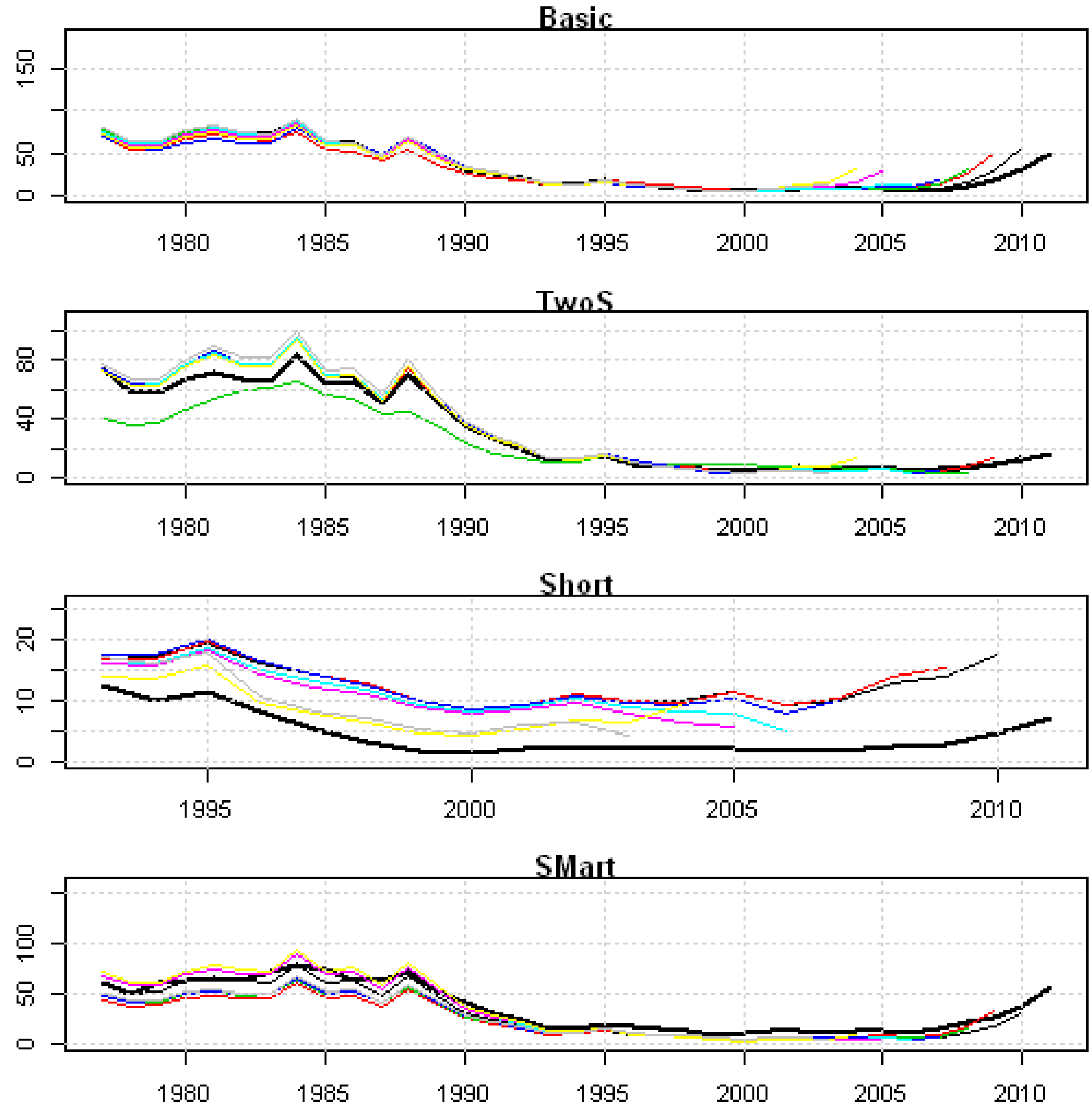


Figure 66. Retrospective patterns in SSB as the terminal year is removed for the four statistical catch-at-age models.

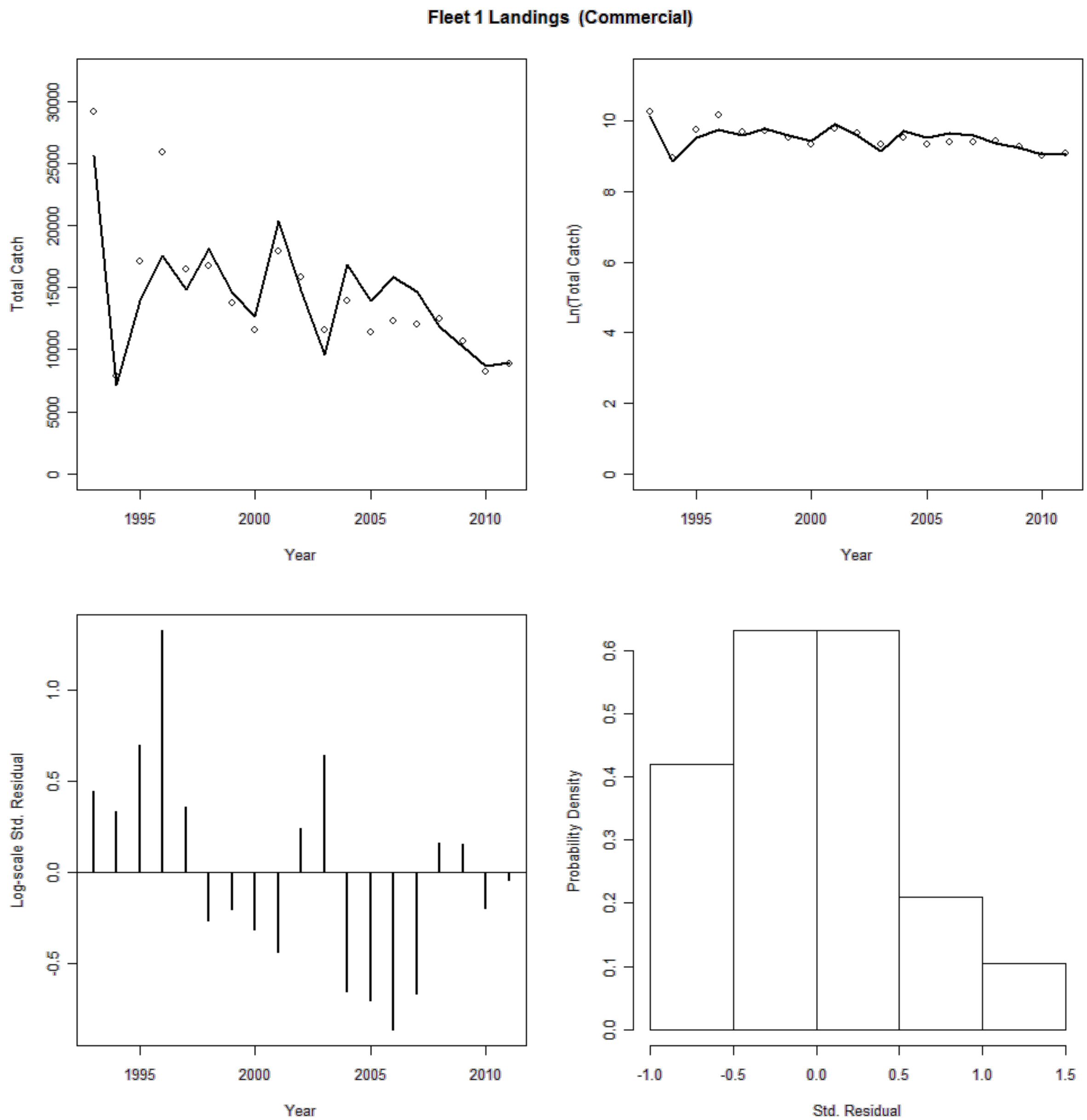


Figure 67. ASAP model Run 12 fit to the total 4VWX silver hake fishery landings.

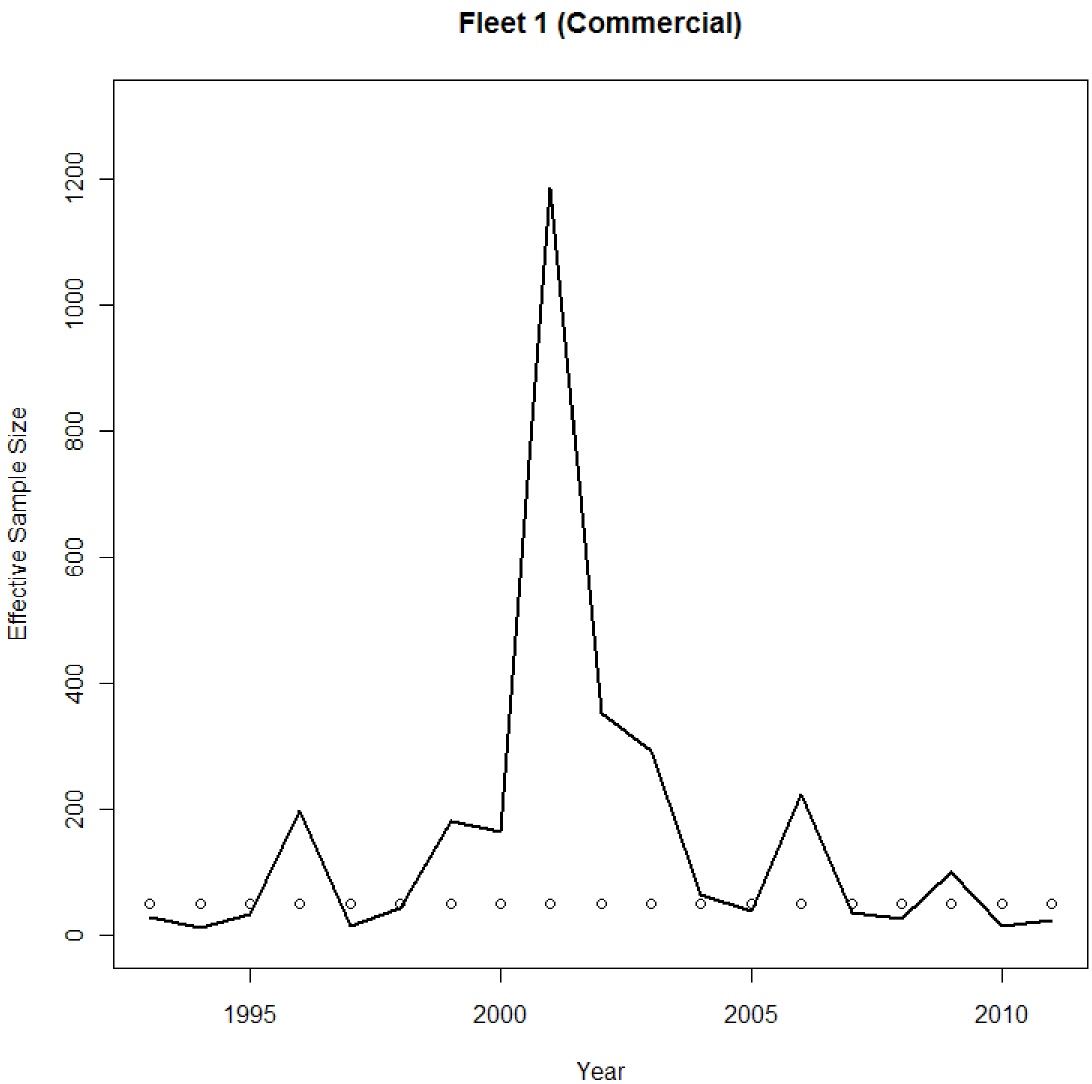


Figure 68. ASAP model Run 12 comparison of input ESS versus model estimated ESS for 4VWX silver hake fishery landings.

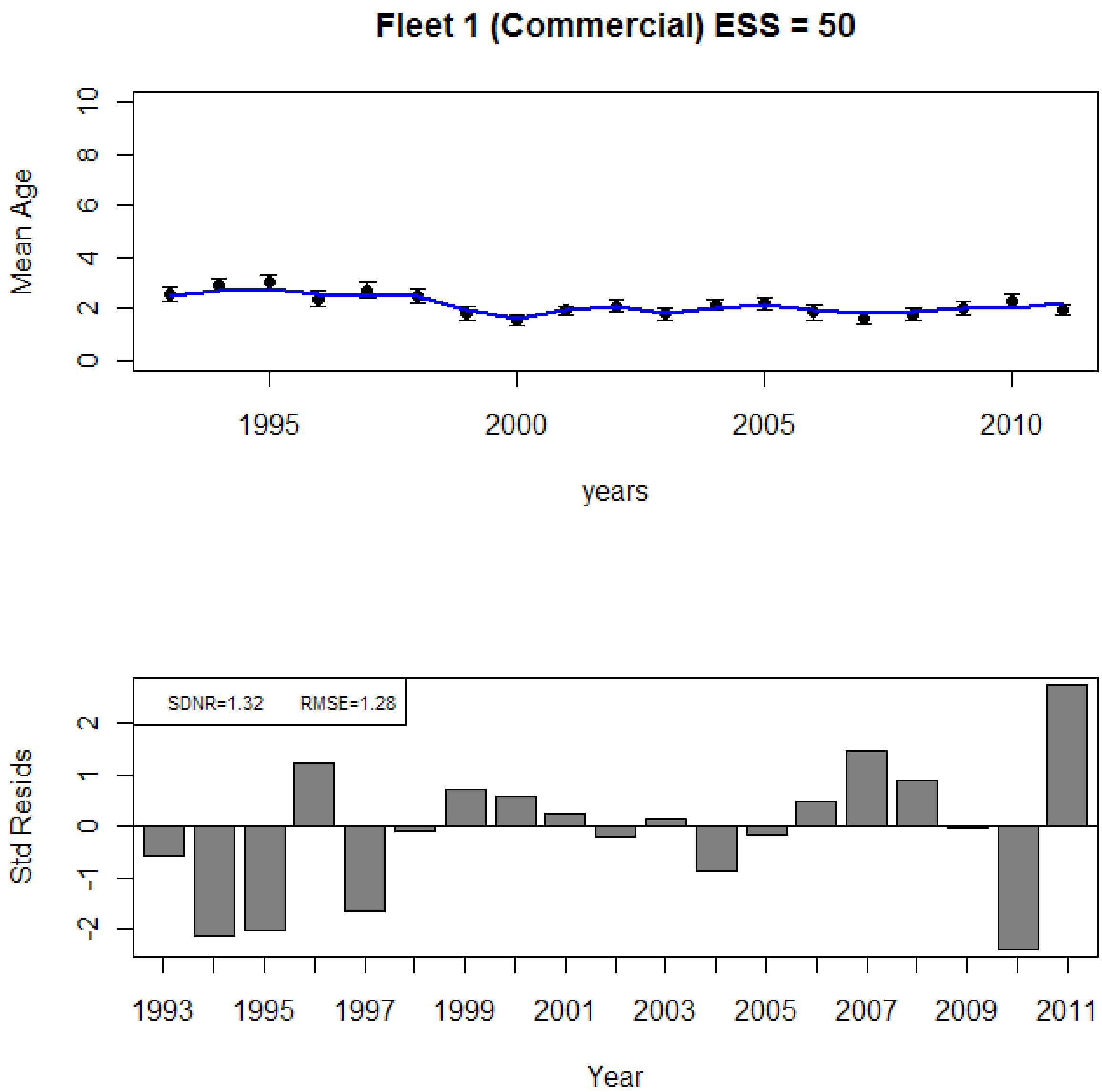


Figure 69. ASAP model Run 12 predicted mean age of 4VWX silver hake in the fishery landings (blue line) compared to the observed mean age (top plot) and the residuals about the mean (bottom plot).

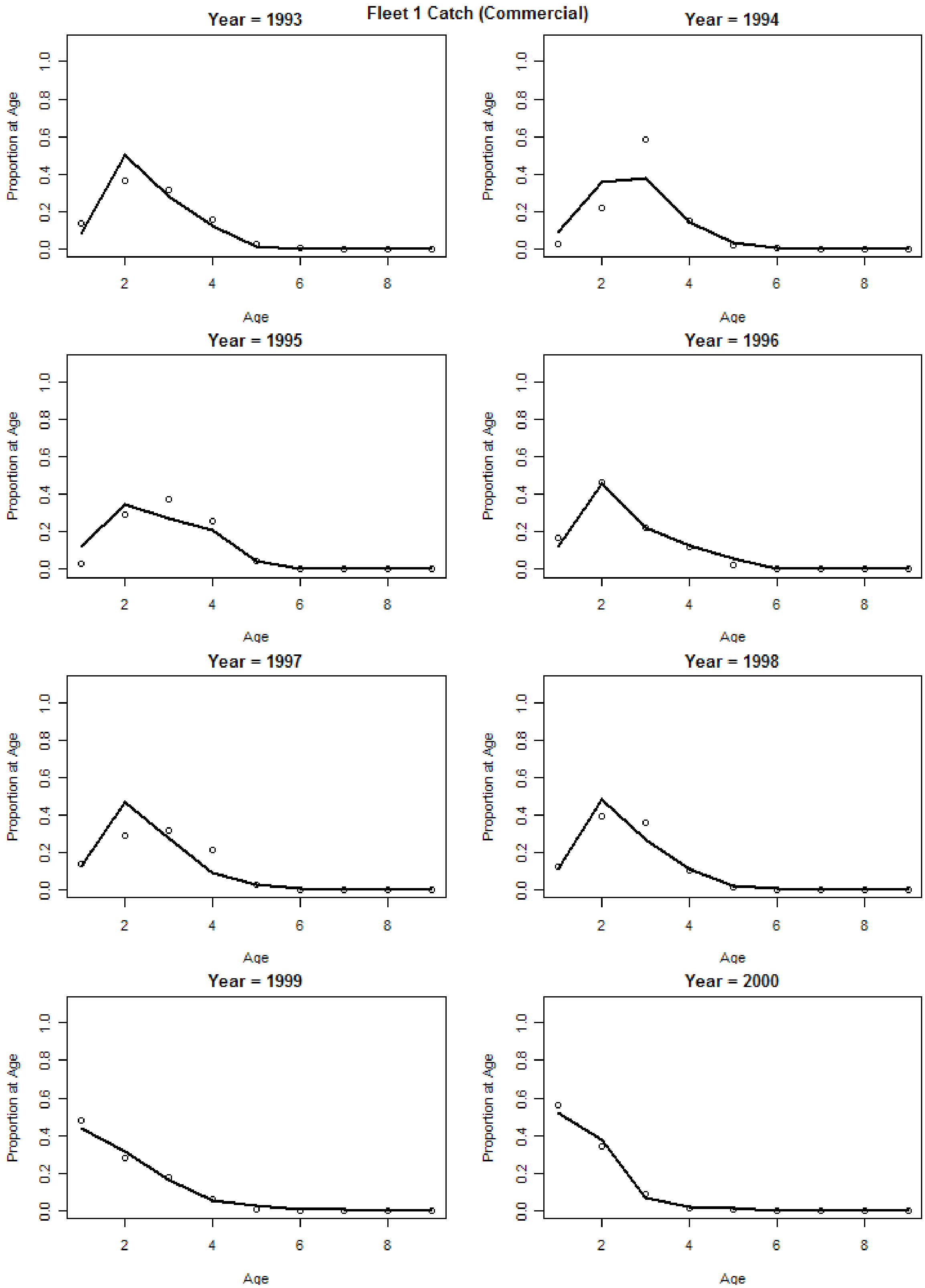


Figure 70a. Comparison of the ASAP model Run 12 estimates of 4VWX silver hake proportion at age to the data estimate (1993-2000).

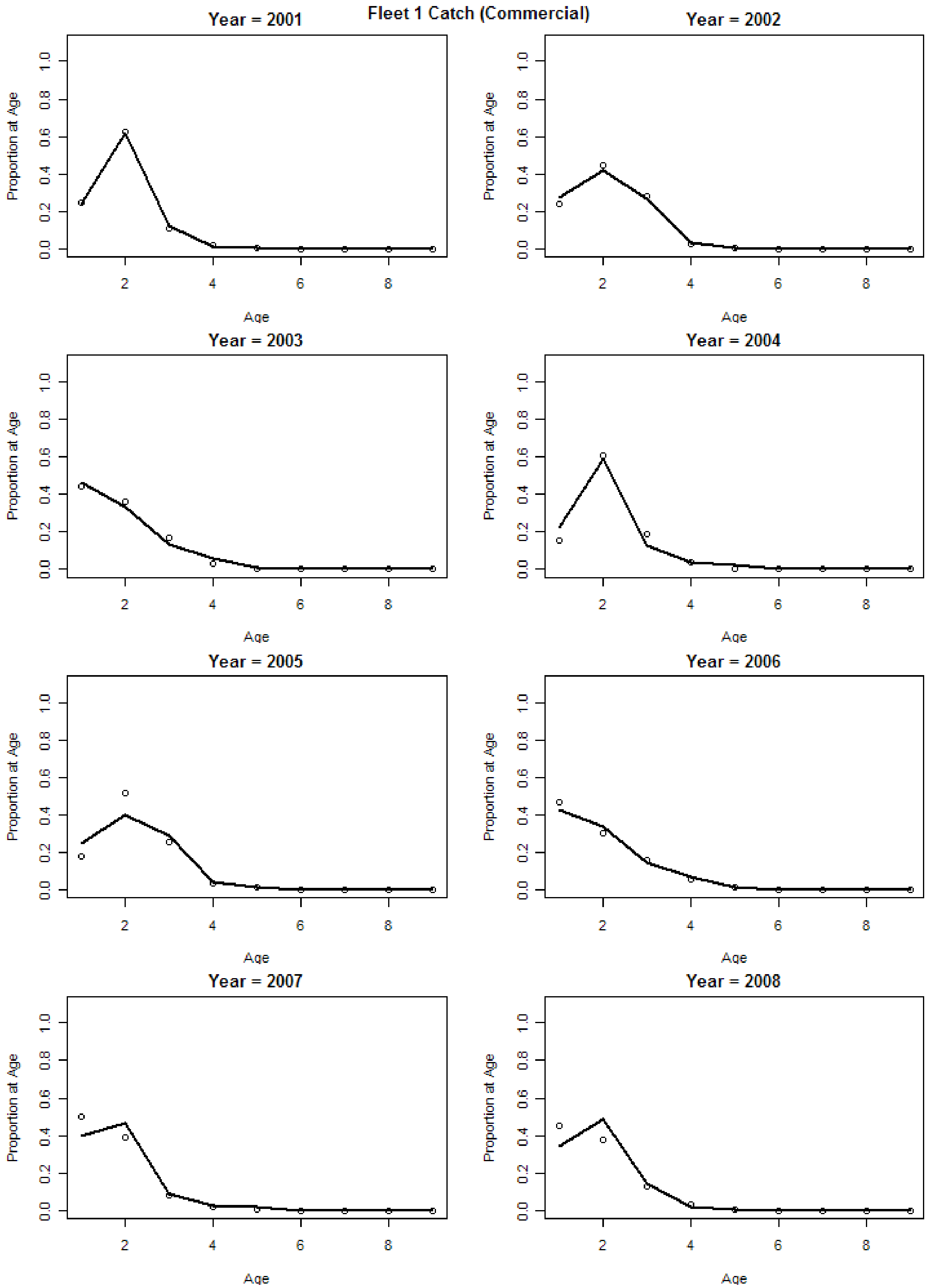


Figure 70b. Comparison of the ASAP model Run 12 estimates of 4VWX silver hake proportion at age to the data estimate (2001-2008).

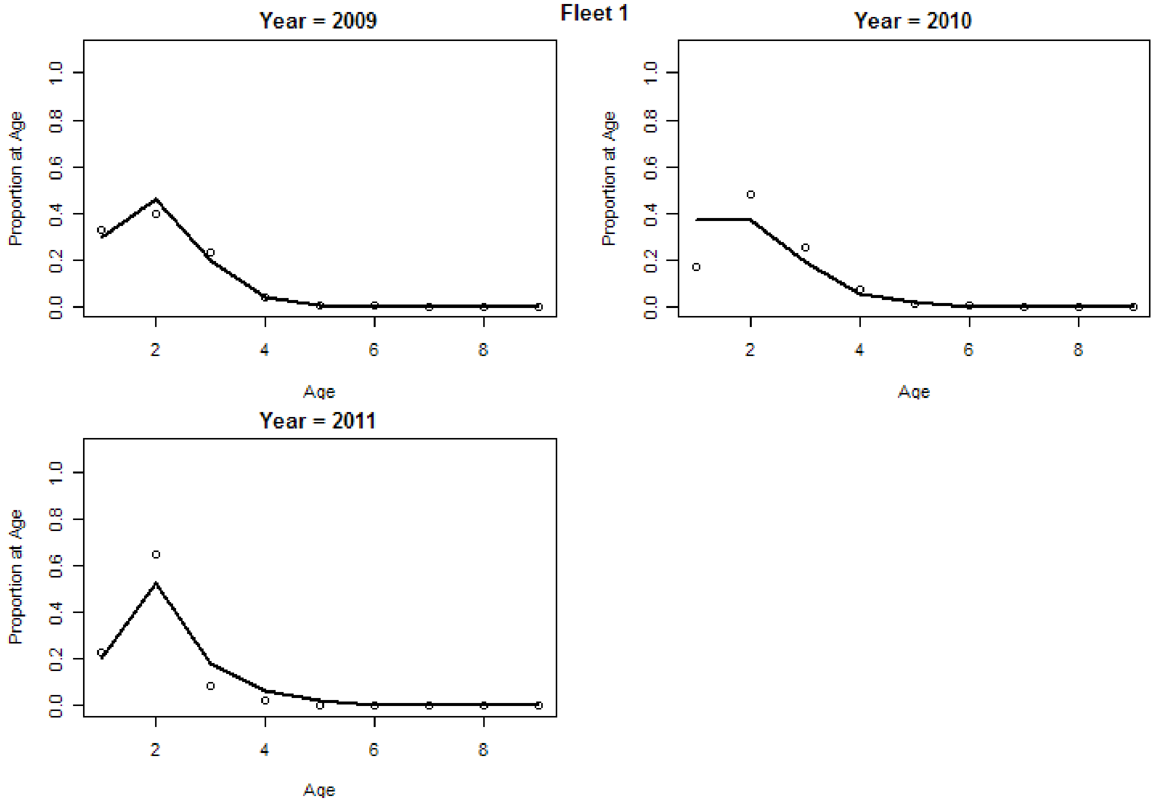


Figure 70c. Comparison of the ASAP model Run 12 estimates of 4VWX silver hake proportion at age to the data estimate (2009-2011).

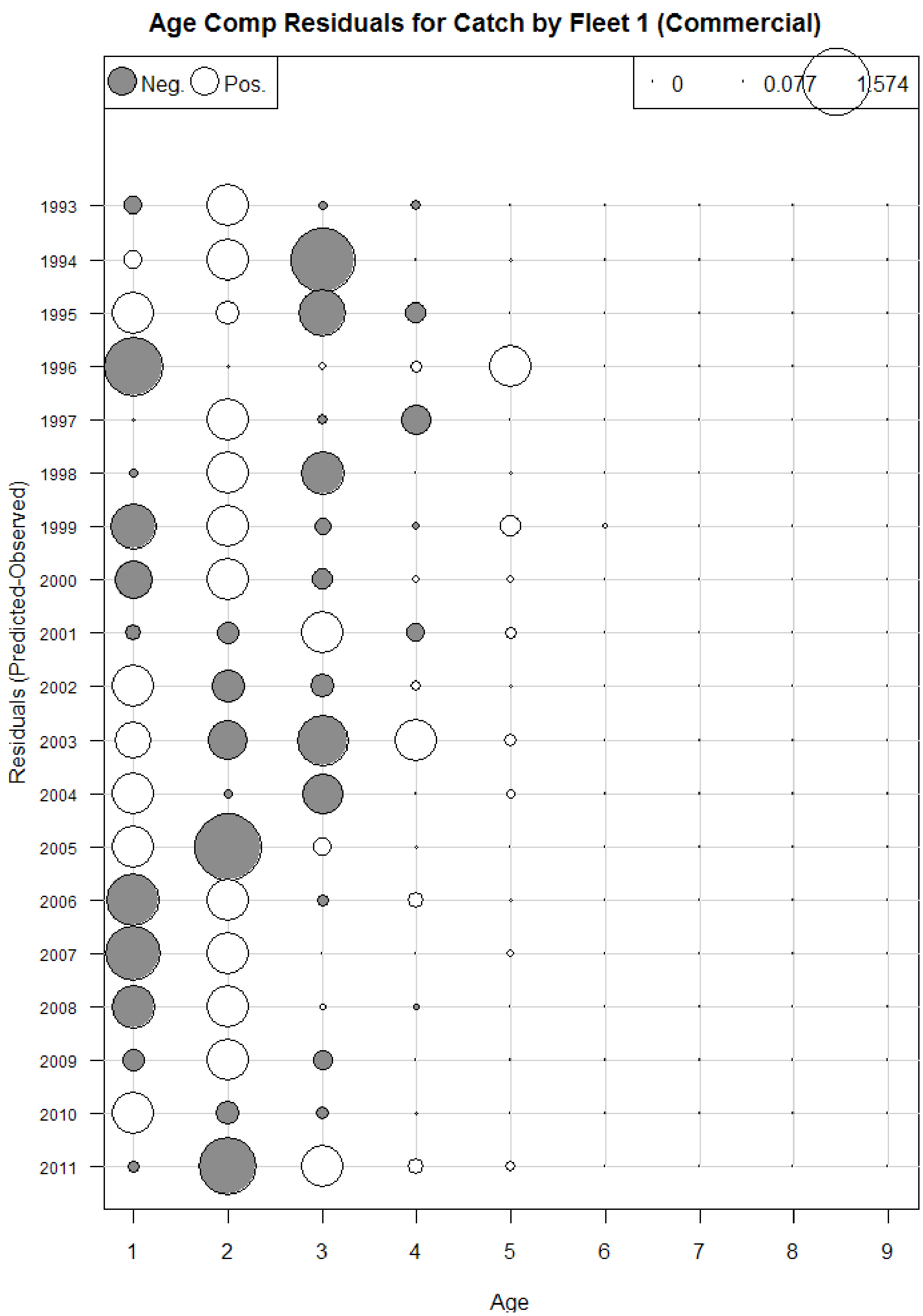


Figure 71. ASAP model Run 12 residual fit to the fishery landings-at-age for 4VWX silver hake.

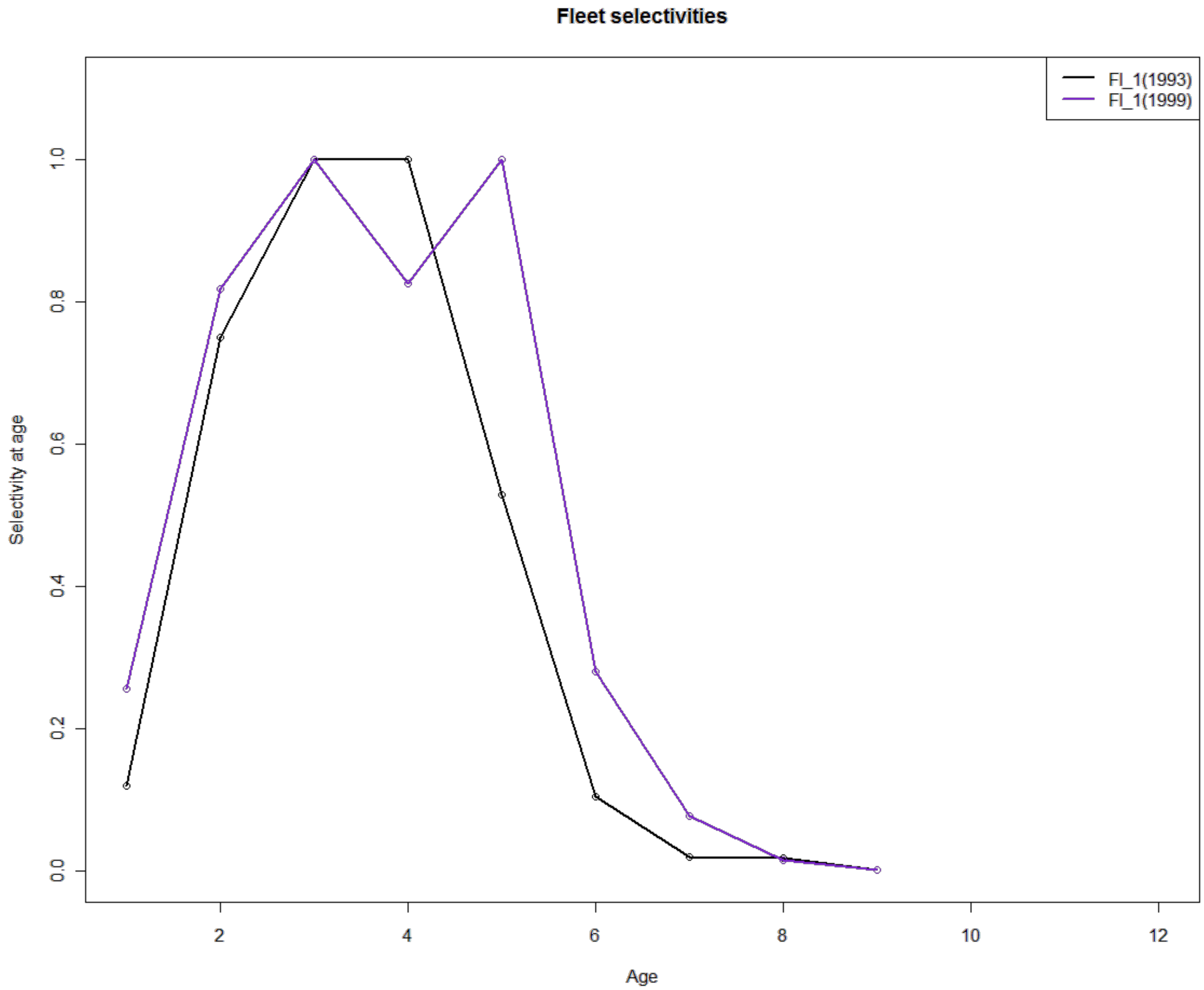


Figure 72. ASAP model Run 12 estimated selectivity blocks for 4VWX silver hake. Block 1 (1993-1998) and Block 2 (1999-2011). Note selectivity was estimated for fixed for ages 2 and 3 and estimated for all other ages in Block 1, while in Block 2, selectivity was fixed on age 5 only.

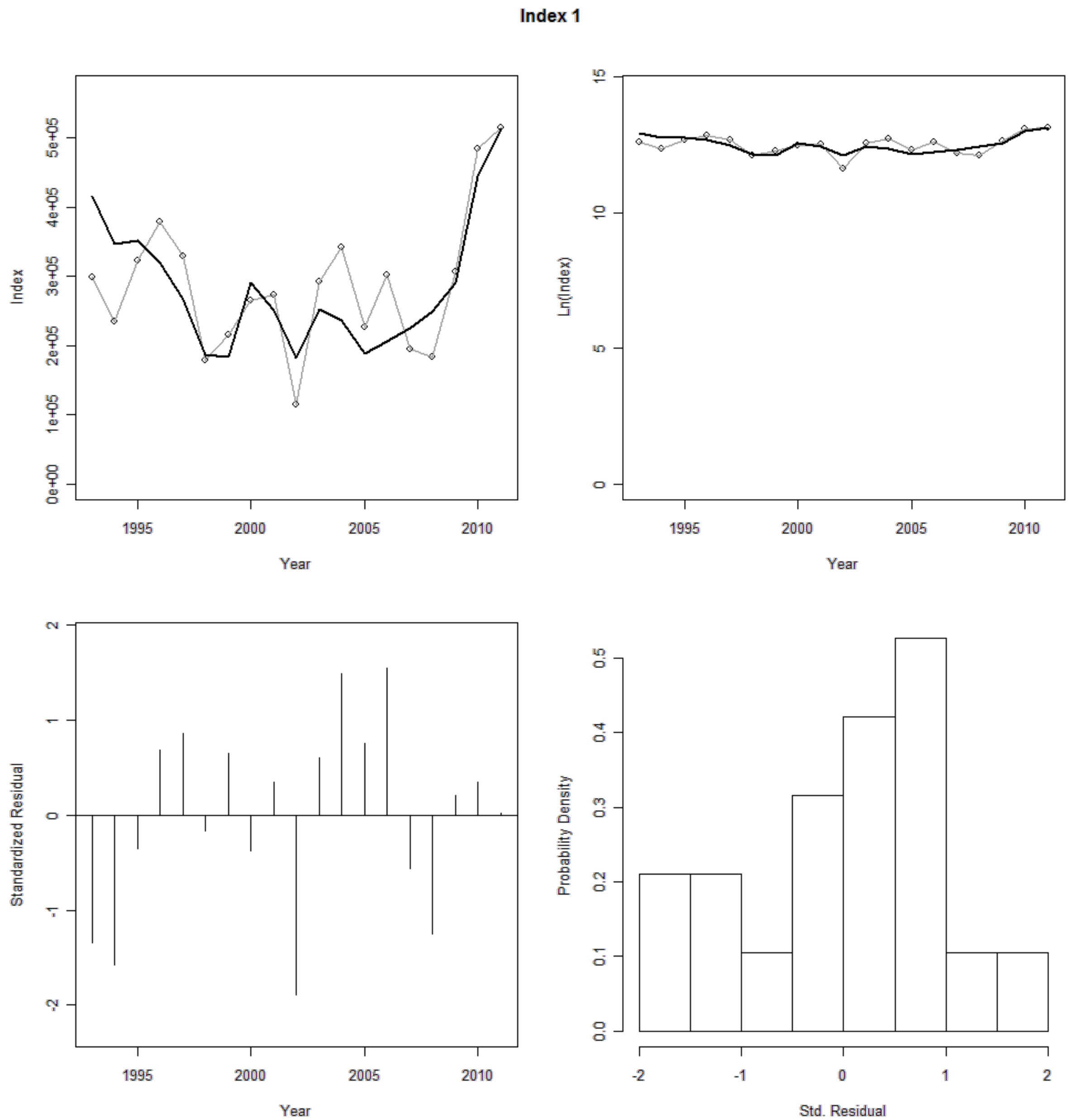


Figure 73. ASAP model Run 12 fit to the 4VWX silver hake summer RV survey.

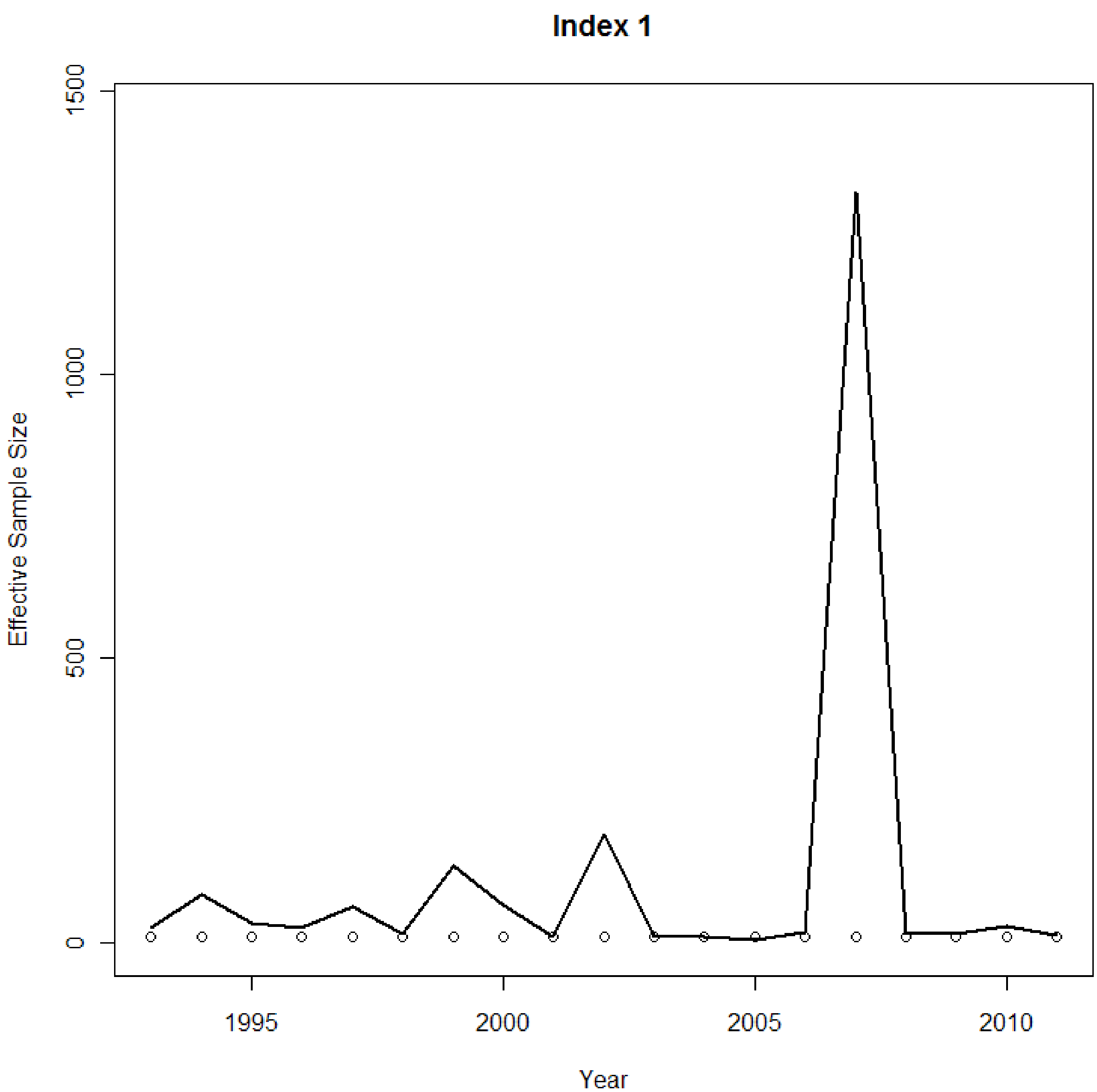


Figure 74. ASAP model Run 12 comparison of input ESS versus the model estimated sample size for the summer RV survey for 4VWX silver hake.

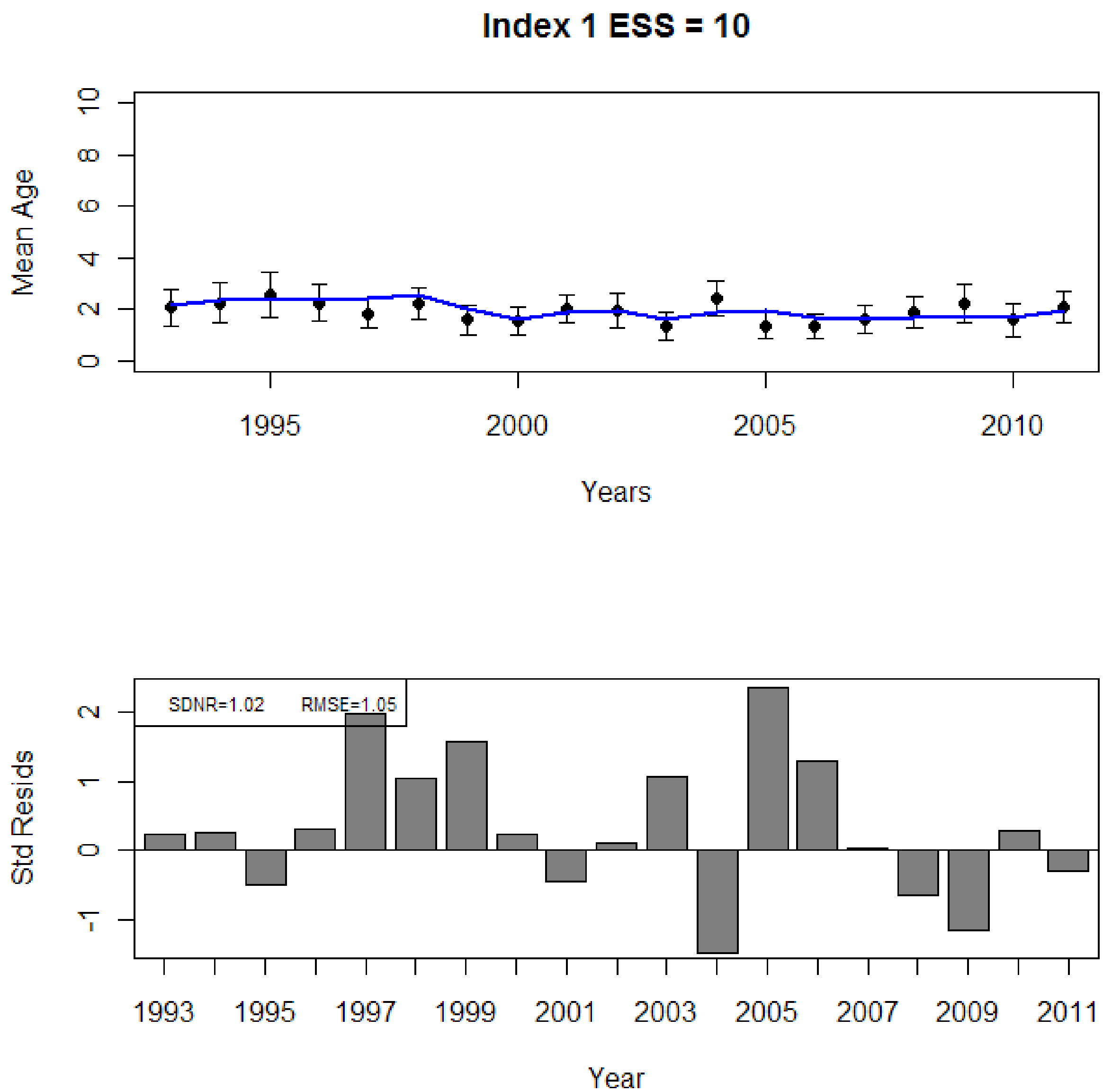


Figure 75. ASAP model Run 12 predicted mean age of 4VWX silver hake in the summer RV survey (blue line) compared to the observed mean age (top plot) and the residuals about the mean (bottom plot).

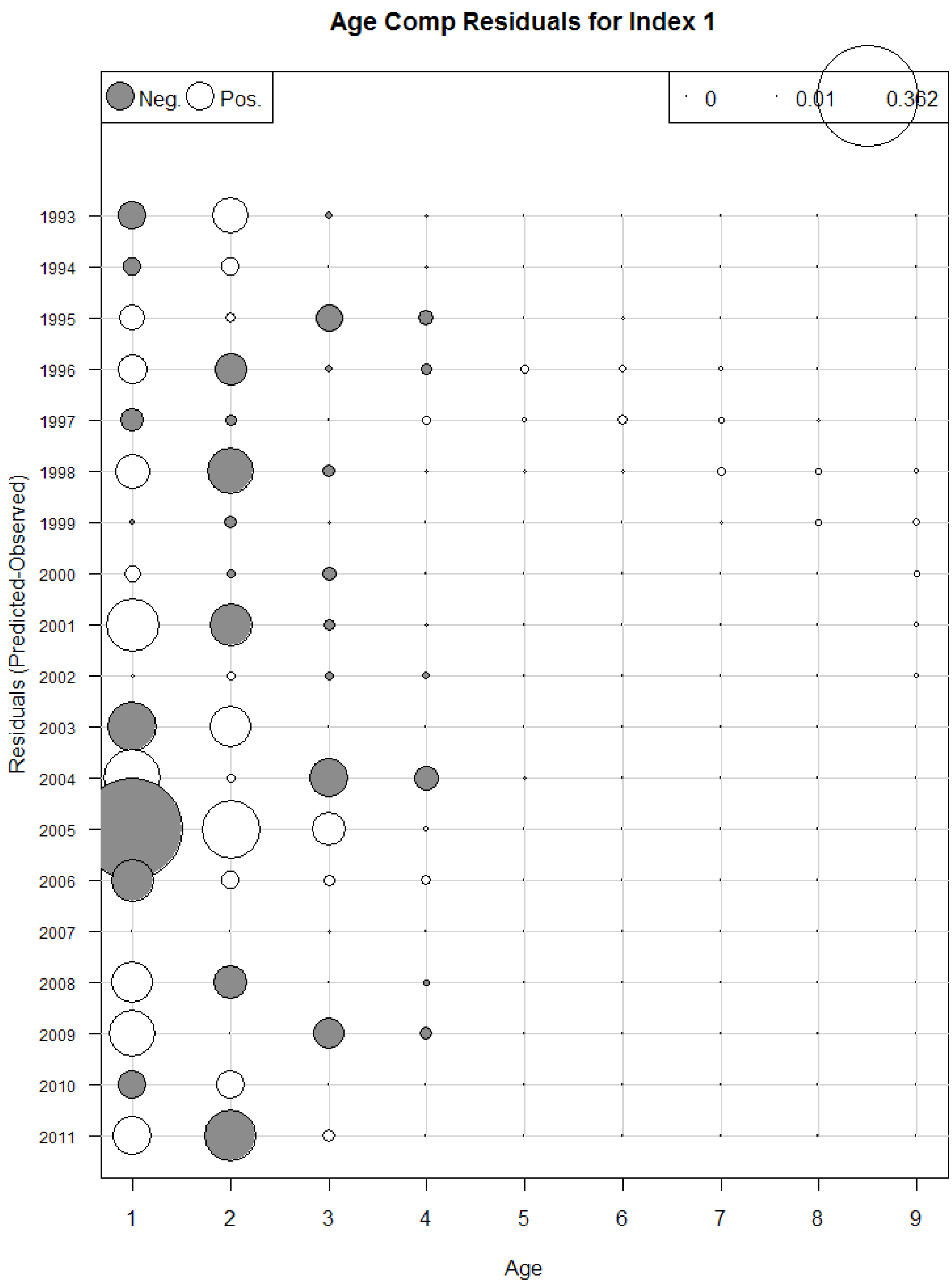


Figure 76. ASAP model Run 12 fit to the residual summer RV survey for 4VWX silver hake age. composition.

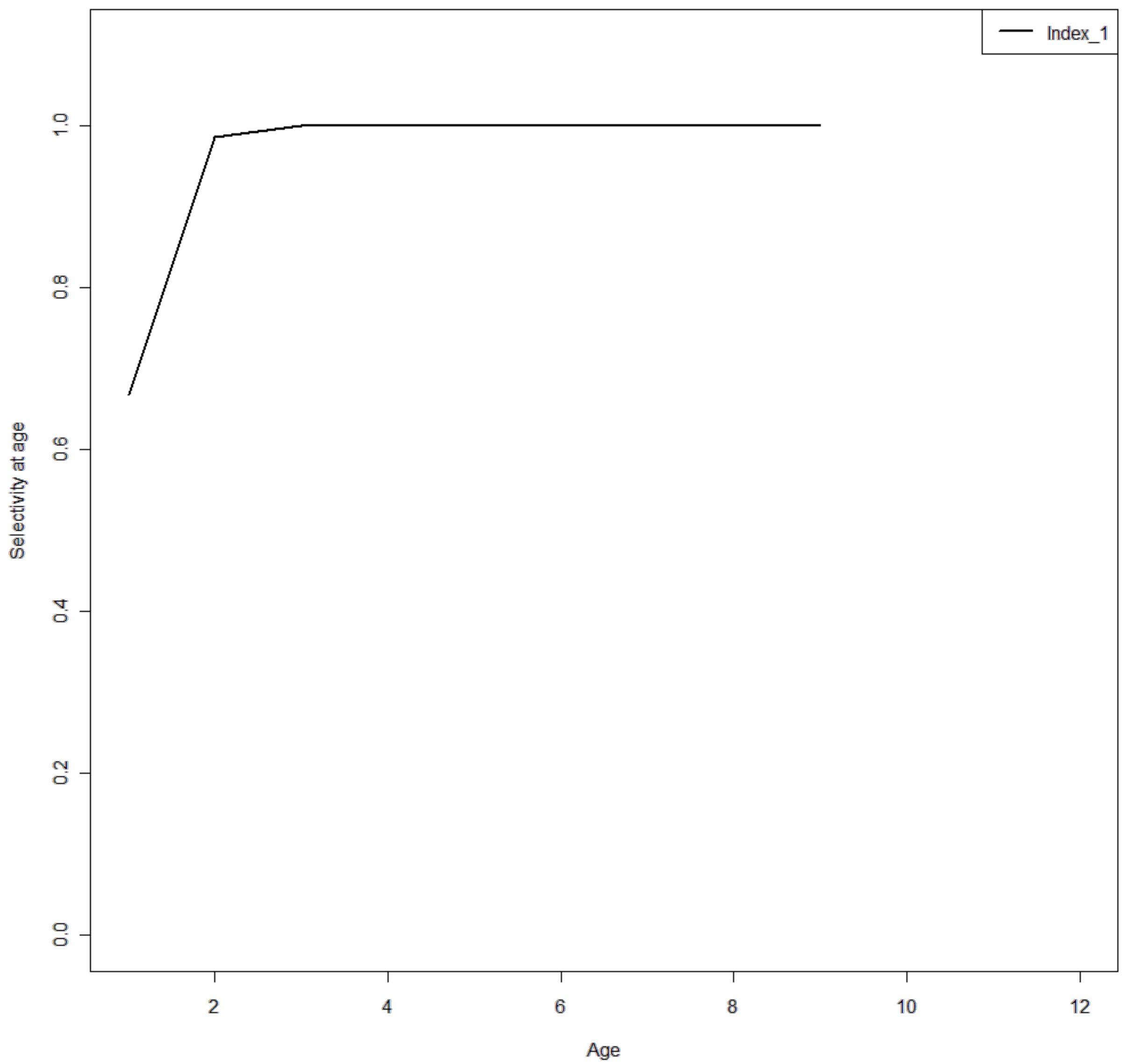


Figure 77. ASAP model Run 12 estimated selectivity for the summer RV survey for 4VWX silver hake.

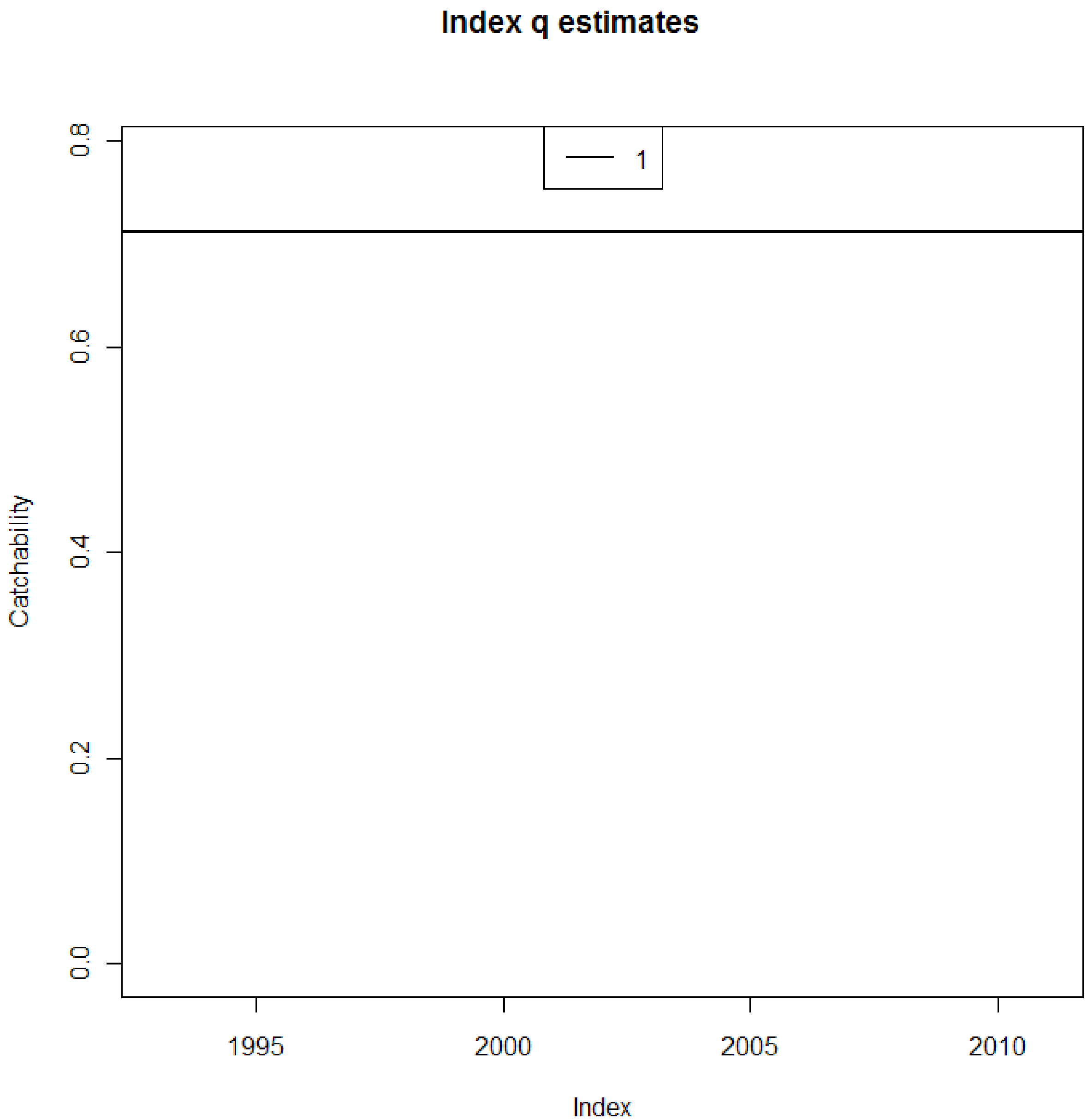


Figure 78. ASAP model Run 12 estimated catchability (q) for the summer RV survey of 4VWX silver hake.

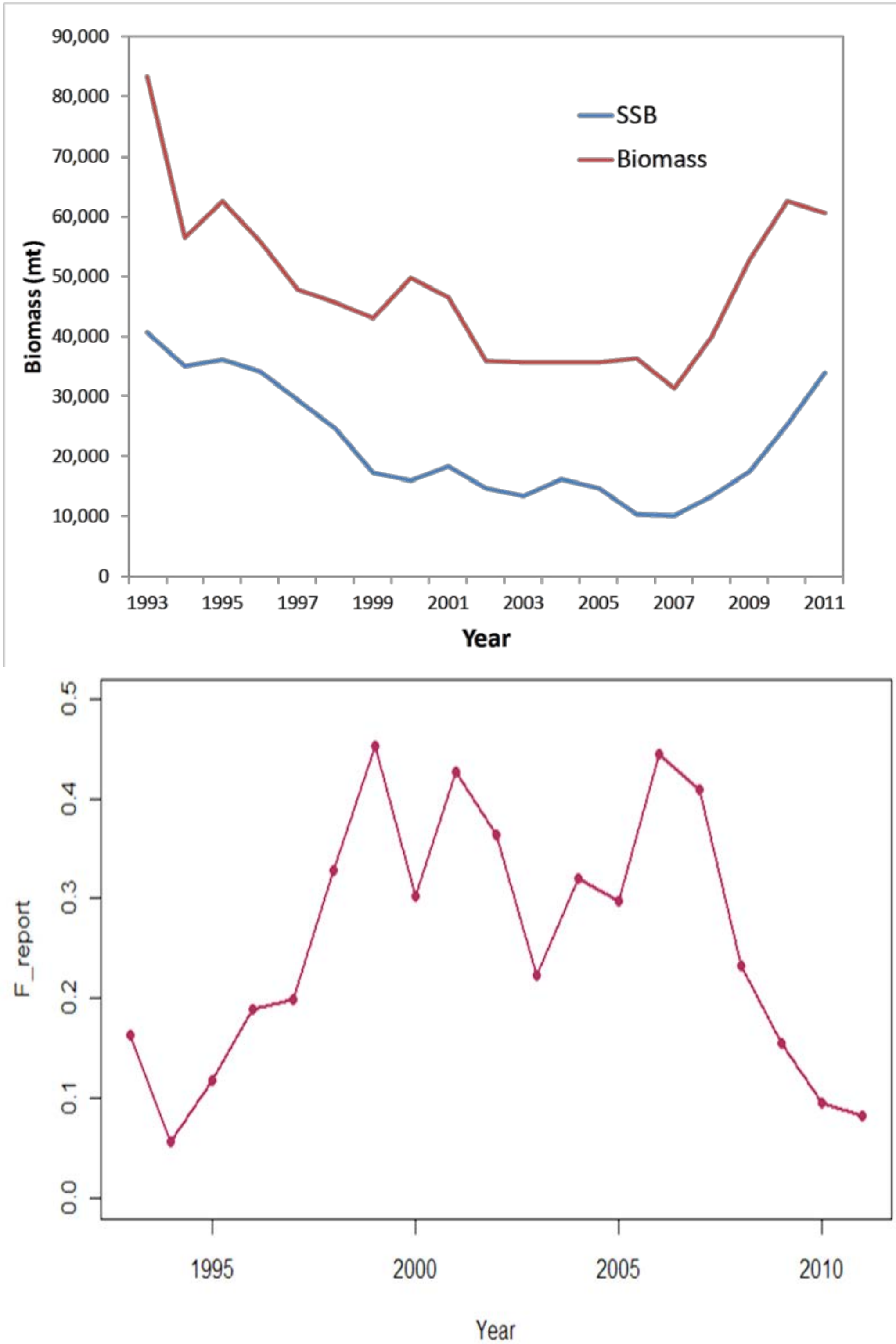
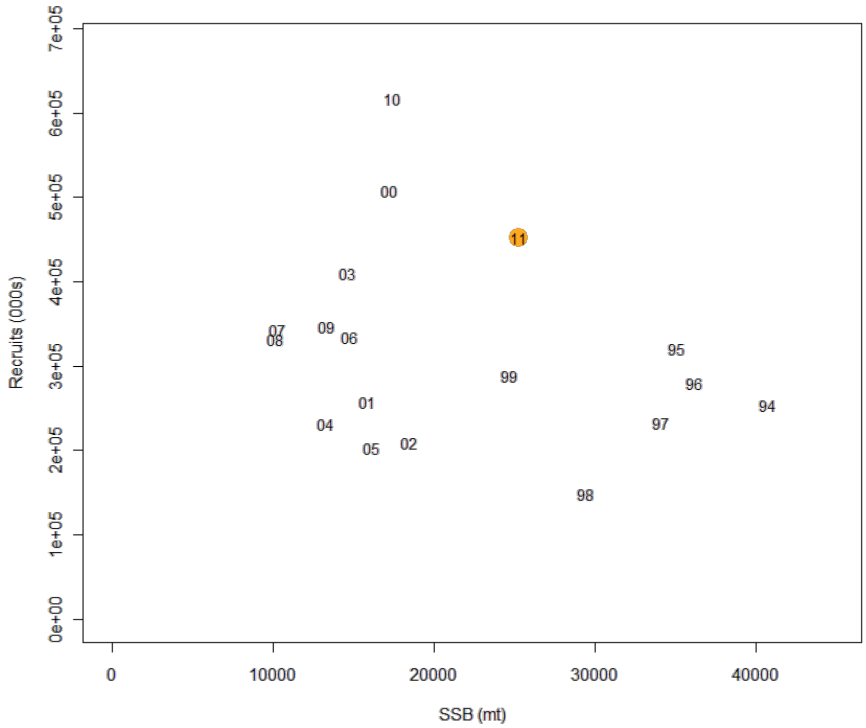


Figure 79. ASAP model Run 12 estimates of 4VWX silver hake total biomass and SSB in t (top) and average fishing mortality (bottom; F_report).



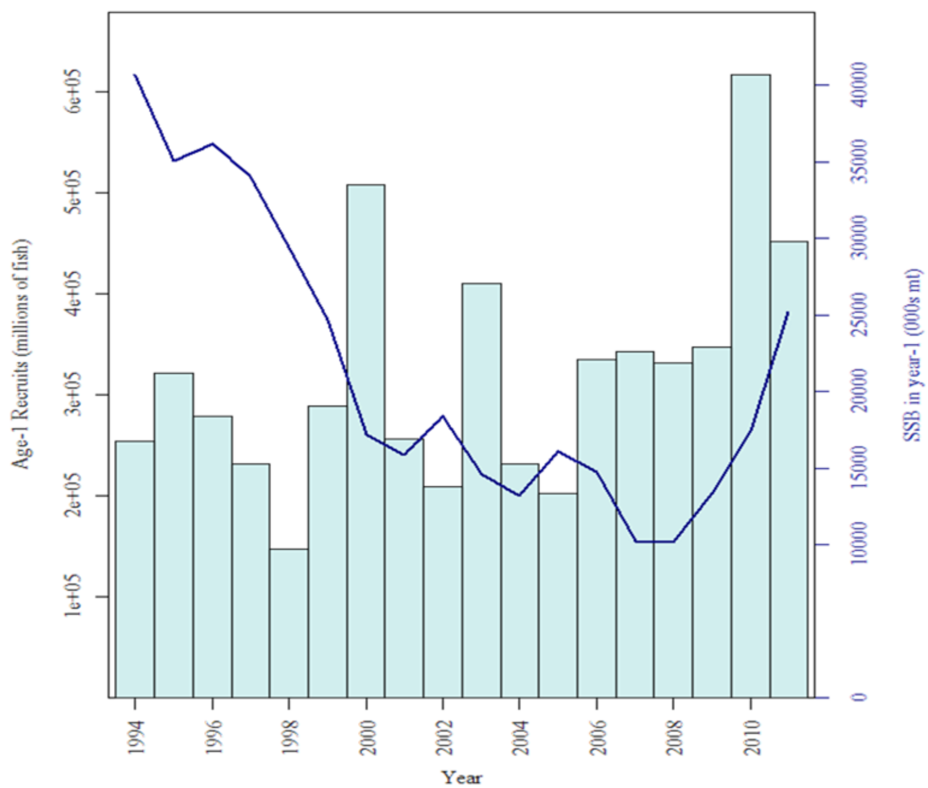


Figure 80. Top: Scatter of ASAP model Run 12 estimates of 4VWX silver hake SSB in t versus recruitment at age 1 (000's). The symbol for each observation is the last two digits of the year (e.g. 98 indicated age 1 estimates of the 97 year class). The most recent estimate is highlighted in an orange circle. Bottom: ASAP model Run 12 time series of SSB (blue line) and age 1 recruitment (bars).

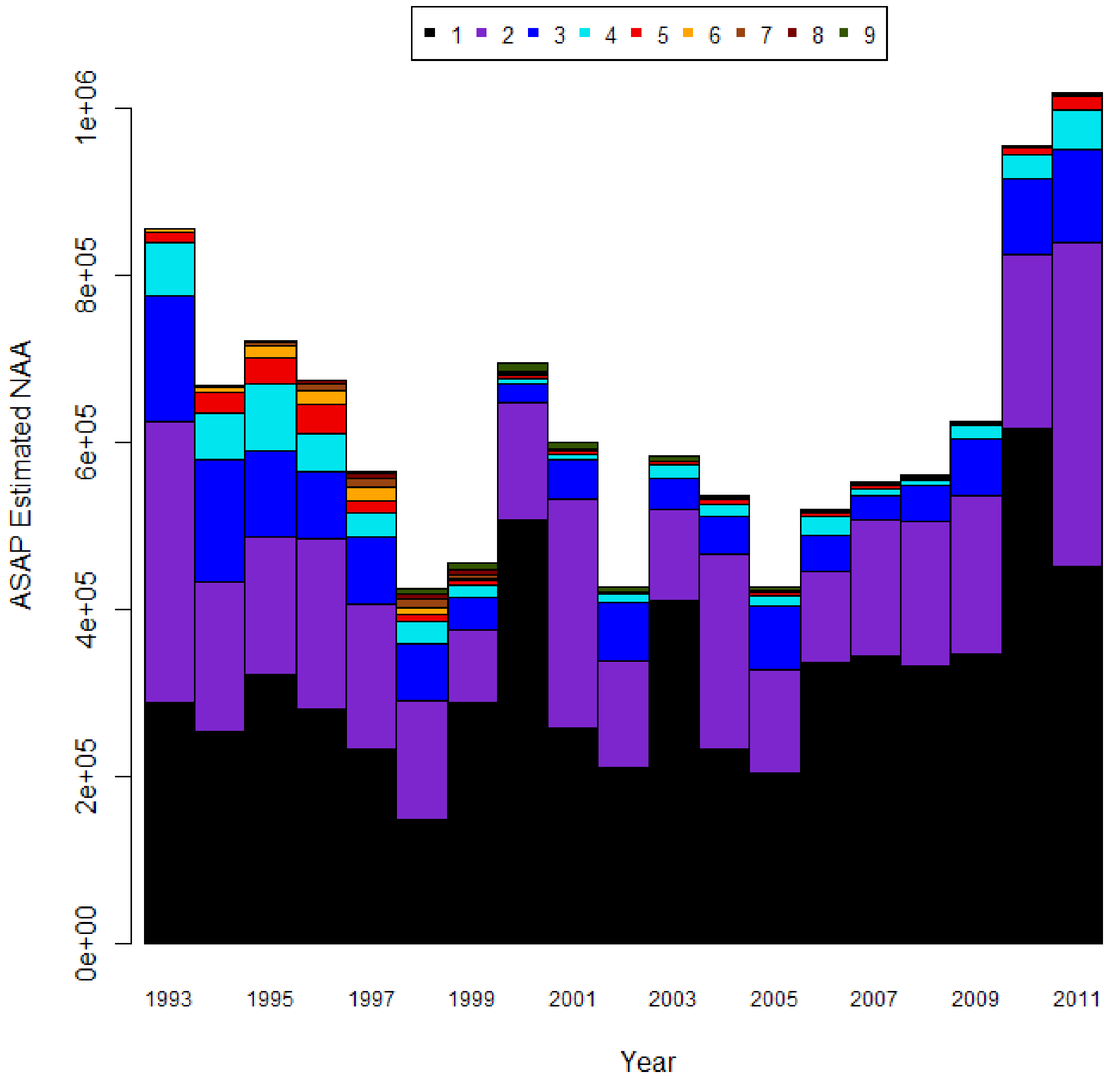


Figure 81. ASAP model Run 12 estimates of 4VWX silver hake at age in thousands (000's) of fish.

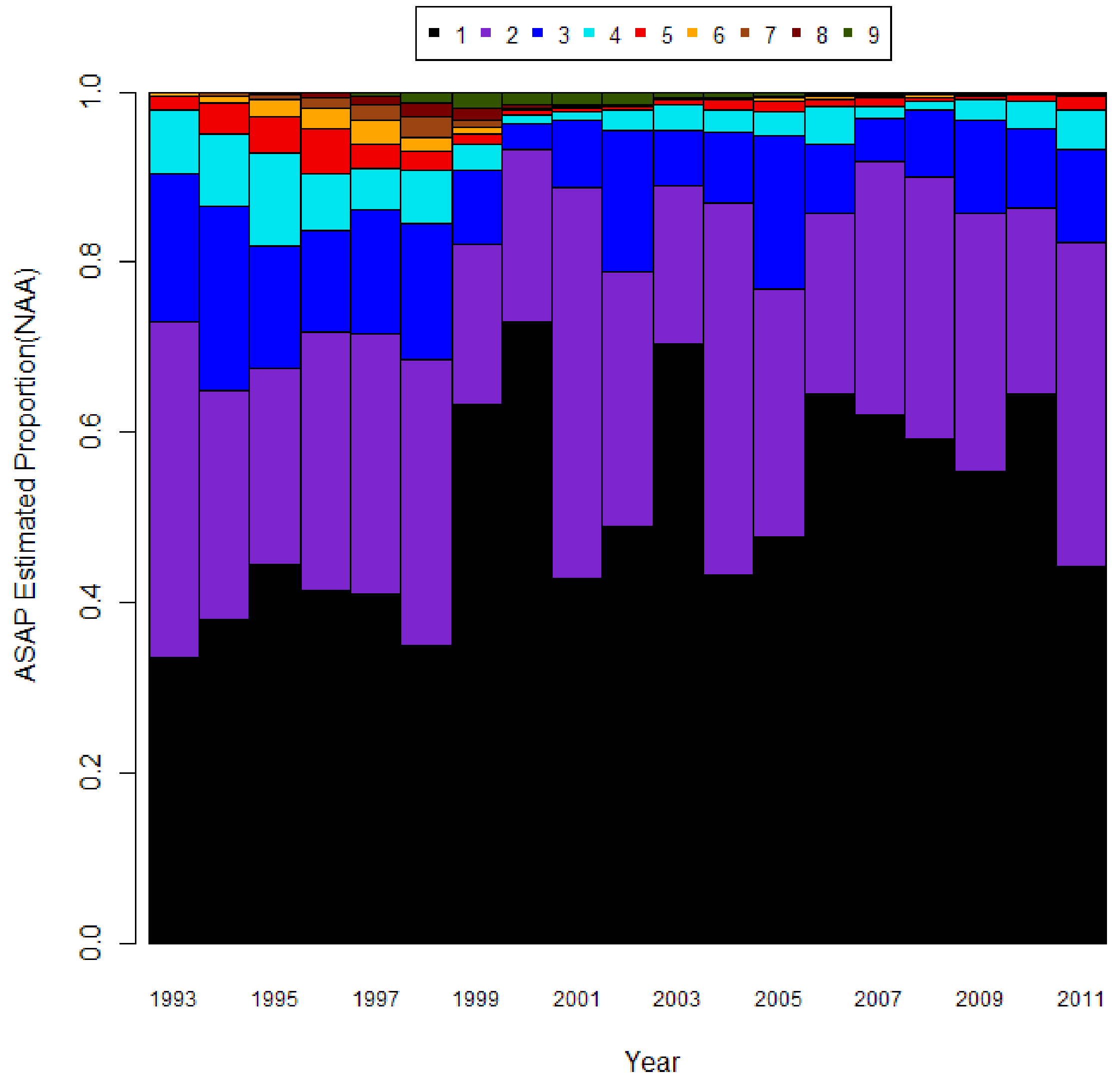


Figure 82. ASAP model Run 12 estimates of 4VWX silver hake numbers at age expressed as proportions.

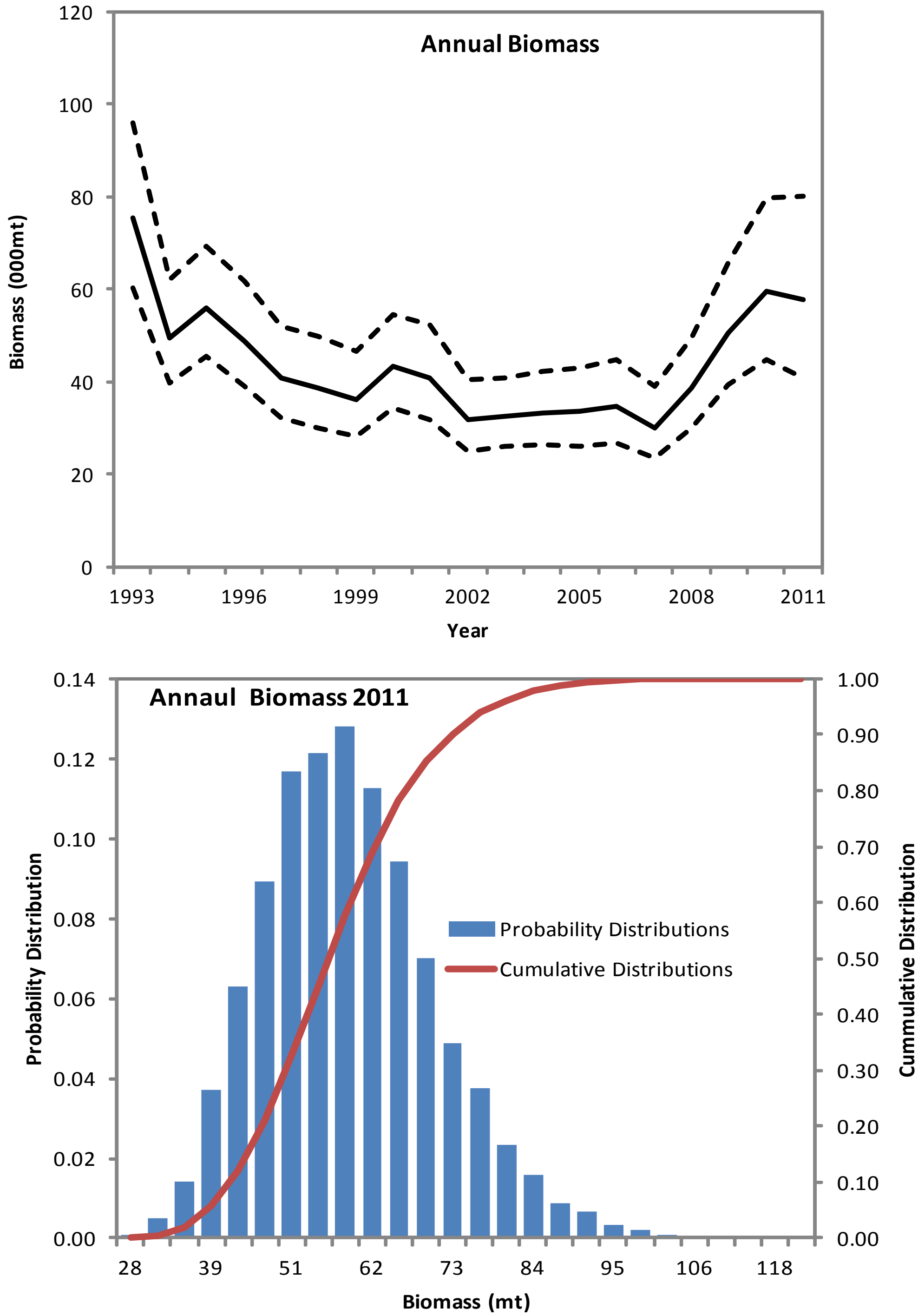
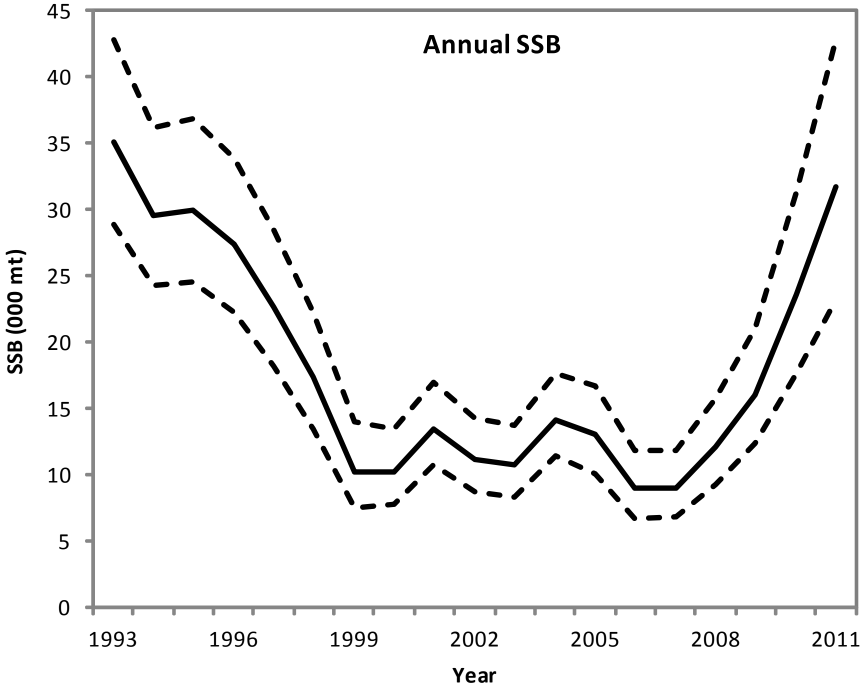


Figure 83. Top: 90% probability interval for 4VWX silver hake total biomass from ASAP model Run 12. The median is the value in the black solid line, while the 5th and 95th percentiles are the dash black lines. Bottom: MCMC probability distribution (blue bars) and cumulative distribution (red line) of total biomass in 2011.



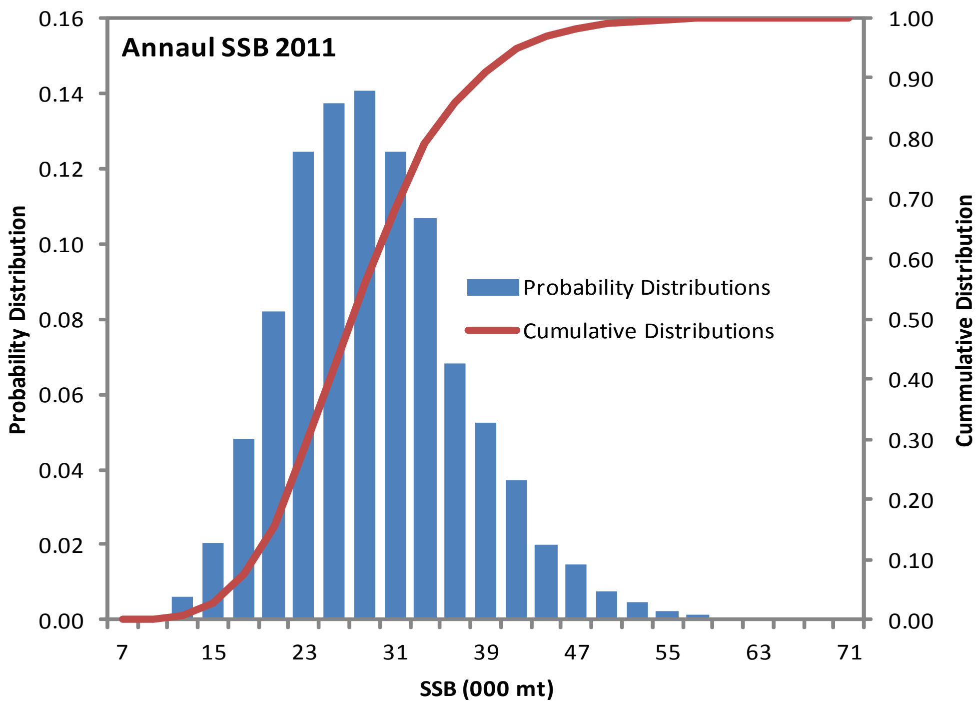


Figure 84. Top: 90% probability interval for 4VWX shelf silver hake SSB from ASAP model Run 12. The median is the value in the black solid line, while the 5th and 95th percentiles are the dash black lines. Bottom: MCMC probability distribution (blue bars) and cumulative distribution (red line) of SSB in 2011.

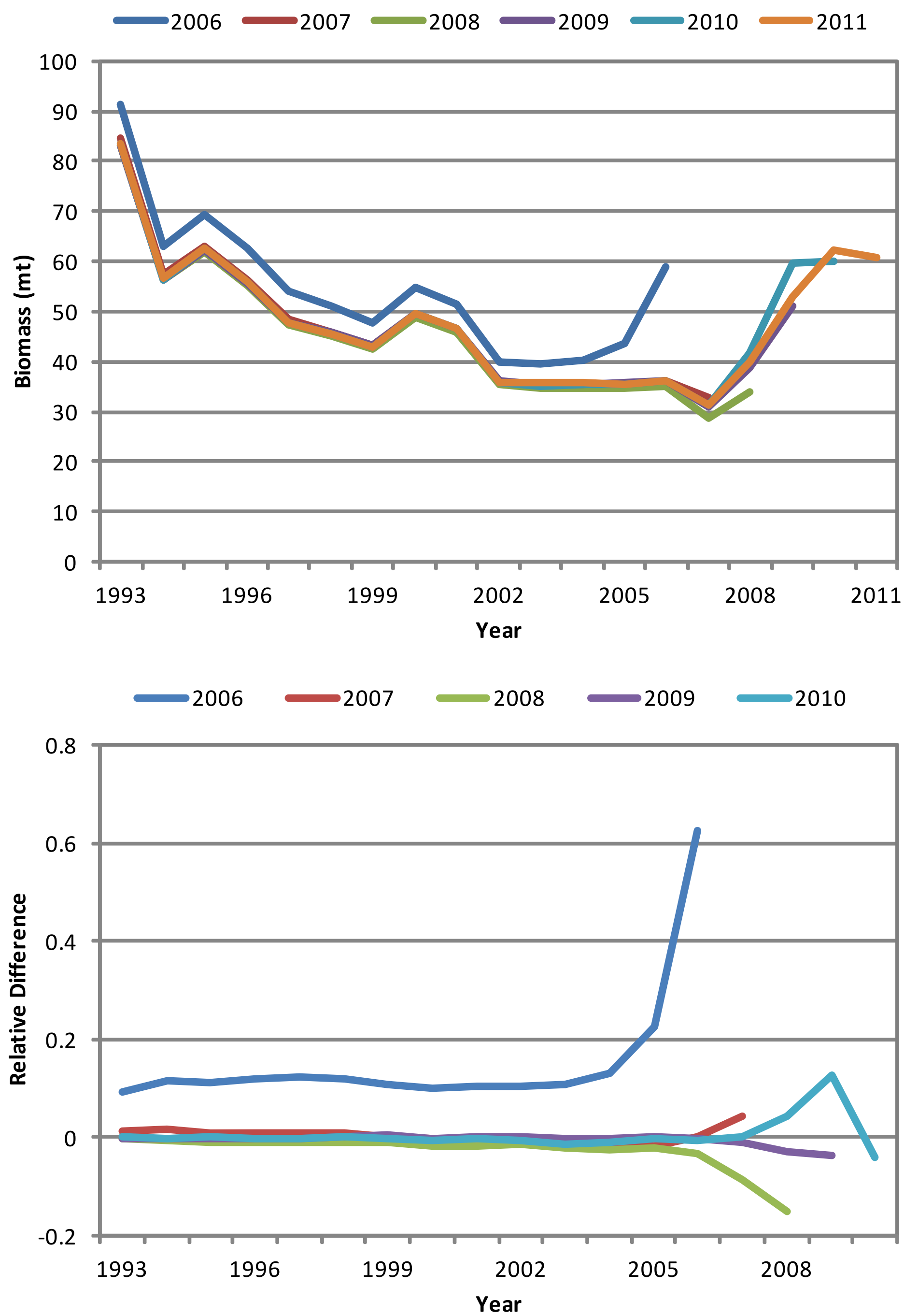
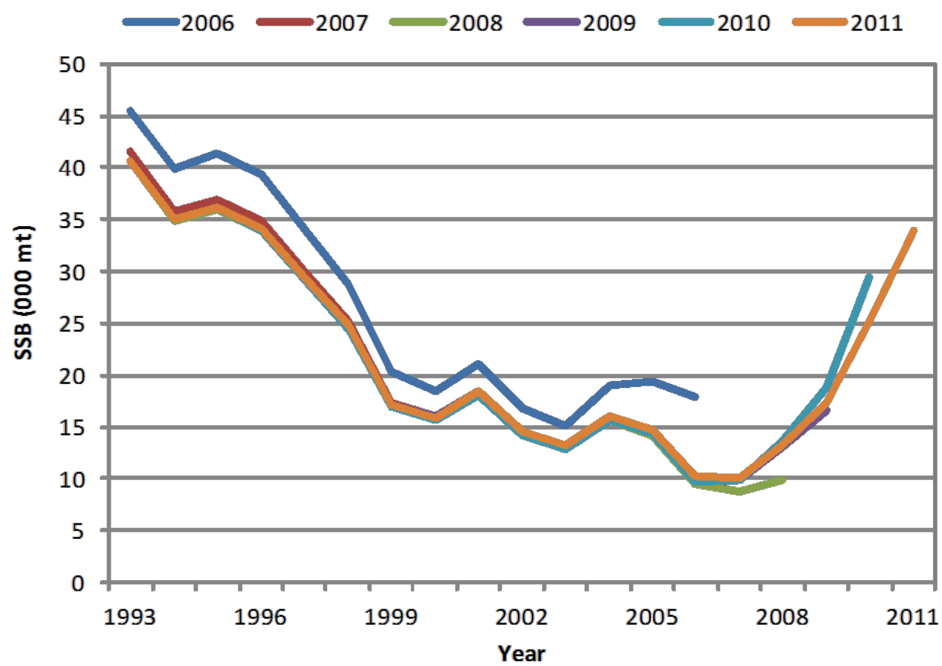


Figure 85. ASAP model Run 12 retrospective patterns for 4VWX silver hake total biomass (t) in absolute (top) and relative (bottom) terms.



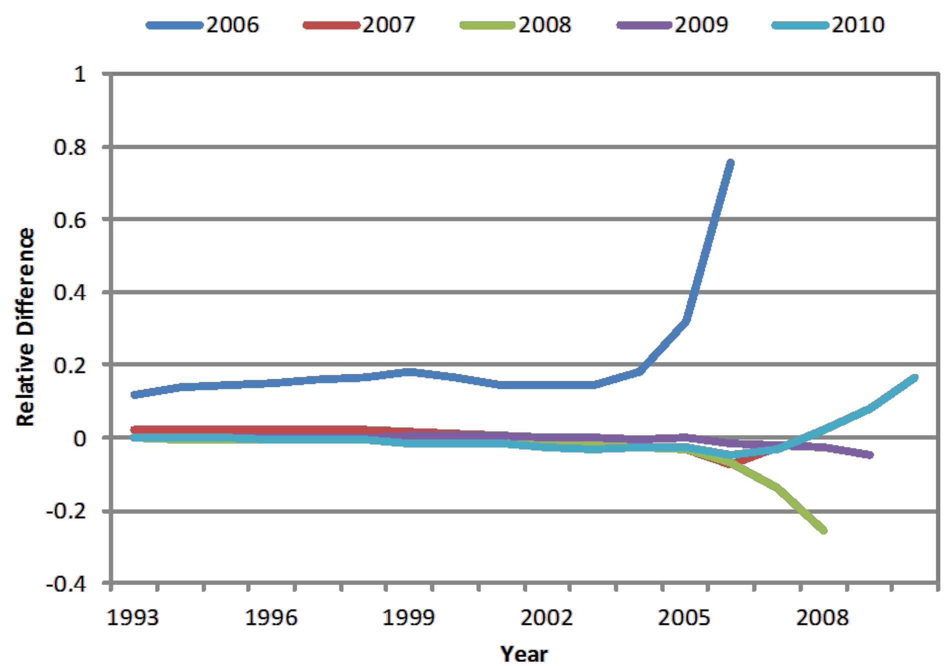


Figure 86. ASAP model Run 12 retrospective patterns for 4VWX silver hake SSB (t) in absolute (top) and relative (bottom) terms.

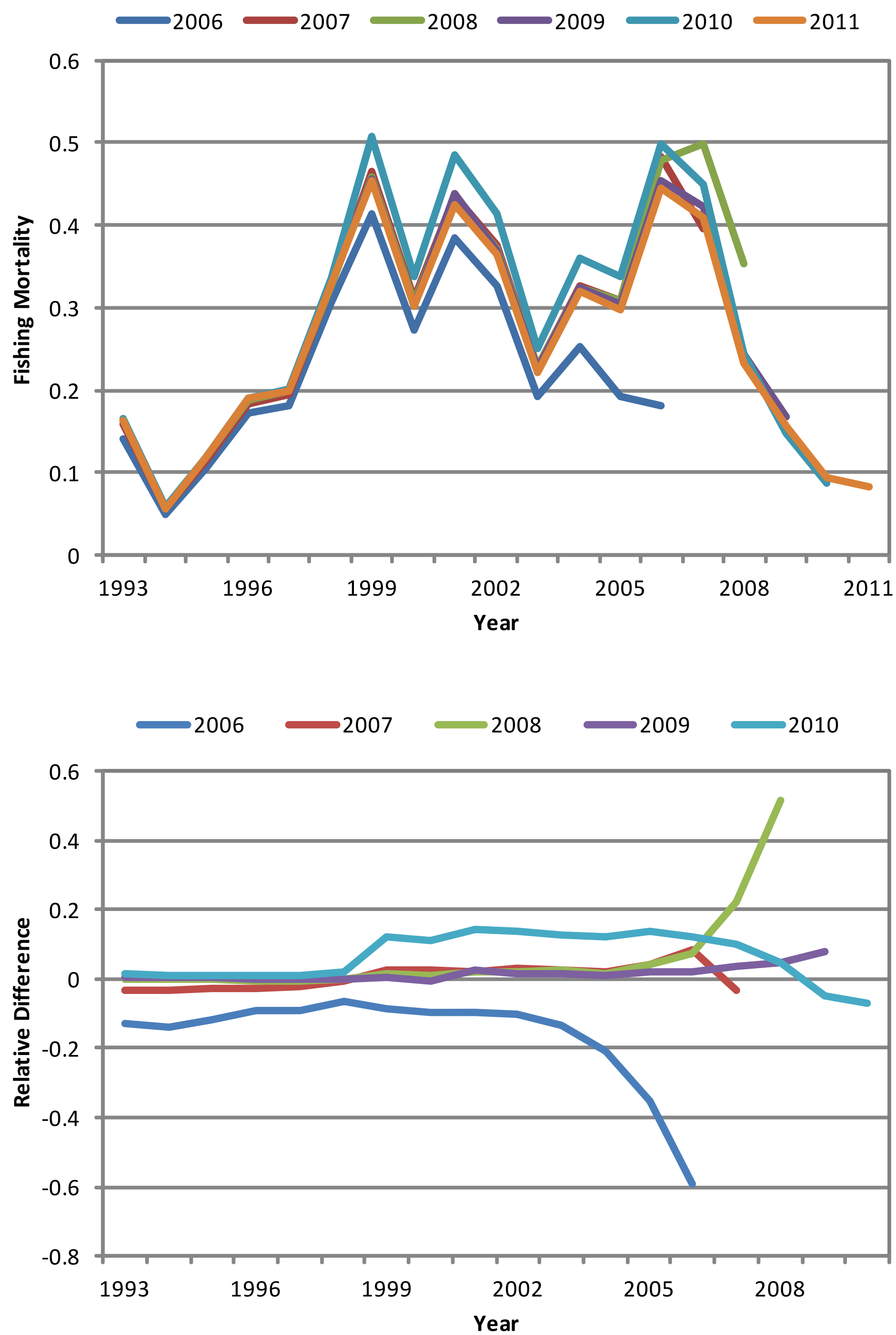


Figure 87. ASAP model Run 12 retrospective patterns for 4VWX silver hake average fishing mortality rate in absolute (top) and relative (bottom) terms.

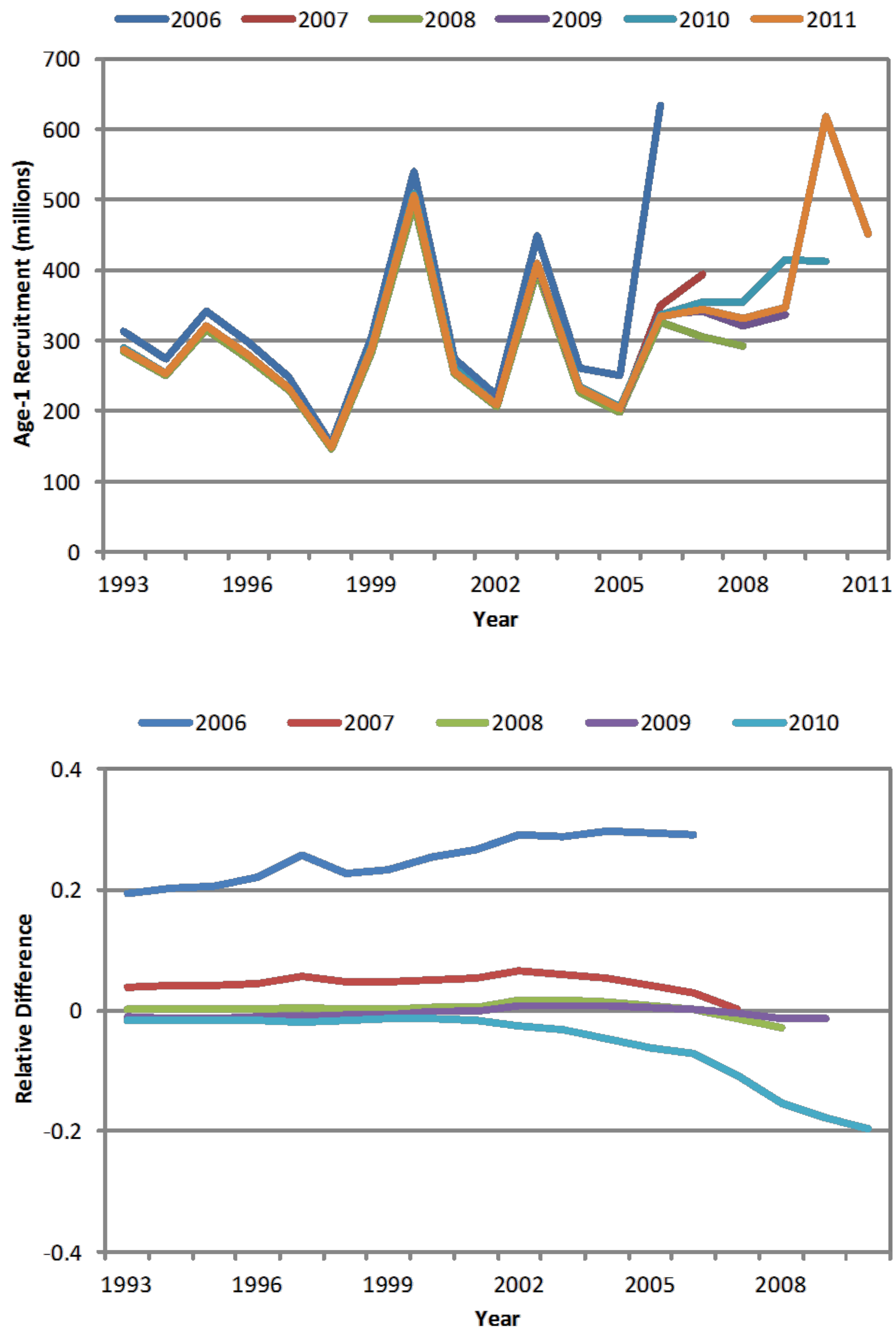
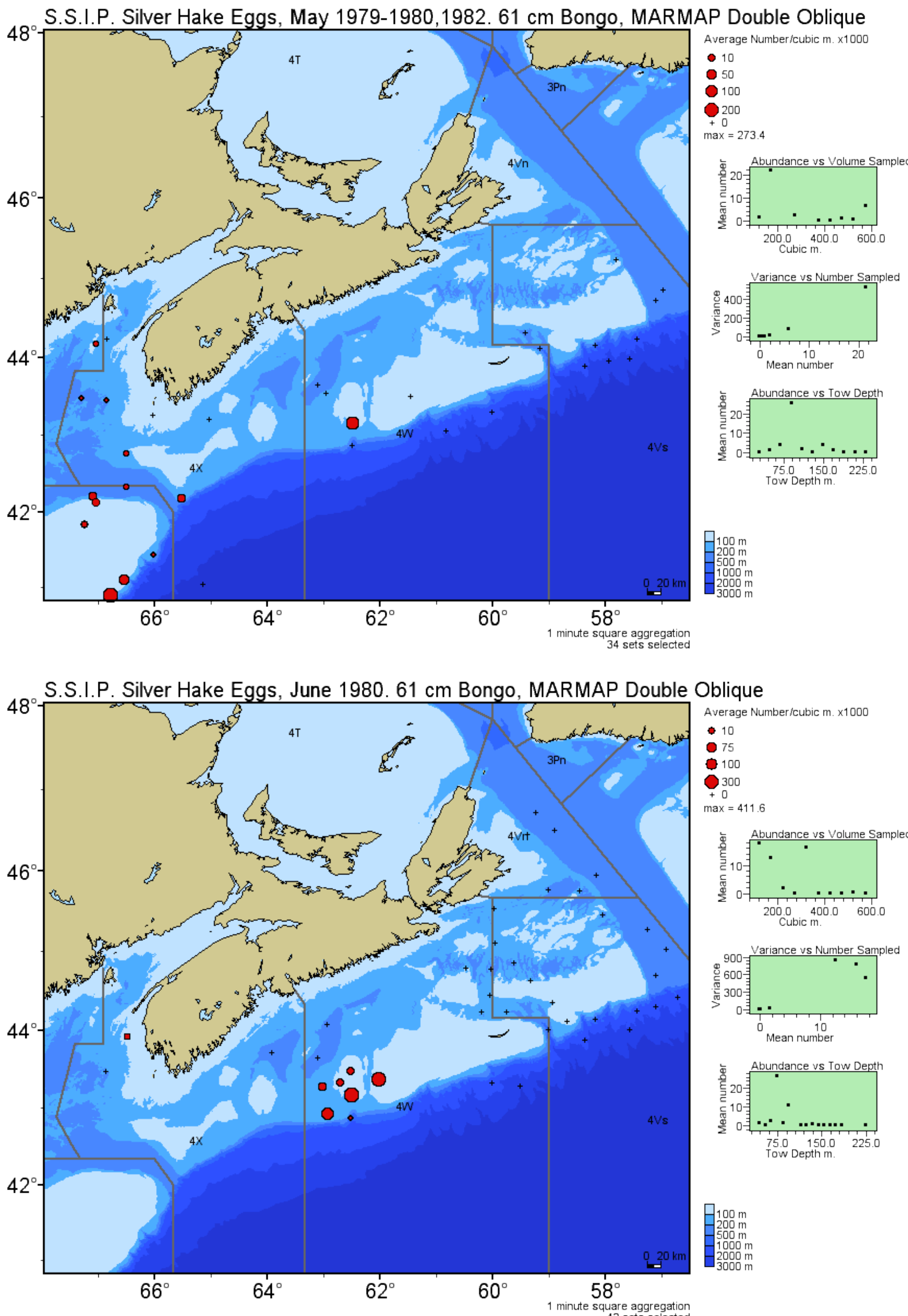


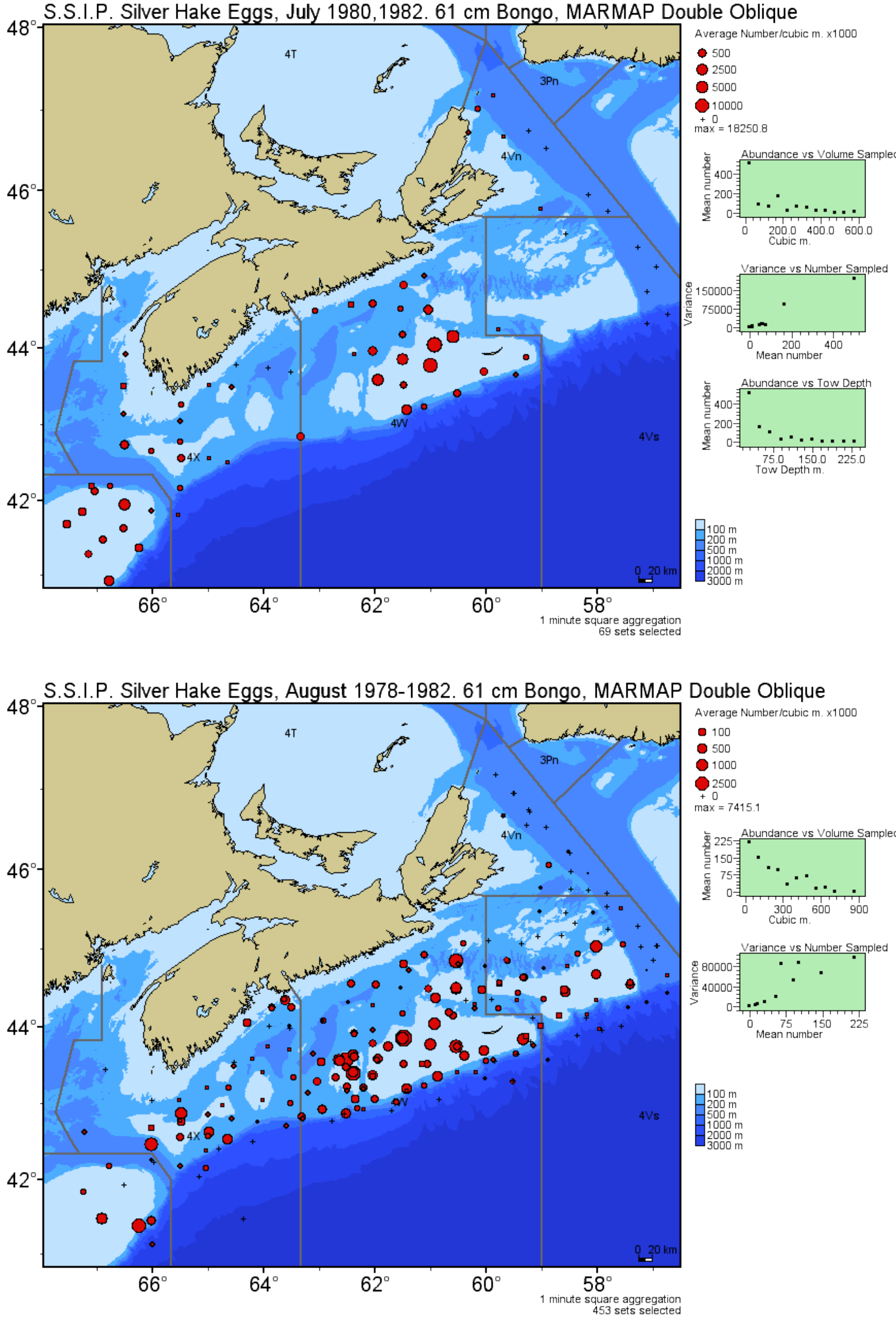
Figure 88. ASAP model Run 12 retrospective patterns for 4VWX silver hake age 1 recruitment (000's) in absolute (top) and relative (bottom) terms.

APPENDIX

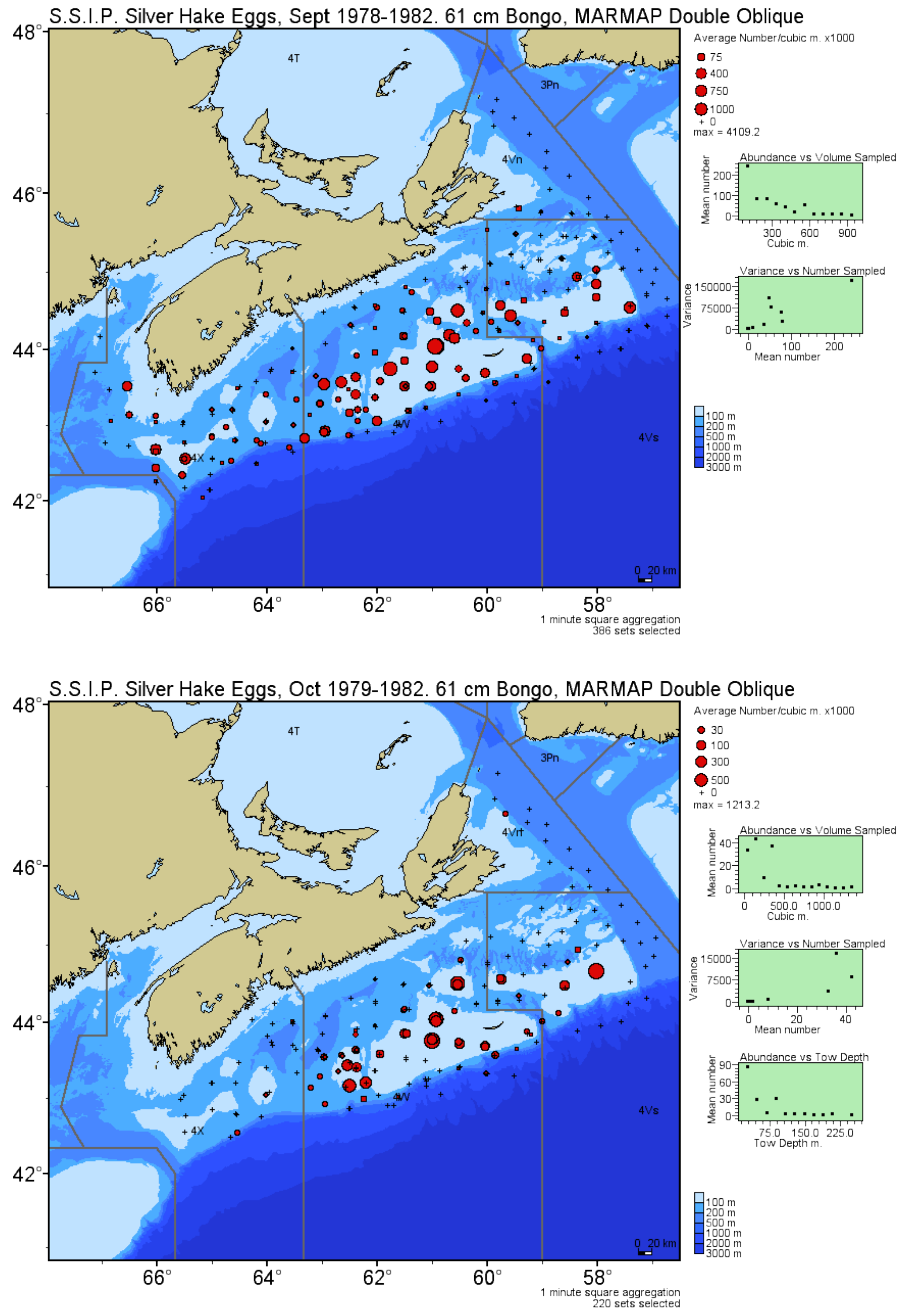
Data on the distribution of silver hake eggs and larvae from 1979 to 1982 from the Scotian Shelf Ichthyoplankton Program (SSIP) database and from 1982 to 1985 from the Fisheries Ecology Program (FEP) database.



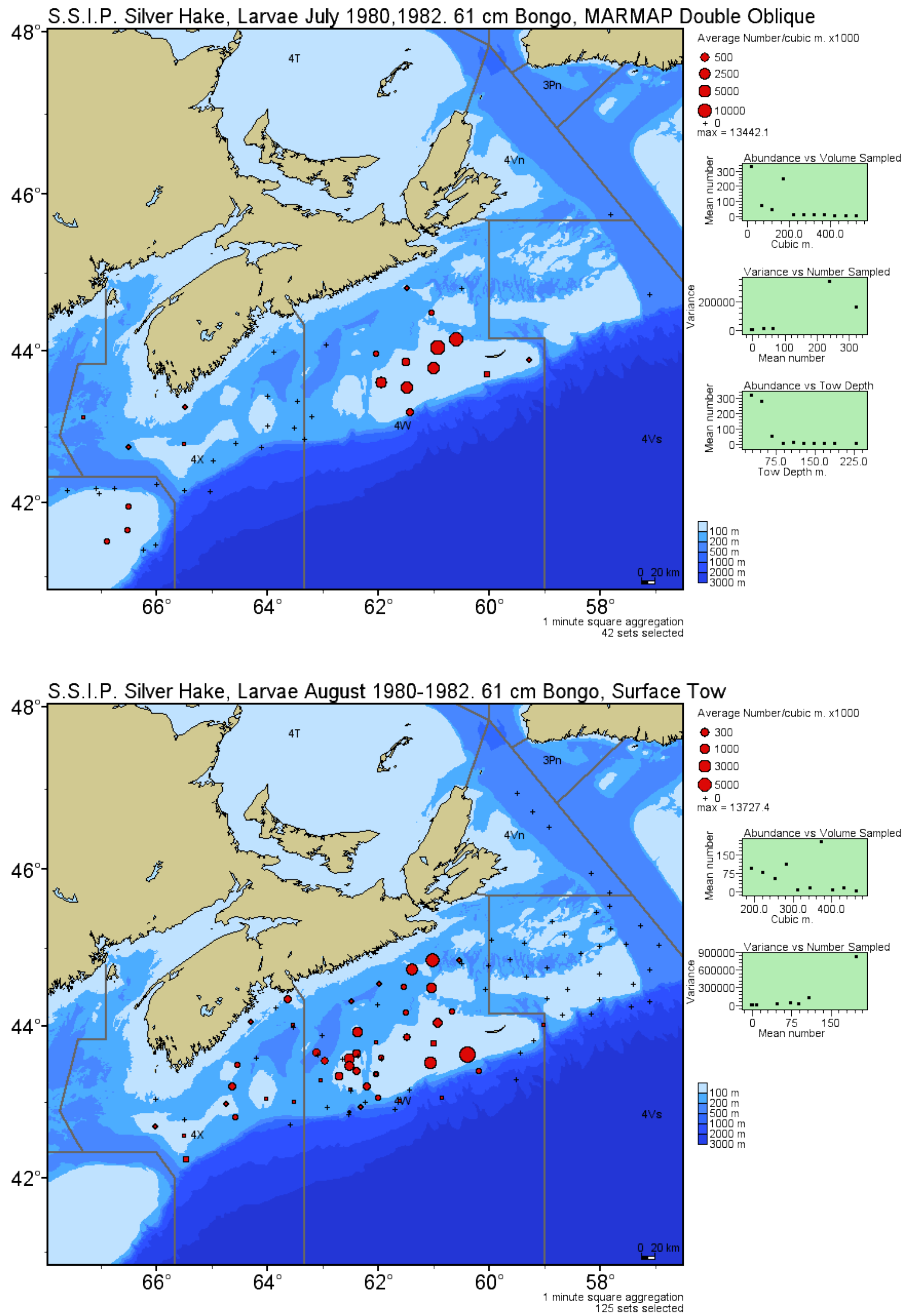
Appendix Figure 1. Distribution of silver hake eggs from the Scotian Shelf Ichthyoplankton Program database in May (top panel) and June (bottom panel), 1979-1980 and 1982.



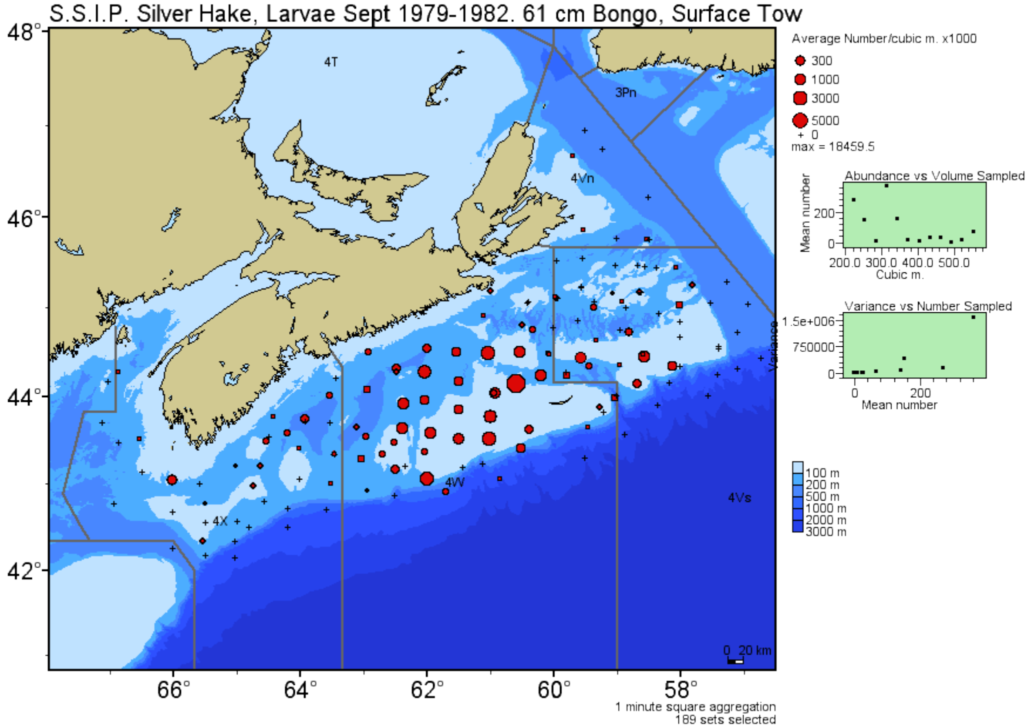
Appendix Figure 1 continued. Distribution of silver hake eggs from the Scotian Shelf Ichthyoplankton Program database in July (top panel) and August (bottom panel), 1978-1982.

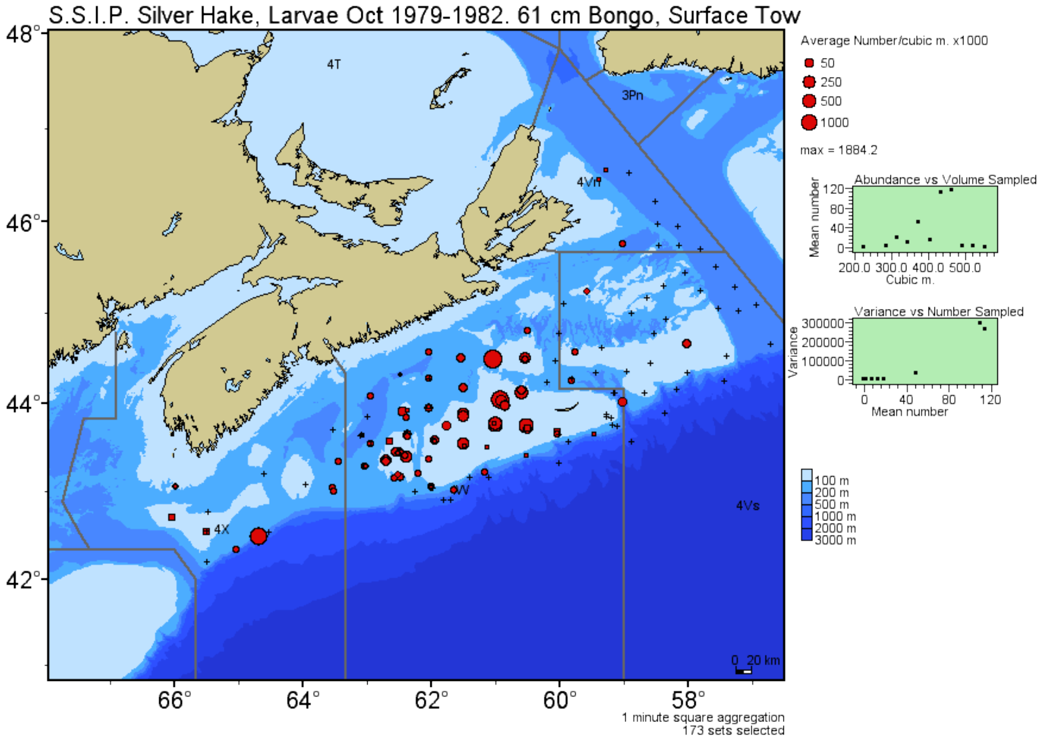


Appendix Figure 1 continued. Distribution of silver hake eggs from the Scotian Shelf Ichthyoplankton Program database in September (top panel) and October (bottom panel), 1978-1982.

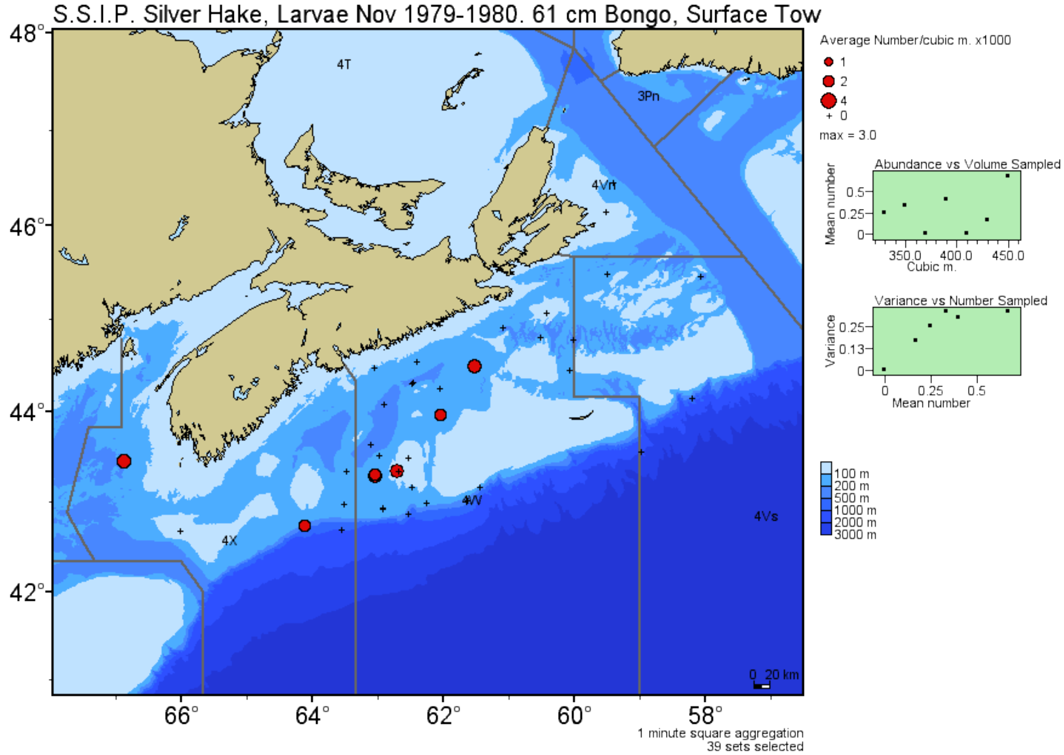


Appendix Figure 2. Distribution of silver hake larvae from the Scotian Shelf Ichthyoplankton Program database in July (top panel) and August (bottom panel), 1980-1982.

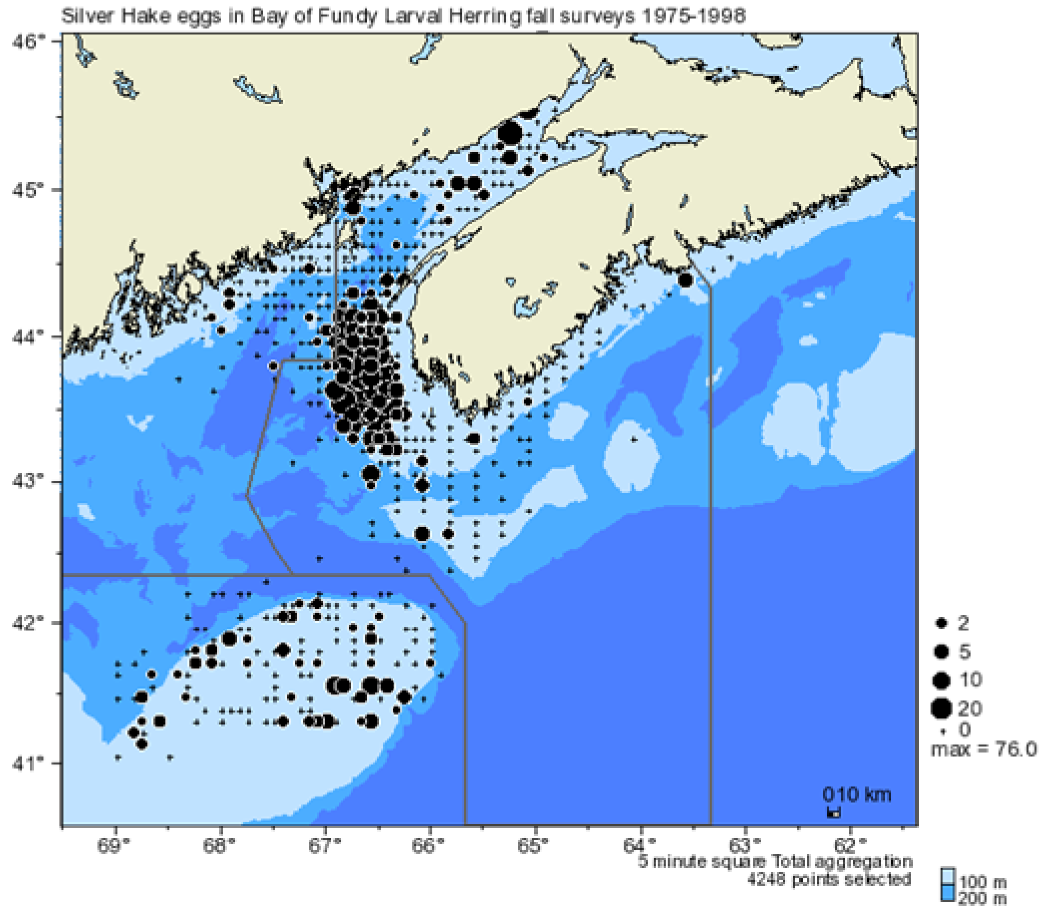




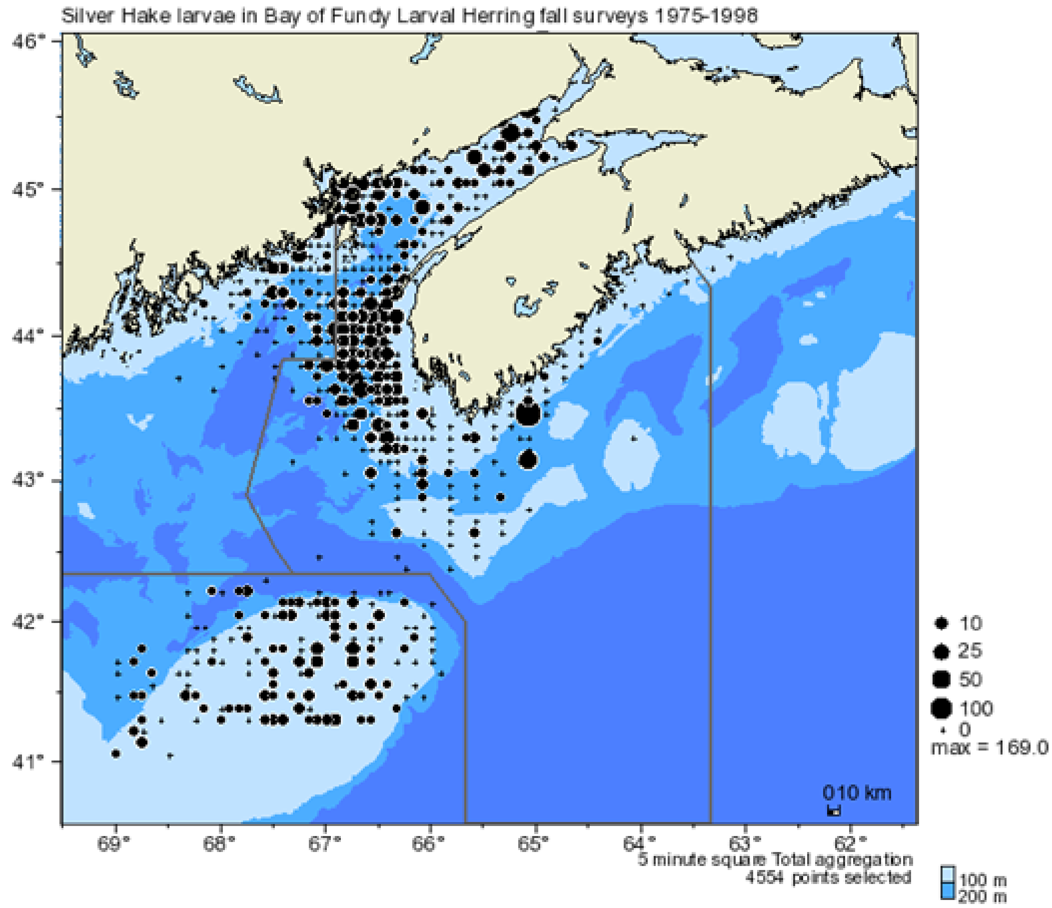
Appendix Figure 2 continued. Distribution of silver hake larvae from the Scotian Shelf Ichthyoplankton Program database in September and October, 1979-1982.



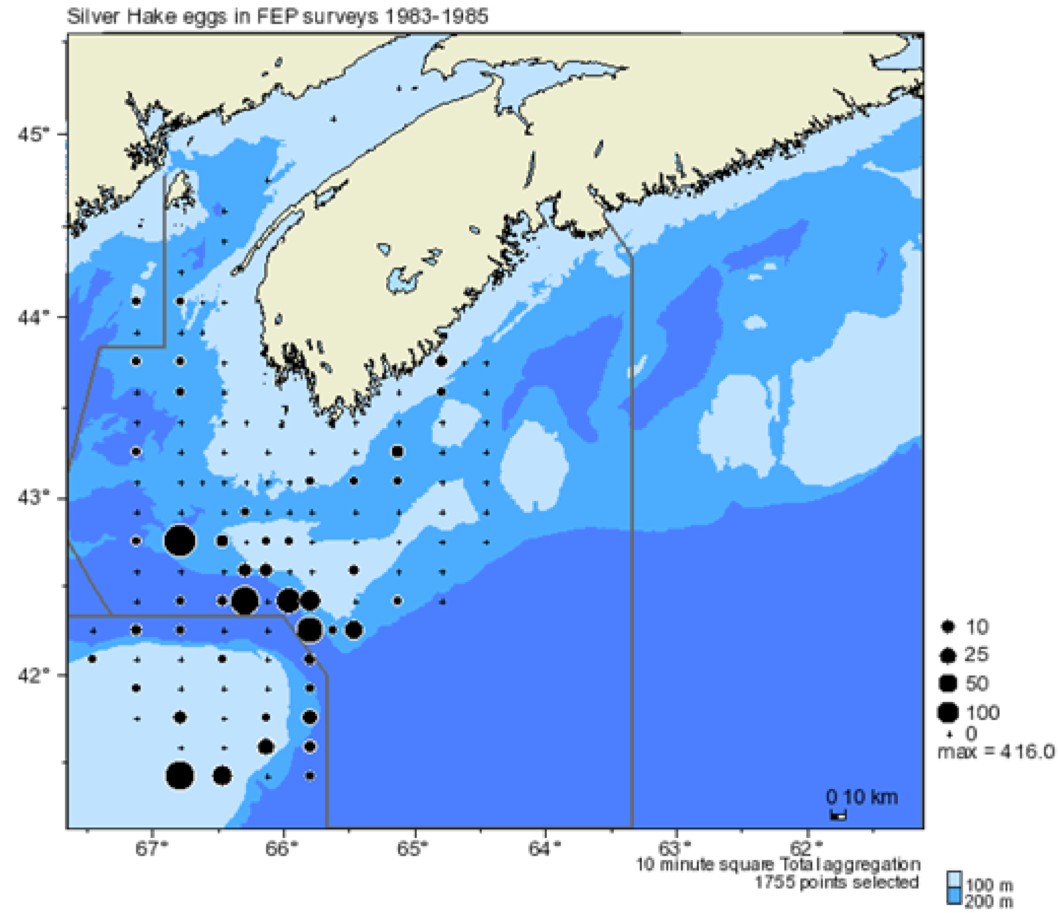
Appendix Figure 2 continued. Distribution of silver hake larvae from the Scotian Shelf Ichthyoplankton Program database in November, 1979-1980.



Appendix Figure 3. Distribution of silver hake eggs from larval herring surveys conducted in the Bay of Fundy and off southwestern Nova Scotia, 1975-1998.

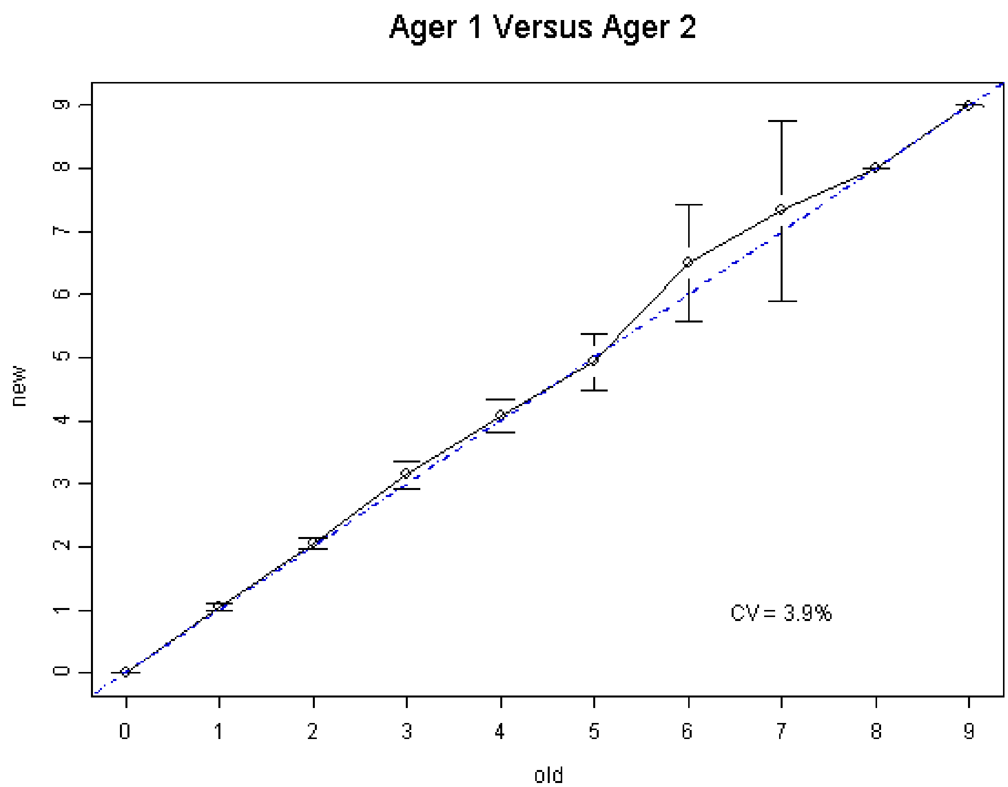


Appendix Figure 4. Distribution of silver hake larvae from larval herring surveys conducted in the Bay of Fundy and off southwestern Nova Scotia, 1975-1998.



Appendix Figure 5. Distribution of silver hake larvae from the Fisheries Ecology Program surveys conducted in 4X and Georges Bank from 1983 to 1985.

Age assigned previously (X axis)	Age assigned this time (Y axis)										
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**
0	9	0	0	0	0	0	0	0	0	0	9
1	0	66	3	0	0	0	0	0	0	0	69
2	0	0	35	2	0	0	0	0	0	0	37
3	0	0	4	23	7	1	0	0	0	0	35
4	0	0	0	3	19	3	1	0	0	0	26
5	0	0	0	0	4	9	1	1	0	0	15
6	0	0	0	0	0	0	2	2	0	0	4
7	0	0	0	0	0	0	0	2	1	0	3
8	0	0	0	0	0	0	0	0	1	0	1
9	0	0	0	0	0	0	0	0	0	1	1
Total	9	66	42	28	30	13	4	5	2	1	200



Appendix Figure 6. Age frequency plot (upper panel) and age bias plot (lower panel) comparing silver hake age interpretations by the primary ager for the 4VWX silver hake stock. Overall agreement was 84% with a CV of 3.9%.