4 CASA Modeling - (TOR 4)

Jui-Han Chang and Deborah R. Hart
Northeast Fisheries Science Center, NMFS/NOAA

Use the appropriate assessment approach to estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Compare the time series of these estimates with those from the previously accepted assessment(s). Evaluate a suite of model fit diagnostics e.g., residual patterns, sensitivity analyses, retrospective patterns), and (a) comment on likely causes of problematic issues, and (b), if possible and appropriate, account for those issues when providing scientific advice and evaluate the consequences of any correction(s) applied.

4.1 General Model Configuration

A catch-at-size-analysis (CASA, Sullivan et al. 1990) has been used as the primary assessment estimation model for US sea scallop assessments since 2007 (NEFSC 2007, 2010, 2014, 2018, and 2020). It performed well in simulation testing using the Scallop Area Management Simulator (SAMS, NEFSC 2010: Appendix XI) as the operating model (NEFSC 2007; Hart et al. 2013). Technical documentation for CASA can be found in TOR4b working paper.

4.1.1 Stock Boundary

The boundaries of the scallop stocks assessed using CASA models are shown in Figure 4.1. Prior to 2014, Georges Bank sea scallops were assessed as a whole. This required using domed fishery selectivity patterns during periods when there was little or no fishing in the closed areas. During these times, large scallops accumulated in the closures, which resulted in lower fishing mortality for large individuals (mainly in the closed areas) compared to intermediate-sized ones (Sampson and Scott 2011). Using simulated and real data, Hart et al. (2013) concluded that splitting Georges Bank into open and closed areas gave more stable and likely more precise results, probably due to problems modeling complicated and ephemeral domed selectivity patterns. Separating the open and closed areas allows the use of simple logistic selectivity models for fishery size composition data, rather than domes. Thus, as in the SARC-59 and SARC-65 assessments (NEFSC 2014 and 2018), separate models were used for Georges Bank's open and closed areas for this assessment. Scallops in the Mid-Atlantic were assessed using a single CASA model. Due to their unique growth patterns and high abundance, the Deep Southeast Nantucket Lightship scallops (DSENLS) were not included in the CASA modeling.

4.1.2 Catch and Survey Data

All three CASA models, Georges Bank open, Georges Bank closed, and Mid-Atlantic, were run from 1975 to 2023. The commercial catch time series was from 1975 to 2023. Commercial size composition data were available for 1975-1984 from port samples and 1992-2023 from sea samples (observers). Survey indices and size composition data began with two years of unlined dredge surveys in 1975 and 1977, followed by the lined dredge survey, which is the longest scallop survey time series from 1979 to 2023; the winter bottom trawl survey from 1992 to 2007 (Mid-Atlantic only); SMAST surveys from 2003 to 2015 using a large video camera and from 2017 to 2023 using a digital camera; and the Habcam survey from 2011 to 2023; with some years of missing surveys varied by survey and stock.

The lined dredge, Habcam, and SMAST digital camera surveys were assumed to have flat selectivity for scallops 40+ mm. Selectivities of the SMAST large camera and unlined dredge were fixed at experimentally determined values (NEFSC 2014; Figure 4.2). The winter bottom trawl survey used flatfish trawl gear similar to commercial scallop trawls and should have caught scallops fairly reliably. Preliminary runs with potentially domed selectivity for the winter bottom trawl survey did not indicate that selectivity was reduced for large scallops, so selectivity was modeled using an ascending logistic curve with parameters fixed at values estimated by the SARC-59 assessment (NEFSC 2014; Figure 4.2).

Catch and survey time series and size compositions were fitted in the CASA model with the assumed CVs (0.05 for catch, and from data for surveys) and effective sample sizes. Effective sample sizes for size composition data were tuned in preliminary model runs so that the median of assumed values used in tuning were similar to expected values based on the goodness of fit. Asymptotic delta method variances calculated in CASA with AD-Model Builder software were used to compute variances and CVs.

4.1.3 Population

CASA models were initialized using the size frequency data observed from the unlined dredge survey conducted in 1975. Shell heights were modeled with 5 mm shell height bins. The modeled population started at 0-5 mm; thus, recruitment was estimated at age 1 (0-35 mm; with no assumed stock-recruitment relationship). As in previous assessments, only scallops larger than 40 mm were used in tuning because smaller scallops were not fully selected by any of the surveys. Population shell height (L) to meat weight (W) conversions used parameters estimated from 2001-2023 survey data:

$$\text{Mid-Atlantic: } W = -9.8076L^{2.784} \tag{1}$$

$$\text{Georges Bank: } W = -10.262L^{2.851} \tag{2}$$

Fishery meat weights were estimated using the above shell height to meat weight conversions and adjusted based on estimated seasonal anomalies from the observer data (1992-2023) and the seasonal distribution of landings in that year. The final (plus) group included L_∞. The meat weights for the plus group bin in a given year was the mean observed weight of scallops in the plus group in the dredge survey for the population, or in port or sea samples for the fishery (Figure 4.3).

4.1.4 Growth

CASA models growth using stochastic growth transition matrices that describe the probabilities for each starting size group to reach new size groups after one year of growth. In SARC-45 and SARC-50 assessments (NEFSC 2007 and 2010), transition matrices were derived directly from shell increment data. This has the advantage of not assuming a specific form of growth, but it requires a large amount of data, and the modeled growth of sizes with few observations may not be reliable. As in SARC-59 and SARC-65 assessments (NEFSC 2014 and 2018), growth matrices were constructed based on von Bertanlaffy growth parameters and their variances among individuals, estimated from growth increment data using mixed-effects models for this assessment (Hart and Chute 2009; Table 4.1). The matrices were constructed by drawing L_∞ and K values from independent normal distributions with means and variances among individuals estimated by the mixed-effect model. One thousand parameters were drawn for each 0.05 mm interval within each 5 mm starting size bin and used to simulate one year of growth. The resulting binned scallop shell heights were converted to proportions that estimate the desired transition probabilities. Transition matrices constructed in this way were smoother, but similar, to matrices derived directly from growth increments prior to 2014. There is evidence that growth has changed over time. To account for this, several growth transition matrices were used to represent growth in different time periods, as in the SARC-65 assessment (Table 4.1; NEFSC 2018).

4.1.5 Natural Mortality and Incidental Fishing Mortality

In the assessments prior to 2018, scallop abundance estimates from the CASA model trended below the surveys when strong recruitment was observed in the surveys (NEFSC 2014). This suggests that the natural mortality of juveniles may increase at high density. If this were the case, CASA model estimates would be below the surveys for those years because observations of the strong year class in subsequent years would indicate fewer scallops than expected based on observed declines in the year class that cannot be accounted for by fishing. High natural mortality on large year classes of juveniles that are not captured in the model would likely induce retrospective patterns as has been observed in previous assessments, where estimates of strong year classes and abundance would decline as more years of data were added. Some experimental evidence suggests higher natural mortality rates in juvenile sea scallops, particularly at high densities. *Cancer* crabs are potential agents of density dependence in juvenile sea scallops as they primarily consume scallops less than 70 mm and rarely eat scallops greater than 90 mm (Elner and Jamieson 1979; Lake et al. 1987).

To differentially model juvenile and adult natural mortality, total natural mortality in the CASA model has the option to be estimated as the sum of juvenile and adult mortality components (Hart and Chang 2022):

$$M(h,y) = \alpha(h)M_{\text{juv}} + [1-\alpha(h)]M_{\text{ad}} \tag{3}$$

where juvenile (M_{juv}) and adult natural mortality (M_{ad}) can be decomposed into their mean values ($\bar{M}_{\text{juv}}$ and $\bar{M}_{\text{ad}}$) and annual deviations from the mean ($\theta(y)$ and $\omega(y)$): $M_{\text{juv}}(y) = \bar{M}_{\text{juv}} + \theta(y)$ and $M_{\text{ad}}(y) = \bar{M}_{\text{ad}} + \omega(y)$. $\alpha(h) = 1 - \dfrac{1}{1+\exp(-a[h-h_0])}$ is a decreasing logistic function, with left asymptote equal to one and right asymptote equal to zero. This logistic function is used to partition natural mortalities between juveniles and adults, thus determining how the natural mortality changes with size. h_0 is the shell height that the total natural mortality started shifting from weighting more on the juvenile component M_{juv} to weighting more on the adult component M_{ad}, and a is the slope to denote the rate of weighting shifting between the juvenile M_{juv} and adult M_{ad} component. h_0 is fixed at 75 mm for this assessment obtained from a likelihood profile analysis, and a is fixed at 0.1 from the SARC-65 assessment (NEFSC 2018; Figure 4.4).

Natural mortality in CASA model can also be estimated annually without varying by size:

$$M(y) = \bar{M} + \gamma(y) \tag{4}$$

where $\bar{M}$ is mean natural mortality (over time) and $\gamma(y)$ is annual deviations from the mean.

The incidental fishing mortality was formulated as a multiplier of fully recruited fishing mortality for each size group in CASA. The incidental fishing mortality multiplier was 0.06 for Mid-Atlantic stocks and 0.11 for Georges Bank stocks (NEFSC 2018).

4.1.6 Survey Catchability

Beta prior probabilities (also known as likelihood constraints) are used to incorporate knowledge regarding absolute scale from the surveys. Priors on survey catchability were applied for the lined dredge, SMAST large camera, SMAST digital camera, and Habcam surveys. These priors were calculated under the assumption that catchability parameters for these surveys follow a beta distribution with a specified mean and CV. The assumed CVs for catchability priors were 0.1-0.15 for SMAST and 0.1 for the dredge and Habcam surveys. The assumed mean for catchability priors was 0.5. The following paragraphs will illustrate the reasoning behind this assumption.

First, to use beta priors, the lined dredge survey data were expanded to absolute abundance assuming flat selectivity, experimentally derived estimates of capture efficiency, and best estimates of stock area and areas swept by the dredge tows (Miller et al. 2018). SMAST large camera survey data were expanded after using the experimentally derived selectivity curve to adjust for the reduced selectivity of small scallops (Figure 4.2). After this adjustment, SMAST large camera abundance and size data were expanded, assuming flat selectivity and 100% capture efficiency. The expansion of the Habcam and SMAST digital camera surveys assumed 100% detectability of scallops >40 mm by the camera.

The catchability parameter estimates could, in principle, be larger or smaller than 1, but beta distributions do not allow values larger than 1. Therefore, the mean of the catchability priors was assumed to be 0.5, and the survey abundance data in the model were multiplied by 0.5 so that the mean of the prior distributions and expected catchability values were 0.5. The parameter is estimated as a symmetrical beta distribution so that the probability of being slightly larger or smaller than the expected value 0.5 is the same. This rescaling is simply for convenience; it replaces the target 1 for catchability by 0.5 with no other effect on model estimates and allows the catchability to be over 1 after being transferred back to the original scale.

The estimated catchability parameters from CASA are useful diagnostics when compared to their priors. An estimated catchability at about 0.5 indicates that the modeled abundance aligns closely with survey indices. In contrast, an estimated catchability over 0.5 suggests that survey indices are above model-estimated abundance and vice versa. In the CASA model, $I = qN$ where I is a survey abundance observation, N is abundance available to the survey, and q is the catchability parameter. Relatively high estimates of q indicate relatively low estimated abundance and vice versa, because abundance $N = \frac{I}{q}$.

The following sections presented the base case model configuration and model results for the three stocks, starting with the Mid-Atlantic models, followed by the Georges Bank closed models. The results from the Mid-Atlantic and Georges Bank closed models were used to inform the natural mortality parameters for the Georges Bank open model. AIC and our knowledge of these stocks were used as the primary tools for model selection. Retrospective analysis, likelihood profiles, and sensitivity analysis were used to describe uncertainties for each stock.

4.2 CASA Model for Mid-Atlantic Areas

4.2.1 MAB Model Configuration

The Mid-Atlantic CASA model was tuned to the unlined dredge survey (1975 and 1977), lined dredge survey (1979-2023), winter bottom trawl survey (1992-2007), SMAST large video camera survey (2003-2012, 2014, and 2015), SMAST digital camera survey (2017 and 2019), and Habcam survey (2012-2023).

The fishery selectivity periods were 1975-1979, 1980-1997, 1998-2001, 2002-2004, and 2005-2023. The first period was modeled as domed (double logistic) selectivity due to indications in the data of higher mortality on intermediate-sized scallops. The domed selectivity was likely caused by fishing efforts concentrating on only a portion of the stock, with most large scallops outside the intensively fished area (Samson and Scott 2011). All the other periods were assumed to have a logistic selectivity.

The growth matrices for the Mid-Atlantic stock were estimated using 6,600 shells collected between 1982 and 2023. Four discontinuous growth periods were used, with the slowest growth for period 1 and the fastest growth for period 4 (Table 4.1):

- matrix 1: 1990-1999
- matrix 2: 1975-1978, 1984-1989, 2000-2003, 2016-2018
- matrix 3: 1979, 1982, 1983, 2004-2008, 2014, 2015, 2019, 2020
- matrix 4: 1980, 1981, 2009-2013, 2021-2023

Natural mortality was fixed at 0.2 (0.3 for the plus group) in the SARC-59 assessment (NEFSC 2014), but estimated by size and year in the SARC-65 assessment (NEFSC 2018). The mean juvenile and adult natural mortalities for the Mid-Atlantic models were not estimated and set at 0.25 in the SARC-65 assessment, based on the natural mortality estimated for the Georges Bank closed stock from that assessment (NEFSC 2018). The annual deviations of juvenile natural mortality were estimated in the model, but not for the adults. The logistic curve used to partition natural moralities for juveniles and adults was not estimated and set at $h_0 = 70$ mm (equivalent to the average size at about age 2.5) and a slope of $a = 0.1$.

For this assessment, the annual deviations of juveniles and adults were both estimated in the model to account for the increase in adult natural mortality observed in multiple surveys in recent years, likely due to the increase in seawater temperature in this region (see TOR1 working papers). Based on the result of profiling over various mean natural mortalities and h_0 for this stock, the mean natural mortality for both juveniles and adults was set at 0.4, and the parameters for the logistic curve used to partition juvenile and adult natural mortality was $h_0 = 75$ mm and $a = 0.1$ (Figure 4.4). The 0.4 of mean natural mortality assumed in the CASA model was comparable with the natural mortalities estimated using life history parameters for this stock (independent of CASA, see Life History working paper).

4.2.2 MAB Model Result

The base case model converged (gradient 1.2×10^{-5}), and the Hessian matrix was positive definite. The model fit catch and survey indices well without apparent residual patterns (Figures 4.5 to 4.8). Mean estimated posterior survey catchabilities were 0.53 for the dredge, 0.58 for SMAST large camera, 0.57 for Habcam, and 0.65 for SMAST digital camera surveys (relative to the beta prior target 0.5; Figure 4.9), indicating that CASA abundance estimates were close but slightly lower than the survey indices on average (Figure 4.10). The effective sample sizes assumed for the fishery and surveys for the Mid-Atlantic stock are in Figure 4.11. Model estimates of shell heights generally fit the data for both fishery and surveys (Figures 4.12 to 4.18). No serious trends in residuals were observed (Figures 4.19 to 4.25).

The mean estimated natural mortalities were 0.42 for all years and sizes (Figure 4.26), whereas the mean was 0.26 and 0.27 for SARC-65 and updated SARC-65 assessments, respectively (NFFSC 2018 and 2020). The average natural mortality for the small size groups (0-30 mm) increased around 2003 (averaged 0.5) and 2012 (averaged 0.65) when large juvenile year classes were observed (Figure 4.27). The large size groups (75-135 mm) have had higher natural mortality since 2016; the average natural mortality for 75-135+ mm scallops was 0.4 before 2016 and 0.58 from 2016 to 2023. Elevated natural mortality for these years is consistent with the declines observed in multiple surveys in the Mid-Atlantic in recent years.

CASA estimated fishing mortality was consistent in scale with the Beverton-Holt (1956) length-based equilibrium estimator, which is used as a diagnostic tool for the CASA model (Figure 4.28). Fishery selectivity was strongly domed during 1975-1979 but shifted to a logistic shape and moved further to the right during subsequent periods, as would be expected based on management and fishery changes (Figure 4.29). By 2005-2023, only the plus group was fully selected (Figure 4.29). The estimated fishing mortality on larger scallops generally increased from 1975 to 1995, reaching a maximum fully recruited fishing mortality of 0.93 in 1978, then declining (Figure 4.30). This decline was much more significant for small scallops, which were affected by the shifting selectivity as well as the decline in fully recruited fishing mortality (Figures 4.30 and 4.31). Total mortality, estimated by the sum of instantaneous fishing and natural mortality, suggested that the adults are subject to more mortality than the juveniles for the Mid-Atlantic stock, even during the periods of strong recruitment events (Figure 4.32).

CASA estimated abundance and biomass aligned well with survey observations (Figure 4.10). Abundance and biomass were relatively low during 1975-1997, rapidly increased from

1998-2003, declined during 2009-2011 due to poor recruitment compared to previous years, increased dramatically again in 2015, primarily driven by the strong recruitment in 2014, and then have been declining since (Figures 4.10 and 4.33). Recruitment appears to have been substantially stronger from 1998 to 2016 (Figure 4.33). The model correctly identified the two high recruitment events in 2002 and 2014, which subsequently contributed to the increase in the population (Figures 4.33 and 4.34). However, poor recruitments were estimated (and observed as well) after 2016, back to the state around the 1980s (Figure 4.33). Estimated biomass and fully recruited fishing mortality for the terminal year 2023 were 20,556 mt meats and 0.06, respectively (Table 4.2). The Mid-Atlantic model shows minor retrospective patterns from a 7-year peel retrospective analysis (Mohn's $\rho = 0.14$ for biomass and 0.04 for fishing mortality; Figure 4.35).

4.2.3 MAB Likelihood Profile Analysis

The following parameters were simultaneously profiled over a range of values:

- model starting size: 0 mm to 25 mm, by 5 mm increment
- mean natural mortality for juveniles and adults: 0.15 to 0.5, by 0.05 increment
- h_0: 50 mm to 90 mm, by 5 mm increment

The resulting total negative log likelihoods are shown in Figure 4.36. Among all the parameters tested, model starting size has the most influence on the model performance, followed by mean natural mortality, and lastly, h_0. The model favored starting at a smaller size, likely because the recruitment can then be estimated at age 1, which could be helpful when large recruitment events and high juvenile natural mortality occur. The model starting at size 0-5 mm produced the smallest total likelihood and was chosen as the base case model configuration.

The models performed better with higher mean natural mortality and a larger h_0; the best run was 0.5 and 90 mm, respectively. The mean natural mortality selected for the base case model was 0.4, based on likelihood profiling indicating that this stock favors larger natural mortality and reviewing the natural mortalities calculated using life history parameters for this stock (independent of CASA, see Life History working paper). Even though h_0 has a smaller influence on the total likelihood, different values of h_0 resulted in different trends in natural mortalities by size. We examined the model results from runs with various h_0 values and chose $h_0 = 75$ mm based on our best understanding of this stock.

4.2.4 MAB Sensitivity Analysis

A bridge model run was conducted using the SARC-65 CASA model configuration (mean natural mortality for juveniles and adults is 0.25, estimating juvenile but not adult natural mortality) with data updated through 2023. The bridge model underestimated the abundance and biomass compared to the dredge survey, similar to previous assessments (NEFSC 2018; Figure 4.37). Increasing the mean natural mortality for juveniles and adults to 0.4 without estimating the adult natural mortality improved but still slightly underestimated the abundance and biomass (Figure 4.37). The base case model, in which the mean natural mortality for juveniles and adults was increased to 0.4, and juvenile and adult natural mortalities were both estimated in the model, produced the abundance and biomass estimates that are the most in line with the dredge survey (Figure 4.37). The sensitivity runs conducted for Mid-Atlantic stock have minimal effects on terminal years' estimates (Figures 4.37).

4.3 CASA Model for Georges Bank Closed Areas

4.3.1 GB Closed Model Configuration

The Georges Bank closed model was tuned to the unlined dredge survey (1975 and 1977), lined dredge survey (1979-2023), SMAST large video camera survey (2003-2012, 2014, and 2015), SMAST digital camera survey (2017, 2021-2023), and Habcam survey (2011-2019, 2021, and 2022). The Habcam survey data were combined with SMAST digital camera survey data to produce a complete abundance index and size frequency for the Georges Bank closed area in 2019.

The fishery selectivity periods were 1975-1998, 1999-2016, 2017, 2018, 2019, 2020-2021, and 2022-2023. Several fishery selectivity periods were implemented in recent years, as different closed areas with various scallop sizes were opened to fishing. The 2019 and 2022-2023 periods were modeled as domed (double logistic) selectivity due to large fishing in the west portion of Nantucket Lightship Area and Closed Area II, respectively, targeting intermediate-sized scallops. All the other periods were assumed to have a logistic selectivity.

The growth matrices for the Georges Bank closed stock were estimated using 116,54 shells collected between 1982 and 2023. Two discontinuous growth periods were used, with slower growth for period 1 and faster growth for period 2:

- matrix 1: 1986-1997, 2015-2023
- matrix 2: 1975-1985, 1998-2014

Natural mortality was fixed at 0.16 (0.24 for the plus group) in the SARC-59 assessment (NEFSC 2014), but estimated by year (not by size) in the SARC-65 assessment (NEFSC

2018). Estimation of size-varying natural mortalities was explored during preliminary model runs from this assessment, but the results were unrealistic for this stock. Therefore, as with the SARC-65 assessment (NEFSC 2018), the natural mortality for the Georges Bank closed stock was estimated annually without varying by size.

4.3.2 GB Closed Model Result

The base case model converged (gradient 1.8×10^{-5}) and the Hessian matrix was positive definite. The base case model fits catch and survey indices reasonably well with no obvious residual patterns (Figures 4.38 to 4.41). Mean estimated posterior survey catchabilities were 0.54 for the dredge, 0.61 for SMAST large camera, 0.59 for Habcam, and 0.73 for SMAST digital camera surveys (relative to the prior target 0.5; Figure 4.42), indicating that CASA abundance estimates were slightly lower than the survey indices on average, especially for the SMAST digital camera survey (Figure 4.43). The effective sample sizes assumed for the fishery and surveys for the Georges Bank closed stock are in Figure 4.44. Model estimates of shell heights generally fit the data for both fishery and surveys (Figures 4.45 to 4.50). No serious trends in residuals were observed (Figures 4.51 to 4.56).

The estimated mean natural mortality by year is 0.27 (Figure 4.57), whereas the mean was 0.23 for the SARC-65 and updated SARC-65 assessments (NFFSC 2018 and 2020). Peak natural mortality was estimated at 0.81 for 2018, followed by 0.49 for 2010 (Figure 4.57). These years coincide with observations of gray meat disease, particularly in Closed Area I (Levesque et al. 2016), as well as the disappearance of scallops in the west portion of the Nantucket Lightship Area observed from multiple surveys.

Fishery selectivity since 1998 has shifted strongly towards large scallops (Figure 4.58), even more so than in the open areas because scallopers often target the largest market category (U-10s), which typically commands a price premium. However, the fisheries have been catching smaller scallops lately, mainly because scallop growth in some high-density areas (e.g., Nantucket Lightship West areas) was slower than commonly observed on the Georges Bank. Fishery selectivity was strongly domed during 2019 and 2022-2023, especially in 2019, when the estimated fishing mortality for the 100 mm scallops was higher than that for the 120 mm scallops (Figure 4.59). CASA estimated fishing mortality was consistent in scale with the Beverton-Holt (1956) length-based equilibrium estimator (Figure 4.60). Estimated fishing mortalities increased from 1975 to 1993 and were low or zero afterward until 2019, when the Nantucket Lightship Closed Areas opened to fishing (Figure 4.61). This resulted in increased biomass during 1994-2004 and a build-up of large scallops in the closed areas (Figures 4.43 and 4.62).

CASA estimated abundance and biomass aligned reasonably well with survey observations (Figure 4.43). Abundance and biomass were relatively low during 1975-1997, increased from 1998-2003, declined during 2004-2014 due to poor recruitment compared to previous years, and increased dramatically in 2015 (Figures 4.43 and 4.63). Maximum abundance occurred in 2015 (5,143 million) and biomass in 2016 (84,764 mt meats), primarily driven by the strong 2012 year class (Figure 4.43). The estimated recruitment was highest in 2013 when the strongest recruitment event was observed in this area (Figure 4.63). Estimated biomass and fully recruited fishing mortality for the terminal year 2023 were 28,883 mt meats and 0.47, respectively (Table 4.3). The Georges Bank closed model exhibits moderate retrospective patterns from a 7-year peel retrospective analysis (Mohn's $\rho = 0.4$ for biomass and -0.11 for fishing mortality; Figure 4.64), where estimates of biomass decrease as more years of data are added, particularly for 2016-2018. The retrospective pattern disappeared after 2019 as more data on the strong year classes became available.

4.3.3 GB Closed Sensitivity Analysis

A bridge model run was conducted using the SARC-65 CASA model configuration with data updated through 2023. Although the abundance and biomass from the two runs were similar, the trend in fishing mortality from 2019 to 2023 was different (Figure 4.65). Terminal year fishing mortality from the bridge model was about 35% lower than the base case model (Figure 4.65). This is likely because the domed-shaped fishery selectivity used in 2019 was extended to 2023 for the bridge model, resulting in poor fits for the catch size frequency for these years (NEFSC 2018; Figure 4.66). Adding the fishery selectivity blocks for 2017, 2020-2021, and 2022-2023 enhanced the model fit for the catch data and resulted in more reliable fishing mortality estimates (Figure 4.66). The natural mortality estimates were more realistic as well (no spikes in 2015) after the fishery selectivities and size frequency estimates were anchored (Figure 4.57). The implemented selectivity blocks aligned with actual fisheries management practices, as only portions of the closed areas were opened to fishing.

Sensitivity runs were conducted to estimate natural mortality by size for the Georges Bank closed stock. The resulting abundance and biomass estimates from this sensitivity run were slightly closer to the dredge survey than the base case model estimates (Figure 4.67). However, the estimated juvenile natural mortality for the first year, 1975, was unrealistically high (over 3); therefore, this model was not recommended for the base case model configuration.

4.4 CASA Model for Georges Bank Open Areas

4.4.1 GB Open Model Configuration

The Georges Bank open model was tuned to the same surveys as the Georges Bank closed models. The fishery selectivity periods were 1975-1998, 1999-2004, and 2005-2023. Logistic selectivities were assumed for all periods.

The growth matrices for the Georges Bank open stock were estimated using 116,54 shells collected between 1982 and 2023. Two discontinuous growth periods were used, with slower growth for period 1 and faster growth for period 2:

- matrix 1: 1987-1990, 2011-2023
- matrix 2: 1975-1986, 1991-2010

As for Georges Bank closed stock, natural mortality was fixed at 0.16 (0.24 on the plus group) in the SARC-59 assessment (NEFSC 2014). In the SARC-65 assessment (NEFSC 2018), the mean natural mortality for juveniles and adults was not estimated and was fixed at 0.2 based on the natural mortality estimated for the Georges Bank closed stock. The value of 0.2 was used instead of 0.23 because a portion of the estimated natural mortality in the closed areas may be aliasing for other processes, including poaching, high-grading practices, and effects of spatially heterogeneous fishing mortality (Hart 2001; Truesdell et al. 2015). The annual deviations of juvenile natural mortality were estimated in the model, but not for the adults. The logistic curve used to partition juvenile and adult natural mortalities was not estimated and set at $h_0 = 65$ mm (equivalent to the average size at about age 2.5) and $a = 0.1$.

For this assessment, same as the SARC-65 assessment (NEFSC 2018), the annual deviations of juvenile natural mortality were estimated in the model, but not for the adults. Estimation of annual deviations of adult natural mortality was explored during preliminary model runs but was not proposed for this assessment, as the results were unrealistic for this stock. The mean natural mortality for juveniles and adults was not estimated and was set at 0.27 based on the natural mortality estimated from the Georges Bank closed stock. The parameters for the logistic curve used to partition juvenile and adult natural mortality were $h_0 = 75$ mm and $a = 0.1$ based on the likelihood profile analysis for the Mid-Atlantic stock (Figure 4.4).

4.4.2 GB Open Model Result

The base case model converged (gradient 1.7×10^{-5}) and the Hessian matrix was positive definite. The base case model fits catch (Figures 4.68 and 4.69), and generally fits survey indices except when high abundances were observed (Figures 4.70 and 4.71). Mean estimated posterior catchabilities were 0.58 for the dredge, 0.76 for SMAST large camera, 0.56 for Habcam, and 0.81 for SMAST digital camera surveys (relative to the beta prior target 0.5; Figure 4.72), indicating that CASA abundance estimates were slightly lower than the survey indices on average, especially for the SMAST surveys (Figure 4.73). The effective sample sizes assumed for the fishery and surveys for the Georges Bank open stock are in Figure 4.74. Model estimates of shell heights generally fit the data for both fishery and surveys (Figures 4.75 to 4.80). No serious trends in residuals were observed (Figures 4.81 to 4.86).

The mean estimated natural mortalities were 0.3 for all years and sizes (Figure 4.87), whereas the mean was 0.21 and 0.22 for the SARC-65 and updated SARC-65 assessments, respectively (NFFSC 2018 and 2020). The average natural mortality for the small size groups (0-30 mm) increased in 2014 (averaged 1.88) and 2015 (averaged 2.37) when a large juvenile year class was observed in the line dredge and Habcam surveys in 2014, much of which was not observed in subsequent years (Figure 4.88).

CASA estimated fishing mortality was consistent in scale with the Beverton-Holt (1956) length-based equilibrium estimator (Figure 4.89). Fishery selectivity strongly shifted over time toward larger shell heights, reflecting changes in gear and targeting practices (Figure 4.90). The size at 50% selectivity moved from about 75 mm before 1999, to 90 mm during 1999-2004, and then 100 mm since 2005 (Figure 4.90). Abundance and biomass generally declined, and fishing mortality increased during 1975-1999, with these trends reversing after 1999 (Figures 4.73 and 4.91). As a result of the changes in selectivity and fully recruited fishing mortality, survival to large shell heights has increased in recent years (Figures 4.92 and 4.93). Total mortality, estimated by the sum of instantaneous fishing and natural mortality, suggested that the adults are subject to more mortality than the juveniles for the Georges Bank open stock, except during the period of the strong recruitment events (Figure 4.94).

CASA estimated abundance and biomass were at the lower end of the survey observations before 2002, but the fits improved thereafter (Figure 4.73). The estimated recruitment was highest in 2014, when the strongest recruitment event was observed in this area (Figure 4.95). Estimated biomass and fully recruited fishing mortality for the terminal year 2023 were 20,517 mt meats and 0.47, respectively (Table 4.4). The Georges Bank Open model shows minor retrospective patterns from a 7-year peel retrospective analysis (Mohn's $\rho = -0.1$ for biomass and 0.23 for fishing mortality; Figure 4.96).

4.4.3 GB Open Sensitivity Analysis

A bridge model run was conducted using the SARC-65 CASA model configuration with data updated through 2023. Both models underestimated the abundance and biomass compared to the dredge survey; however, the underestimation was worse for the bridge model (Figure 4.97). The improvement in model fits from the base case model is primarily from increasing the mean natural mortality for juveniles and adults from 0.2 to 0.27.

Sensitivity runs on various mean natural mortality assumptions (0.25 to 0.4, by 0.05) showed that as mean natural mortality increases, estimated abundance and biomass increase (Figure 4.98). Two additional sensitivity runs were conducted to estimate adult natural mortality, using 0.25 and 0.3 as the mean natural mortality for both juveniles and adults (Figure 4.99). The estimated abundance and biomass from these runs were closer to the dredge survey than the base case model estimates; however, the estimated adult natural mortality was as high as or even higher than that of juveniles for 2015, which is unrealistic. Therefore, the base case model did not estimate adult natural mortalities. All the sensitivity runs conducted for Georges Bank open models have minimal effects on terminal years' estimates (Figures 4.97 to 4.99).

4.5 CASA Model for Combined Georges Bank Closed and Open Areas

Biomass and fishing mortality estimates for Georges Bank open and closed combined (Figure 4.100) show generally low biomass and high fishing mortality from 1975 to 1994, with a peak fishing mortality of 1.54 and a minimum biomass of 8,636 mt meats in 1992. Fishing mortality since 1995 has generally been between 0.2 and 0.4, until 2018 when fishing mortality started to increase (Tables 4.3 and 4.4; Figure 4.100). The estimated terminal fully recruited fishing mortality for Georges Bank open and close stocks combined was 0.47.

Biomass increased substantially between 1994 and 2003 and increased further in 2013 (Figure 4.100). However, biomass has declined significantly since 2016 (Figure 4.100). The estimated terminal biomass for Georges Bank open and close stocks combined was 49,400 (Tables 4.3 and 4.4). Retrospective scores for the combined Georges Bank stocks were similar to the scores for the individual regions (Mohn's $\rho = 0.27$ for biomass and -0.07 for fishing mortality; Figure 4.101).

4.6 Whole Stock Biomass, Abundance, and Mortality

Biomass, SSB, abundance, recruitment, and fishable mean abundance were estimated for the whole stock by adding the estimates for the Mid-Atlantic and Georges Bank open and closed (Table 4.5). For example, whole stock fishing mortality rates for each year were calculated as:

$$F = \frac{C_{MA} + C_{Go} + C_{Gc}}{\bar{N}_{MA} + \bar{N}_{Go} + \bar{N}_{Gc}}, \tag{5}$$

where C_{MA}, C_{Go}, and C_{Gc} are catch (in numbers) for the Mid-Atlantic, Georges Bank open, and Georges Bank closed areas, respectively. Terms in the denominator are average fishable abundances during each year calculated in the CASA model as:

$$\bar{N} = \sum_{L} \frac{N_L(1 - e^{-Z_L})}{Z_L} \tag{6}$$

where L is length bin, N is abundance, and Z is total mortality. The simple ratio formula used to calculate whole stock F is an "exact" solution because the catch equation can be written as $C = F\bar{N}$. Whole stock variances were calculated assuming that estimation errors for Georges Bank open and closed and the Mid-Atlantic were independent. In particular, variances for biomass, abundance, and catch estimates were the sum of the variances for the Georges Bank open and closed and Mid-Atlantic. CVs for the ratios estimating whole stock F were approximated by:

$$CV_F = \sqrt{CV_C^2 + CV_{\bar{N}}^2}, \tag{7}$$

which is exact if catch number C_N and average abundance $\bar{N}$ are independent and lognormally distributed (Deming 1960). The CV for measurement errors in catch for each region $CV_C = 0.05$ is the same as assumed in fitting the CASA model. The CV for the stock as a whole depends on the assumption that model errors in Georges Bank and the Mid-Atlantic are independent.

As in the individual models, whole-stock fishing mortality generally increased from 1975 to 1992, then declined strongly from 1992 to 1995, and has remained low but increased in recent years (Figure 4.100). The trend in whole-stock abundance and biomass is more or less the reverse of the trend in fishing mortality but with higher variations (Figure 4.100). Whole stock biomass, abundance, and fishing mortality in the terminal year 2023 were 69,956 mt meats, 5,112 million scallops, and 0.33, respectively (Table 4.5), not including the DSENLS scallops in Georges Bank. Adding the DSENLS scallop estimates from the Habcam survey, the 2023 total stock estimates are 70,140 mt meats and 5,129 million scallops. The 2016 biomass and 2015 abundance were the highest of the 1975-2023 time series (Figure 4.100). Retrospective scores for the entire sea scallop stock were mild (Mohn's $\rho = 0.17$ for biomass and -0.09 for fishing mortality; Figure 4.102).

The standard errors estimated by the CASA model in this assessment are too small and do not capture all of the underlying uncertainties (Figure 4.103). In particular, the uncertainties calculated by CASA are based on the underlying assumptions that the model is exactly correct. The CASA model is a simplification of reality, and many processes are simplified. It is also possible that the survey catchability estimates near the bounds of their priors artificially reduce variances. Comparisons with expanded survey data, retrospective analysis, likelihood profiles, and sensitivity analysis are better tools for describing the uncertainties in the assessment.

4.7 Comparison of Assessments

The current CASA model estimated abundance, biomass, and fishing mortality were compared to those from the last five assessments (SARC-45/NEFSC 2007, SARC-50/NEFSC 2010, SARC-59/NEFSC 2014, SARC-65/NEFSC 2018, and updated SARC-65/NEFSC 2020) and lined dredge survey (Figure 4.104). While the model performance in Georges Bank was relatively stable and slightly improved by this assessment (with less bias in the earlier years' abundance and biomass estimates), noticeable improvements were made for the Mid-Atlantic model, which no longer produces estimates that are trended low.

4.8 References

Deming WE (1960) Sample design in business research. Wiley & Sons, Inc. New York. 517p

Elner RW, Jamieson GS (1979) Predation of sea scallops, *Placopecten magellanicus*, by the rock crab, Cancer irroratus, and the American lobster, *Homarus americanus*. J Fish Res Board Can 36: 537-543

Hart DR, Chang JH (2022) Estimating natural mortality for Atlantic Sea scallops (*Placopecten magellenicus*) using a size-based stock assessment model. Fish Res 254: 106423.

Hart DR (2001) Individual-based yield-per-recruit analysis, with an application to the Atlantic sea scallop, *Placopecten magellanicus*. Can J Fish Aquat Sci 58: 2351-2358

Hart DR, Chute AS (2009) Estimating von Bertalanffy growth parameters from growth increment data using a linear mixed-effects model, with an application to the sea scallop *Placopecten magellanicus*. ICES J Mar Sci 66: 2165-2175

Hart DR, Jacobson LD, Tang J (2013) To split or not to split: Assessment of Georges Bank sea scallops in the presence of marine protected areas. Fish Res 144: 74-83

Lake NCH, Jones MB, Paul JD (1987) Crab predation on scallop (*Pecten maximus*) and its implication for scallop cultivation. J Mar Biol Assoc UK 67: 55-64

Miller TJ, Hart DR, Hopkins K, Vine NH, Taylor R, York AD, Gallager SM (2018) Estimation of the capture efficiency and abundance of Atlantic sea scallops (*Placopecten magellanicus*) from paired photographic-dredge tows using hierarchical models. Can J Fish Aquat Sci 76(6): 847-855

NEFSC (2007) 45th Northeast Regional Stock Assessment Workshop (45th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc 07-16, Woods Hole, MA

NEFSC (2010) 50th Northeast Regional Stock Assessment Workshop (50th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc 10-17, 844p, Woods Hole, MA

NEFSC (2014) 59th Northeast Regional Stock Assessment Workshop (59th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc 14-09, 782p, Woods Hole, MA

NEFSC (2018) 65th Northeast Regional Stock Assessment Workshop (65th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc 18-11, Woods Hole, MA https://doi.org/10.25923/zapm-ga75

NEFSC (2020) Sea Scallop Management Track Assessment Fall 2020. https://doi.org/10.25923/6g5w-c636

Sampson DB, Scott RD (2011) A spatial model for fishery age-selection at the population level. Can J Fish Aquat Sci 68(6): 1077-1086

Sullivan PJ, Lai HL, Gallucci VF (1990) A catch-at-length analysis that incorporates a stochastic model of growth. Can J Fish Aquat Sci 47: 184-198

Truesdell SB, Hart DR, Chen Y (2015) Effects of spatial heterogeneity in growth and fishing effort on yield-per-recruit models: an application to the US Atlantic sea scallop fishery. ICES J Mar Sci 73(4): 1062-1073

Table 4.1: Estimated reginal von Bertalanffy parameters, by temporal periods and stocks.

Period	L_∞	SDL_∞	K	SDK	SEL_∞	SEK
Georges Bank Closed						
1	142.69	0.44	0.34	0.002	0.12	9.57
2	147.55	0.44	0.35	0.002	0.12	10.30
Georges Bank Open						
1	140.68	0.46	0.16	0.002	0.11	8.13
2	143.43	0.46	0.17	0.002	0.11	8.49
Mid-Atlantic						
1	125.30	0.57	0.35	0.003	0.13	7.06
2	130.27	0.57	0.36	0.003	0.13	7.51
3	134.39	0.57	0.37	0.003	0.13	7.93
4	136.90	0.57	0.37	0.003	0.13	8.21

Table 4.2: CASA Estimates for Mid-Atlantic areas.

Year	Abundance millions	CV	Bms mt meats	CV	SSB mt meats	CV	ExplBms mt meats	CV	F	CV
1975	1639	0.18	19428	0.18	9777	0.37	6802	0.53	0.271	0.73
1976	950	0.14	17482	0.15	9036	0.29	7280	0.36	0.512	0.3
1977	1073	0.1	16189	0.12	8300	0.23	4945	0.38	0.586	0.25
1978	857	0.08	15147	0.1	7652	0.19	5104	0.28	0.928	0.14
1979	533	0.07	11779	0.08	6040	0.15	3549	0.26	0.913	0.16
1980	546	0.08	9754	0.08	5030	0.16	8597	0.09	0.263	0.36
1981	553	0.08	9707	0.08	4969	0.16	8411	0.09	0.099	0.95
1982	517	0.07	9527	0.07	4927	0.14	8476	0.08	0.217	0.42
1983	571	0.06	8503	0.07	4388	0.13	7138	0.08	0.506	0.17
1984	535	0.07	7621	0.08	4208	0.14	6284	0.09	0.656	0.14
1985	1063	0.08	9284	0.08	5202	0.15	5694	0.13	0.642	0.17
1986	1630	0.07	15328	0.07	8390	0.13	9690	0.12	0.391	0.27
1987	2034	0.07	19548	0.07	10319	0.14	13235	0.11	0.668	0.15
1988	1938	0.07	22266	0.08	11863	0.15	16510	0.11	0.428	0.24
1989	2173	0.1	23544	0.1	12563	0.18	17372	0.13	0.527	0.22
1990	2086	0.12	23312	0.12	12015	0.23	17278	0.16	0.477	0.27
1991	1209	0.07	15908	0.08	8135	0.16	13168	0.1	0.687	0.16
1992	744	0.08	10347	0.08	5984	0.14	8742	0.09	0.721	0.13
1993	1770	0.07	12942	0.08	7262	0.14	6825	0.15	0.526	0.22
1994	2122	0.09	18178	0.09	9671	0.16	10567	0.15	0.792	0.14
1995	1815	0.08	18772	0.08	9550	0.16	13298	0.11	0.655	0.16
1996	968	0.06	14579	0.07	7511	0.13	12502	0.08	0.515	0.17
1997	865	0.08	11872	0.08	6957	0.13	10011	0.09	0.376	0.24
1998	2527	0.08	18967	0.07	10728	0.13	7801	0.18	0.46	0.27
1999	3971	0.07	36202	0.07	19070	0.13	13504	0.18	0.396	0.33

CASA Estimates for Mid-Atlantic areas, continued.

Year	Abundance millions	CV	Bms mt meats	CV	SSB mt meats	CV	ExplBms mt meats	CV	F	CV
2000	4396	0.06	52569	0.06	27430	0.12	28376	0.11	0.379	0.3
2001	5118	0.06	67834	0.06	34676	0.11	44751	0.09	0.398	0.23
2002	4730	0.07	76649	0.06	40987	0.12	47716	0.1	0.406	0.23
2003	8339	0.08	95249	0.07	49168	0.14	55710	0.12	0.397	0.24
2004	7109	0.07	103901	0.07	53126	0.13	54601	0.12	0.47	0.19
2005	5948	0.06	96962	0.06	49720	0.11	54450	0.1	0.321	0.26
2006	6048	0.05	97474	0.05	49528	0.1	58014	0.09	0.179	0.45
2007	5166	0.05	96198	0.05	49584	0.1	59537	0.08	0.313	0.24
2008	5941	0.05	86268	0.05	43747	0.11	52650	0.09	0.362	0.22
2009	4351	0.05	78337	0.05	39539	0.11	42073	0.1	0.491	0.17
2010	3010	0.04	63359	0.05	31863	0.09	44399	0.07	0.472	0.16
2011	1937	0.04	46947	0.04	24895	0.08	35980	0.06	0.533	0.13
2012	4039	0.04	49721	0.04	25667	0.09	30379	0.07	0.409	0.18
2013	3628	0.05	60018	0.05	31305	0.1	30158	0.1	0.235	0.32
2014	5008	0.04	71368	0.05	39659	0.08	41100	0.08	0.247	0.31
2015	11830	0.06	117103	0.06	60451	0.11	47034	0.14	0.228	0.36
2016	8713	0.06	127088	0.06	64271	0.11	52459	0.14	0.254	0.32
2017	5627	0.05	100558	0.05	50590	0.1	53216	0.1	0.279	0.3
2018	3698	0.04	83253	0.05	41881	0.09	58000	0.07	0.171	0.42
2019	2652	0.05	64043	0.05	32246	0.09	50737	0.06	0.222	0.32
2020	1517	0.05	34390	0.05	17378	0.1	29081	0.06	0.51	0.15
2021	1095	0.06	20887	0.06	10772	0.12	14136	0.09	0.373	0.23
2022	1328	0.04	20995	0.05	10683	0.1	13254	0.08	0.178	0.45
2023	1069	0.05	20556	0.06	10510	0.12	12742	0.1	0.061	1.48

Table 4.3: CASA estimates for Georges Bank closed areas, excluding the Deep Southeast Nantucket Lightship scallops.

Year	Abundance millions	CV	Bms mt meats	CV	SSB mt meats	CV	ExplBms mt meats	CV	F	CV
1975	507	0.12	10990	0.12	5100	0.26	10443	0.13	0.079	1.53
1976	390	0.11	11275	0.11	5270	0.23	11190	0.11	0.12	0.92
1977	498	0.1	10307	0.1	4620	0.23	9532	0.11	0.29	0.36
1978	473	0.09	9118	0.1	3986	0.22	8372	0.1	0.346	0.28
1979	327	0.1	7034	0.1	2964	0.23	6799	0.1	0.552	0.17
1980	376	0.11	5528	0.11	2392	0.25	4803	0.12	0.474	0.23
1981	352	0.12	5056	0.12	2154	0.28	4409	0.14	0.536	0.21
1982	320	0.13	4739	0.13	2053	0.3	4215	0.15	0.412	0.3
1983	277	0.15	4450	0.15	1948	0.34	4038	0.17	0.405	0.34
1984	334	0.14	4743	0.15	2174	0.33	4083	0.17	0.179	0.84
1985	347	0.14	5303	0.14	2409	0.31	4693	0.16	0.298	0.47
1986	480	0.12	5650	0.13	2505	0.3	4592	0.16	0.456	0.33
1987	551	0.13	5874	0.13	2609	0.3	4626	0.17	0.606	0.24
1988	766	0.11	6722	0.13	2985	0.29	4812	0.18	0.693	0.24
1989	997	0.09	8887	0.09	3955	0.21	6374	0.13	0.555	0.25
1990	902	0.08	8478	0.08	3368	0.2	6664	0.1	1.242	0.09
1991	808	0.09	6470	0.09	2519	0.22	4689	0.12	1.49	0.07
1992	649	0.14	5328	0.14	2210	0.34	3875	0.19	1.402	0.09
1993	1014	0.17	7379	0.17	3299	0.39	4567	0.28	0.503	0.37
1994	1034	0.16	12171	0.17	5813	0.35	10019	0.2	0.06	2.7
1995	1326	0.15	18401	0.15	8791	0.32	16151	0.17	0	0
1996	1372	0.14	24666	0.14	11771	0.28	22794	0.15	0	0
1997	1461	0.13	29811	0.12	14365	0.26	28175	0.13	0	0
1998	1956	0.12	35534	0.11	16941	0.24	23606	0.17	0.002	45.89
1999	1876	0.11	41859	0.11	19785	0.23	28175	0.16	0.109	1.02

CASA estimates for Georges Bank closed areas, continued.

Year	Abundance millions	CV	Bms mt meats	CV	SSB mt meats	CV	ExplBms mt meats	CV	F	CV
2000	2538	0.11	47481	0.11	22366	0.22	32218	0.16	0.088	1.24
2001	2744	0.1	56037	0.1	26535	0.2	37022	0.14	0.016	6.3
2002	2667	0.08	64115	0.08	30391	0.17	44534	0.11	0	0
2003	2619	0.06	69486	0.06	32809	0.13	53294	0.08	0	0
2004	2317	0.06	70598	0.06	33292	0.12	57633	0.07	0.058	1.3
2005	2107	0.06	68342	0.06	32159	0.12	58311	0.07	0.126	0.59
2006	1878	0.06	61700	0.06	28440	0.13	53754	0.07	0.198	0.38
2007	1768	0.06	52589	0.06	23929	0.13	45000	0.07	0.123	0.64
2008	1661	0.06	48299	0.06	22982	0.14	39646	0.08	0.055	1.49
2009	1955	0.07	48954	0.07	23089	0.14	38696	0.08	0.042	1.98
2010	1811	0.06	43469	0.06	19073	0.14	32869	0.08	0.092	0.89
2011	1699	0.08	36874	0.07	16652	0.16	26358	0.1	0.212	0.42
2012	1509	0.06	30922	0.06	13278	0.14	20982	0.09	0.312	0.29
2013	1388	0.05	29819	0.06	14960	0.12	19778	0.09	0.102	0.87
2014	4327	0.06	46056	0.06	22549	0.12	24738	0.11	0.07	1.25
2015	5142	0.07	72717	0.06	34128	0.14	30249	0.15	0.004	20.72
2016	4916	0.1	84764	0.09	38607	0.2	41535	0.19	0.003	36.75
2017	4603	0.12	81495	0.12	35798	0.28	33443	0.29	0.151	1.13
2018	2615	0.08	55194	0.08	21757	0.21	43132	0.11	0.265	0.44
2019	1900	0.1	32418	0.1	13332	0.23	10599	0.29	1.045	0.18
2020	1431	0.06	25960	0.07	11620	0.15	16386	0.11	0.334	0.31
2021	1293	0.05	26496	0.06	12371	0.13	17312	0.09	0.204	0.51
2022	1197	0.06	27200	0.06	12874	0.13	9947	0.17	0.415	0.29
2023	2034	0.09	28883	0.08	13410	0.17	7330	0.3	0.469	0.34

Table 4.4: CASA Estimates for Georges Bank open areas.

Year	Abundance millions	CV	Bms mt meats	CV	SSB mt meats	CV	ExplBms mt meats	CV	F	CV
1975	1049	0.04	12959	0.04	6001	0.08	10785	0.05	0.103	0.49
1976	892	0.04	15513	0.04	7025	0.09	14352	0.04	0.188	0.26
1977	801	0.04	14811	0.04	6511	0.1	14068	0.05	0.31	0.17
1978	717	0.04	12803	0.04	5576	0.1	11850	0.05	0.348	0.16
1979	561	0.04	10437	0.05	4492	0.11	9786	0.05	0.444	0.12
1980	667	0.04	8836	0.05	3854	0.11	7715	0.05	0.417	0.14
1981	577	0.04	7941	0.04	3322	0.1	6879	0.05	0.611	0.09
1982	482	0.05	6071	0.05	2418	0.12	5419	0.05	0.803	0.07
1983	335	0.05	4639	0.06	1912	0.14	4095	0.07	0.648	0.1
1984	294	0.06	3948	0.07	1709	0.16	3516	0.08	0.484	0.16
1985	330	0.06	3796	0.07	1685	0.16	3158	0.09	0.548	0.15
1986	519	0.06	3877	0.07	1644	0.17	2715	0.1	0.965	0.1
1987	590	0.05	5014	0.06	2149	0.14	3575	0.08	0.663	0.12
1988	487	0.05	5291	0.06	2209	0.15	4411	0.08	0.715	0.1
1989	478	0.05	4984	0.07	2152	0.15	4125	0.08	0.629	0.13
1990	536	0.06	4572	0.06	1946	0.14	3455	0.08	0.997	0.08
1991	676	0.08	4182	0.06	1623	0.16	2657	0.1	1.496	0.05
1992	389	0.04	3308	0.04	1176	0.12	2510	0.05	1.73	0.03
1993	215	0.05	2323	0.05	911	0.13	2027	0.06	1.049	0.06
1994	224	0.06	2118	0.06	963	0.14	1671	0.08	0.648	0.12
1995	451	0.05	2951	0.05	1319	0.12	1834	0.08	0.692	0.12
1996	452	0.04	3923	0.05	1621	0.11	2853	0.06	0.898	0.07
1997	409	0.05	3903	0.05	1657	0.12	3148	0.06	0.856	0.07
1998	604	0.05	4518	0.05	2029	0.12	3121	0.08	0.732	0.1
1999	907	0.05	6573	0.05	2964	0.11	2712	0.12	1.018	0.1

CASA Estimates for Georges Bank open areas, continued.

Year	Abundance millions	CV	Bms mt meats	CV	SSB mt meats	CV	ExplBms mt meats	CV	F	CV
2000	1259	0.04	10410	0.04	4687	0.09	4977	0.08	0.629	0.13
2001	1352	0.03	14061	0.03	6121	0.08	8160	0.06	0.644	0.1
2002	1201	0.03	14860	0.03	6309	0.08	10223	0.05	0.708	0.08
2003	1199	0.03	14683	0.03	6342	0.08	10547	0.05	0.545	0.1
2004	1125	0.03	16069	0.03	7230	0.07	11704	0.04	0.271	0.19
2005	1096	0.03	17220	0.03	7734	0.07	12307	0.04	0.303	0.16
2006	1016	0.04	15002	0.03	6365	0.08	10762	0.05	0.754	0.07
2007	1439	0.04	14600	0.04	6489	0.08	8573	0.06	0.561	0.11
2008	1597	0.03	17888	0.03	7966	0.07	8804	0.07	0.55	0.11
2009	1694	0.03	21175	0.03	9380	0.07	12479	0.05	0.431	0.12
2010	1519	0.03	24147	0.03	10938	0.06	16357	0.04	0.217	0.22
2011	1378	0.02	25868	0.02	11789	0.05	20318	0.03	0.162	0.27
2012	1109	0.03	22632	0.03	9905	0.06	18633	0.03	0.415	0.1
2013	1287	0.04	16571	0.03	7617	0.07	12500	0.04	0.761	0.06
2014	2409	0.05	18298	0.03	8262	0.07	8739	0.07	0.389	0.14
2015	1842	0.04	17228	0.03	6820	0.08	8589	0.06	0.554	0.1
2016	1121	0.02	14710	0.03	6591	0.07	9193	0.05	0.38	0.14
2017	1129	0.02	17097	0.03	7894	0.06	11277	0.04	0.144	0.33
2018	968	0.03	17226	0.03	7614	0.06	12766	0.04	0.414	0.11
2019	1182	0.03	15289	0.03	6728	0.07	11195	0.04	0.498	0.1
2020	1453	0.03	17668	0.03	8180	0.07	10266	0.05	0.194	0.27
2021	1356	0.04	19219	0.04	8359	0.08	11570	0.06	0.598	0.09
2022	1380	0.04	18890	0.04	8530	0.09	12730	0.06	0.415	0.15
2023	2009	0.07	20517	0.05	9141	0.12	12248	0.09	0.475	0.15

Table 4.5: . CASA Estimates for Georges Bank and Mid-Atlantic combined, excluding the Deep Southeast Nantucket Lightship scallops.

Year	Abundance millions	CV	Bms mt meats	CV	SSB mt meats	CV	ExplBms mt meats	CV	F	CV
1975	3195	0.09	43377	0.09	20878	0.18	28030	0.14	0.154	0.08
1976	2232	0.06	44270	0.07	21331	0.14	32823	0.09	0.269	0.06
1977	2372	0.05	41307	0.05	19430	0.12	28545	0.08	0.378	0.05
1978	2046	0.04	37068	0.05	17215	0.1	25326	0.07	0.52	0.05
1979	1421	0.04	29250	0.04	13496	0.09	20134	0.06	0.585	0.05
1980	1589	0.04	24118	0.04	11276	0.1	21115	0.05	0.372	0.05
1981	1482	0.04	22704	0.05	10445	0.1	19699	0.05	0.406	0.05
1982	1319	0.05	20337	0.05	9398	0.1	18109	0.05	0.462	0.05
1983	1182	0.05	17593	0.05	8248	0.11	15272	0.06	0.523	0.05
1984	1164	0.05	16312	0.06	8091	0.12	13882	0.07	0.474	0.06
1985	1740	0.06	18383	0.06	9296	0.12	13545	0.08	0.506	0.07
1986	2629	0.05	24855	0.06	12540	0.11	16997	0.08	0.499	0.07
1987	3176	0.05	30437	0.06	15077	0.11	21437	0.08	0.654	0.06
1988	3190	0.05	34278	0.06	17057	0.12	25733	0.08	0.532	0.07
1989	3648	0.06	37415	0.07	18671	0.13	27871	0.09	0.55	0.07
1990	3525	0.07	36361	0.08	17329	0.16	27396	0.1	0.752	0.08
1991	2692	0.05	26560	0.05	12278	0.12	20514	0.07	1.014	0.06
1992	1782	0.06	18983	0.06	9370	0.12	15127	0.07	1.134	0.06
1993	2999	0.07	22644	0.07	11472	0.14	13419	0.12	0.603	0.09
1994	3381	0.07	32467	0.08	16446	0.16	22257	0.12	0.446	0.09
1995	3593	0.07	40124	0.08	19660	0.16	31283	0.1	0.346	0.09
1996	2792	0.07	43168	0.08	20903	0.17	38150	0.09	0.274	0.08
1997	2735	0.07	45587	0.08	22979	0.17	41334	0.09	0.19	0.08
1998	5087	0.06	59019	0.07	29698	0.14	34528	0.12	0.236	0.08
1999	6753	0.05	84634	0.06	41819	0.12	44391	0.12	0.311	0.08

. CASA Estimates for Georges Bank and Mid-Atlantic combined, continued.

Year	Abundance millions	CV	Bms mt meats	CV	SSB mt meats	CV	ExplBms mt meats	CV	F	CV
2000	8193	0.05	110460	0.05	54483	0.11	65572	0.09	0.304	0.07
2001	9213	0.04	137932	0.05	67332	0.1	89933	0.07	0.315	0.06
2002	8598	0.05	155624	0.05	77688	0.09	102473	0.07	0.307	0.05
2003	12157	0.06	179418	0.05	88320	0.09	119552	0.07	0.271	0.05
2004	10551	0.05	190569	0.04	93648	0.08	123937	0.06	0.294	0.05
2005	9150	0.04	182524	0.04	89613	0.08	125068	0.05	0.246	0.04
2006	8942	0.04	174176	0.04	84333	0.07	122530	0.05	0.248	0.04
2007	8374	0.03	163387	0.04	80002	0.07	113110	0.05	0.277	0.04
2008	9199	0.04	152455	0.04	74695	0.08	101099	0.06	0.289	0.04
2009	8000	0.03	148466	0.04	72008	0.07	93248	0.06	0.335	0.04
2010	6340	0.03	130975	0.03	61875	0.07	93625	0.04	0.312	0.04
2011	5014	0.03	109689	0.03	53336	0.07	82656	0.04	0.338	0.03
2012	6657	0.03	103274	0.03	48849	0.06	69994	0.04	0.385	0.03
2013	6303	0.03	106409	0.03	53882	0.07	62436	0.06	0.314	0.04
2014	11744	0.03	135723	0.03	70470	0.06	74577	0.06	0.214	0.04
2015	18814	0.04	207048	0.04	101399	0.08	85872	0.09	0.194	0.05
2016	14750	0.05	226562	0.05	109468	0.1	103187	0.1	0.171	0.05
2017	11359	0.06	199150	0.06	94282	0.12	97936	0.11	0.224	0.06
2018	7281	0.04	155673	0.04	71252	0.08	113898	0.05	0.235	0.05
2019	5734	0.04	111750	0.04	52306	0.08	72531	0.06	0.416	0.05
2020	4401	0.03	78019	0.03	37178	0.07	55733	0.05	0.393	0.04
2021	3744	0.03	66603	0.03	31502	0.07	43018	0.05	0.38	0.05
2022	3905	0.03	67084	0.03	32087	0.07	35931	0.06	0.342	0.04
2023	5112	0.05	69956	0.04	33062	0.08	32320	0.09	0.33	0.05

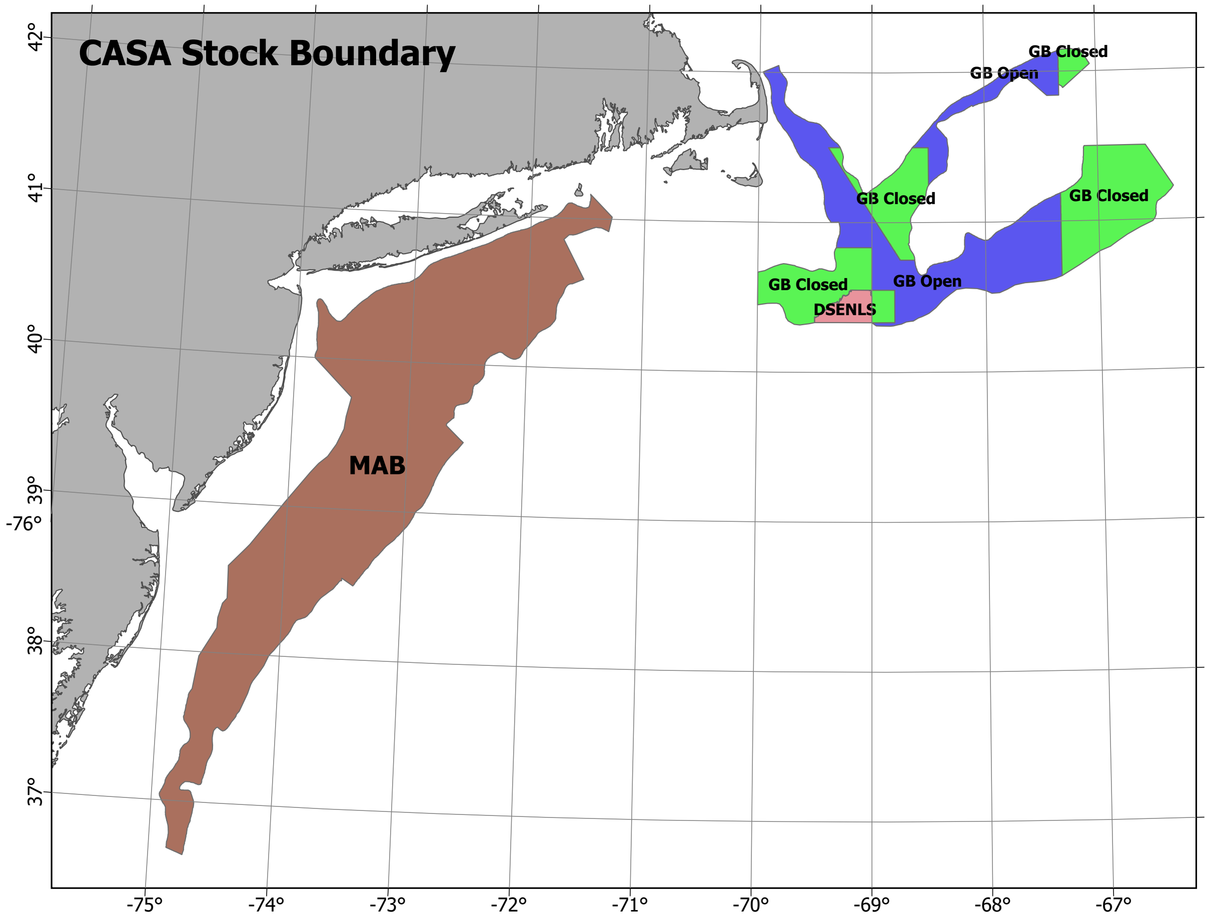


Figure 4.1: Charts of U.S. sea scallop grounds, showing the Mid-Atlantic and Georges Bank stock areas. Georges Bank was split into Open, Closed, and Deep Southeast Nantucket Lightship portions.

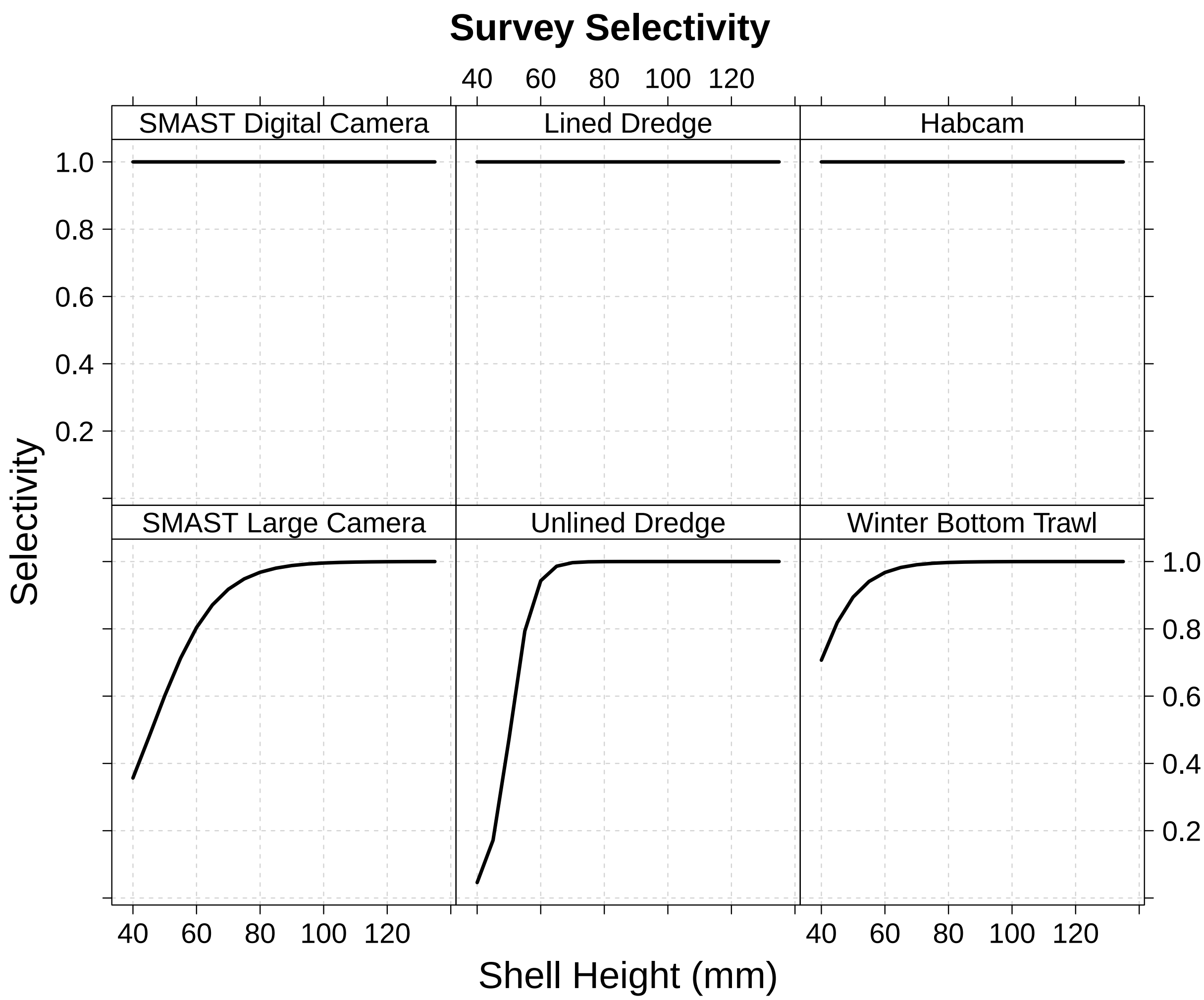


Figure 4.2: Assumed selectivity curves for SMAST digital camera, lined dredge, Habcam, SMAST large camera, unlined dredge, and winter bottom trawl surveys for Georges Bank and Mid-Atlantic stocks.

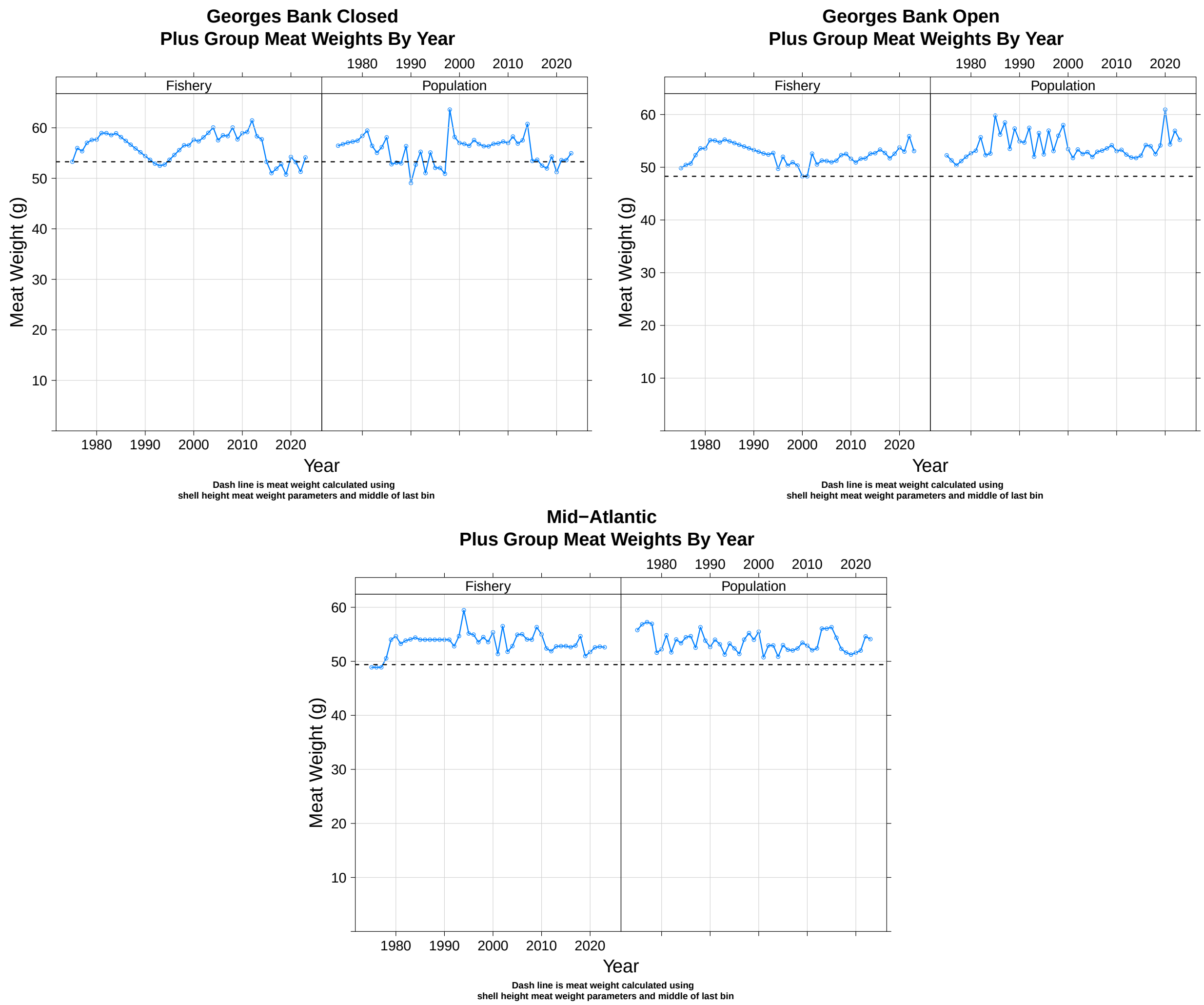


Figure 4.3: Estimated plus group meat weights for the population and fishery in the open and closed portions of Georges Bank, and in the Mid-Atlantic. The plus group represents scallops in the largest bin which contained L_∞. Dash line is the meat weight for the last size bin calculated using the shell height meat weight parameters used in the CASA model.

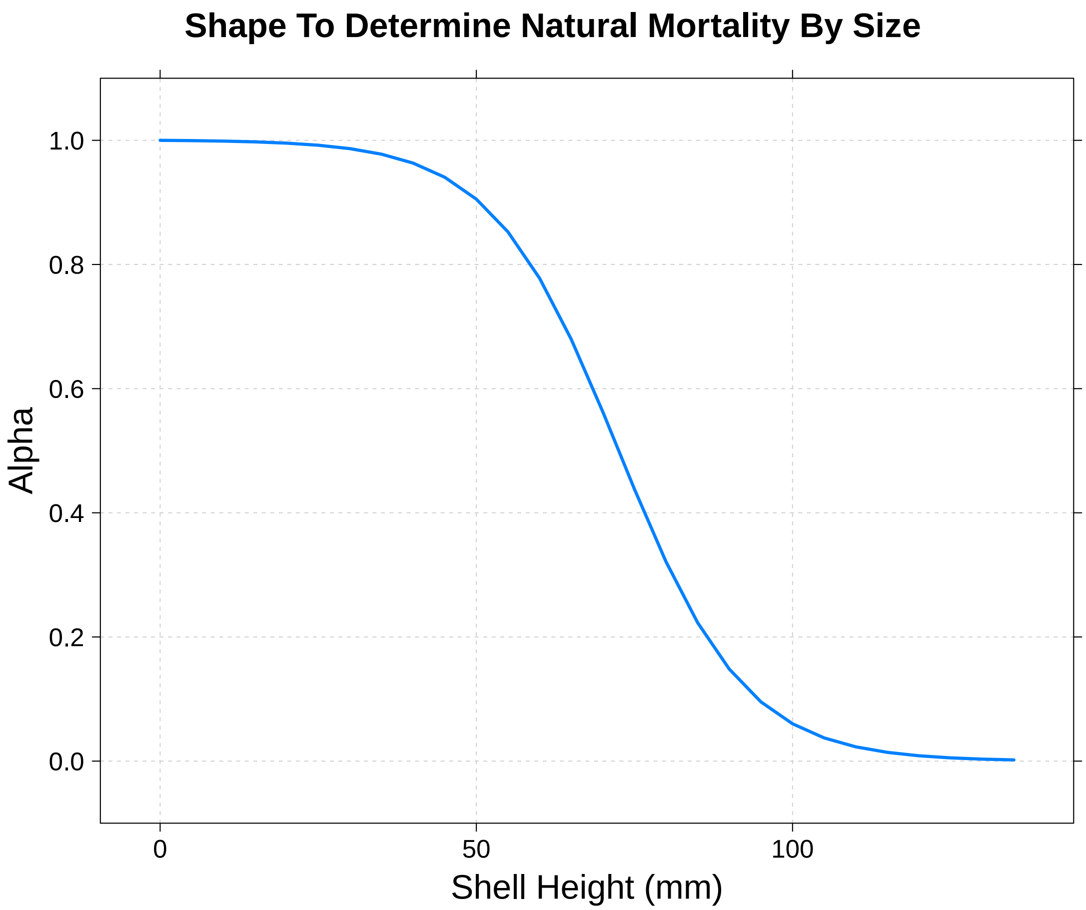


Figure 4.4: Logistic curve ($h_0 = 75$ mm and $a = 0.1$) used to partition juvenile and adult natural mortality.

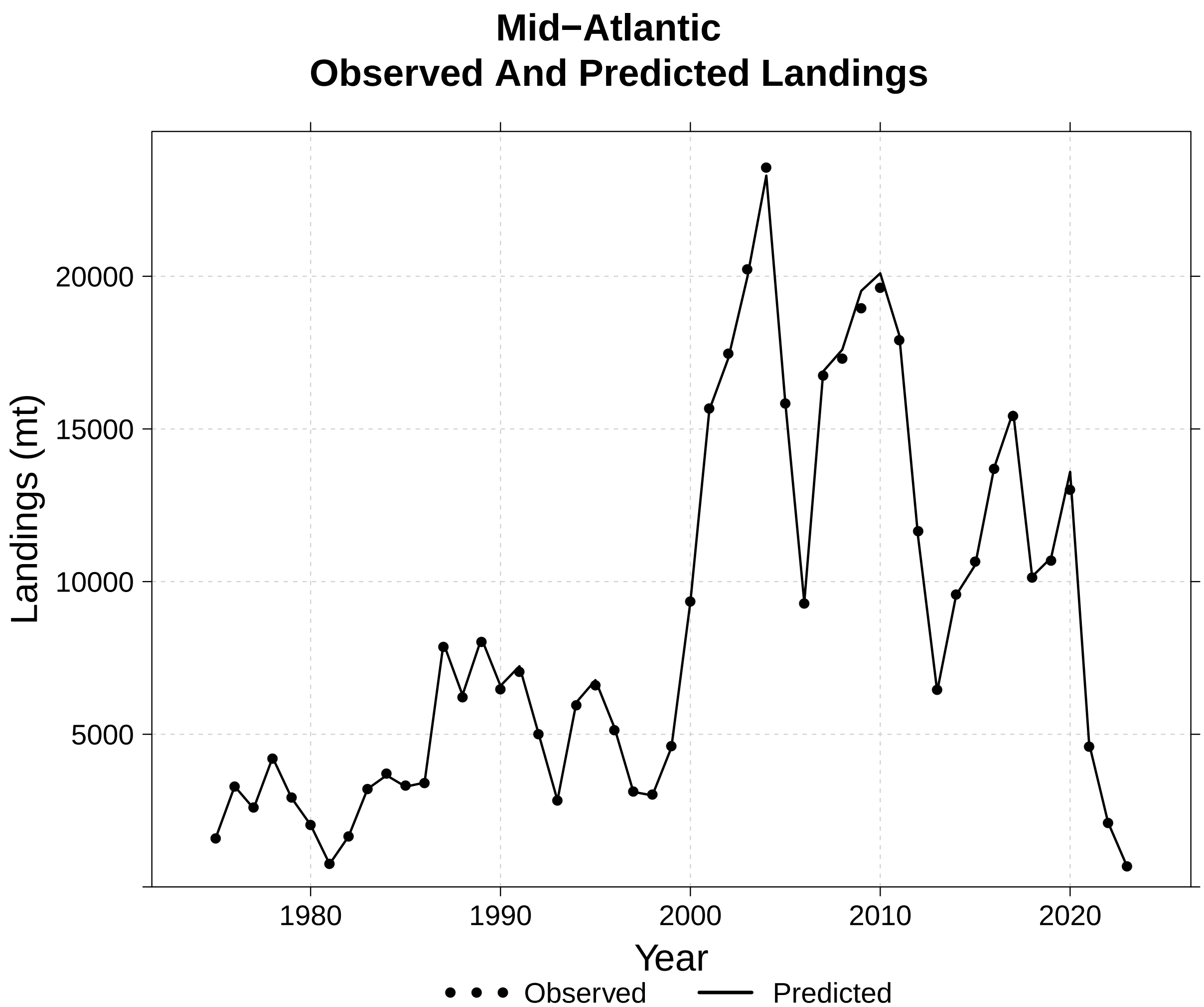


Figure 4.5: Observed catch (mt meats, solid circles) and corresponding model estimates (lines) by year in Mid-Atlantic areas.

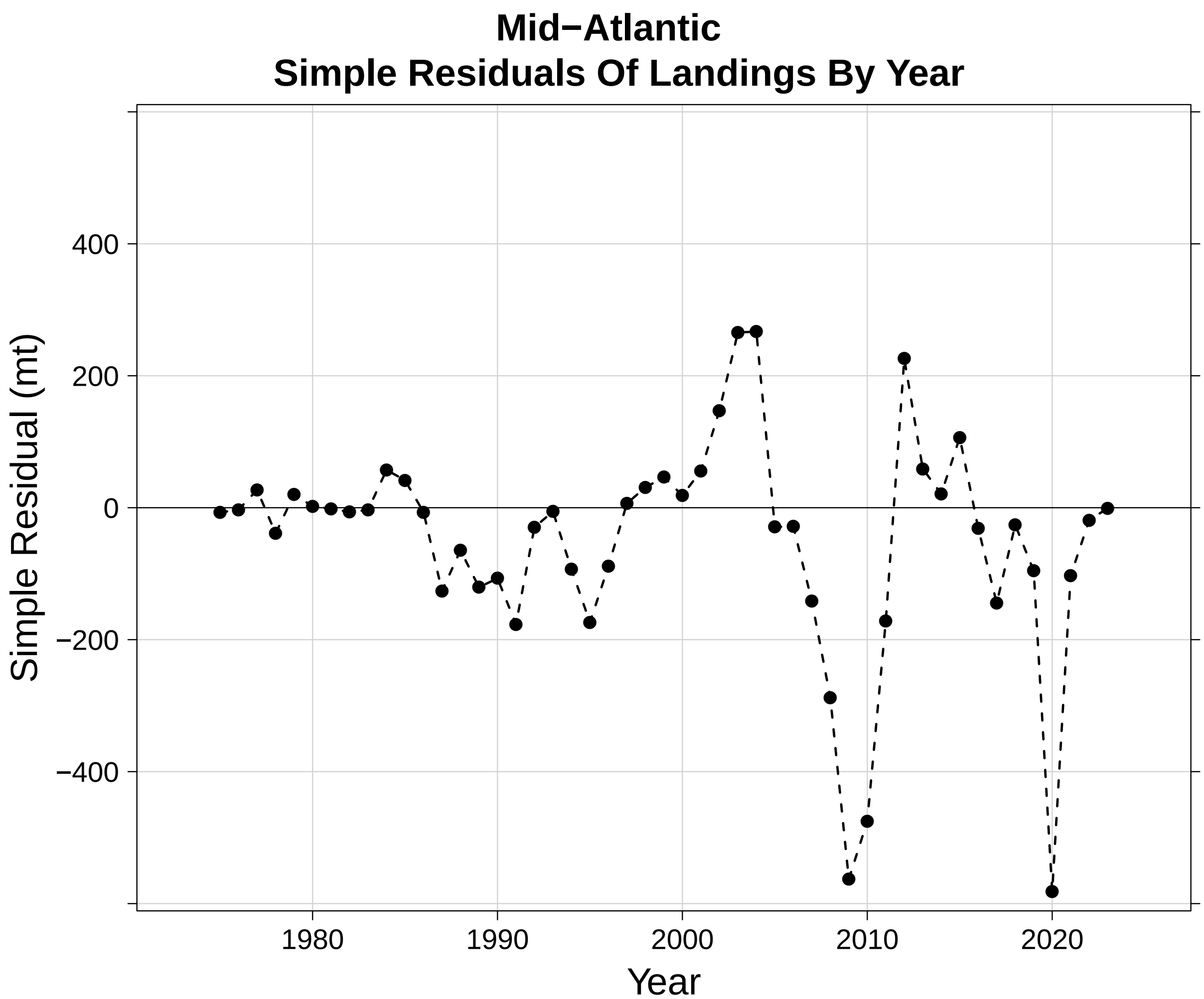


Figure 4.6: Simple residuals of catch (mt meats) by year in Mid-Atlantic areas.

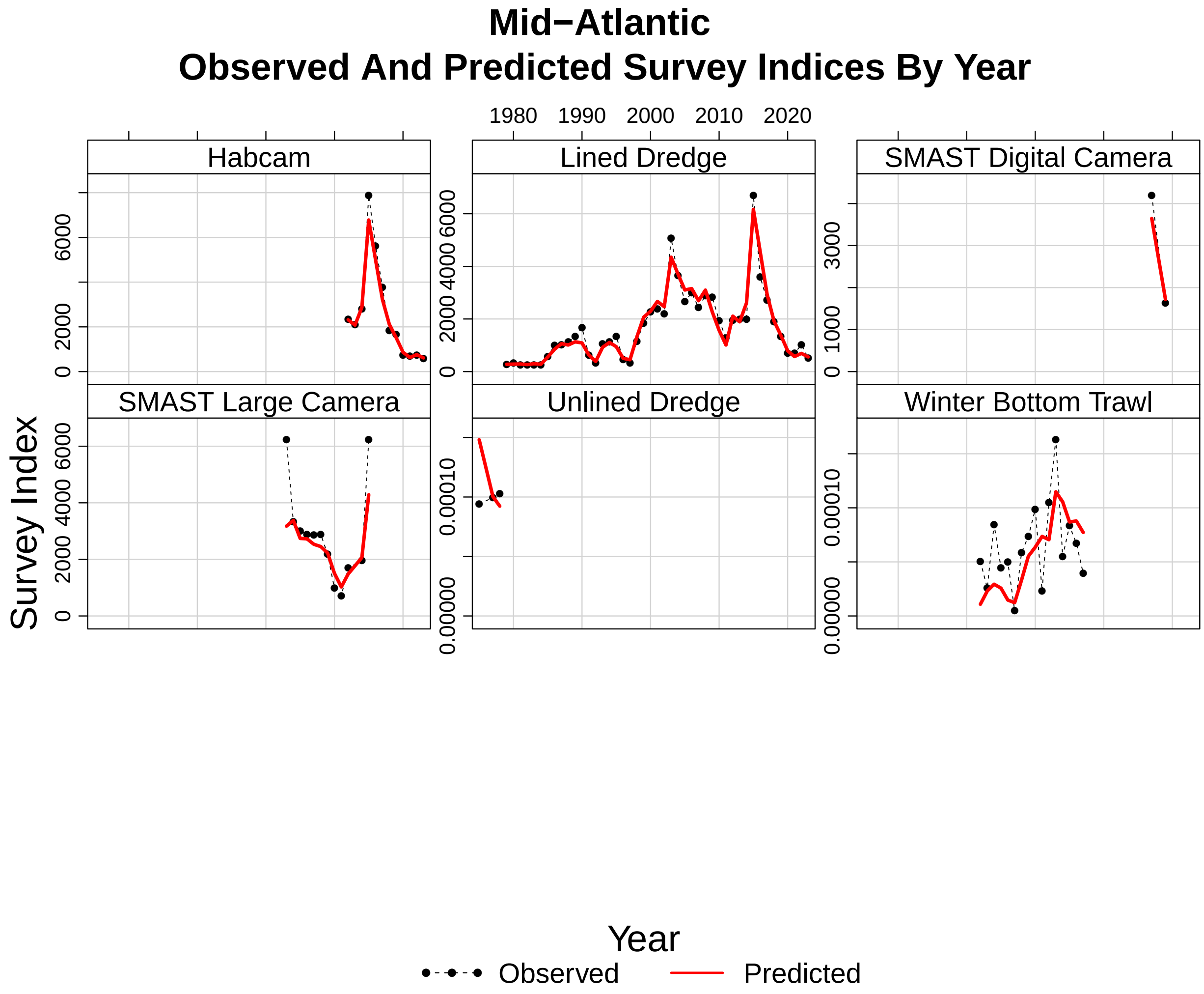


Figure 4.7: Observed survey trend (solid circles) and corresponding model estimates (lines) by year for the SMAST digital camera, lined dredge, Habcam, SMAST large camera, unlined dredge, and winter bottom trawl surveys in Mid-Atlantic areas.

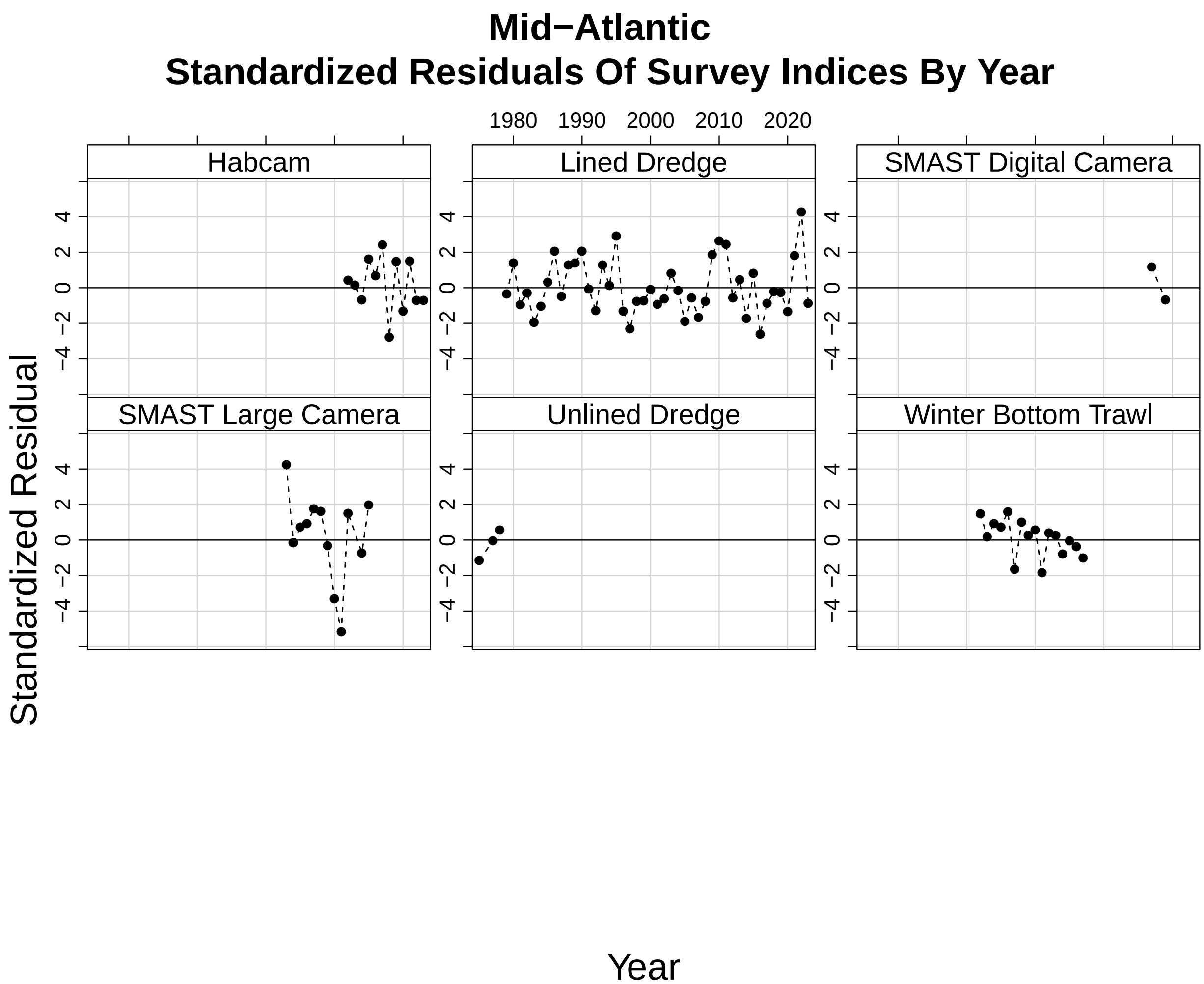


Figure 4.8: Standardized residuals of survey indices by year for the SMAST digital camera, lined dredge, Habcam, SMAST large camera, unlined dredge, and winter bottom trawl surveys in Mid-Atlantic areas.

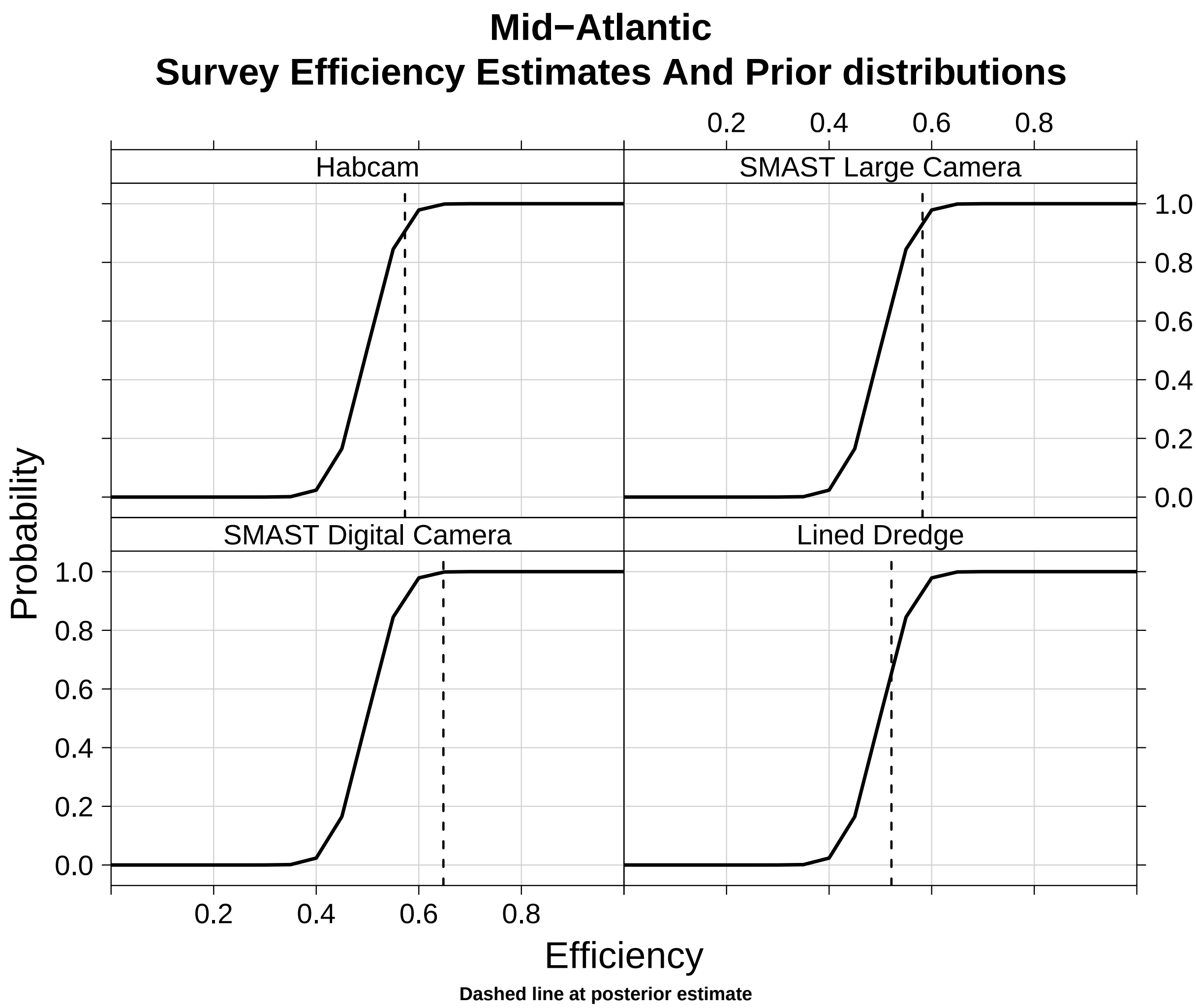


Figure 4.9: Prior cumulative distributions for catchability of Habcam, SMAST large camera, SMAST digital camera, and lined dredge surveys for Mid-Atlantic areas. The dashed lines are the mean posterior estimate for survey catchability. The surveys were adjusted to have a mean prior catchability of 0.5.

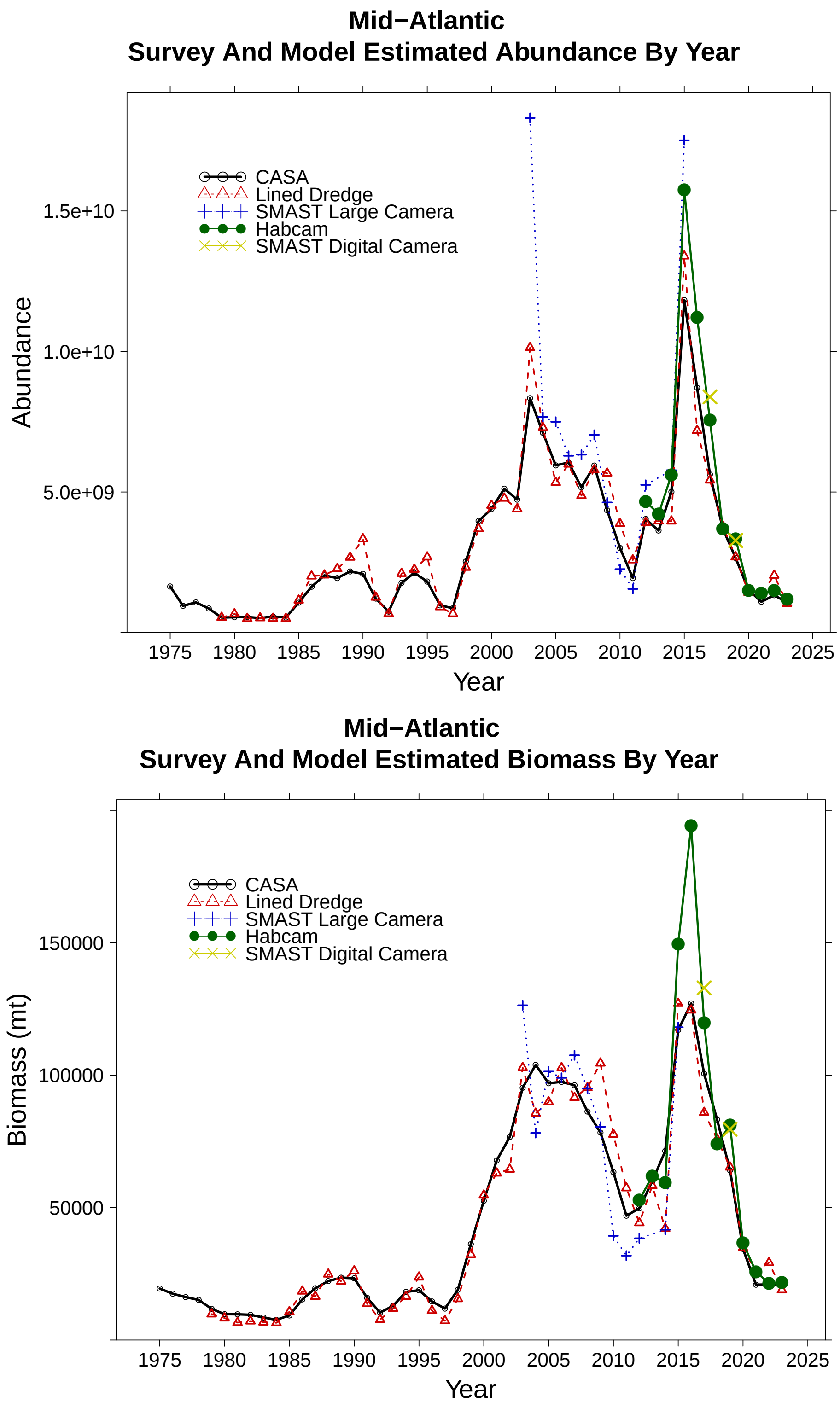


Figure 4.10: Comparison of CASA model estimated abundance (top) and biomass (bottom) with expanded estimates from the lined dredge (red triangle), SMAST large camera (blue cross), HabCam (green dots), and SMAST digital camera (light green x) for Mid-Atlantic areas.

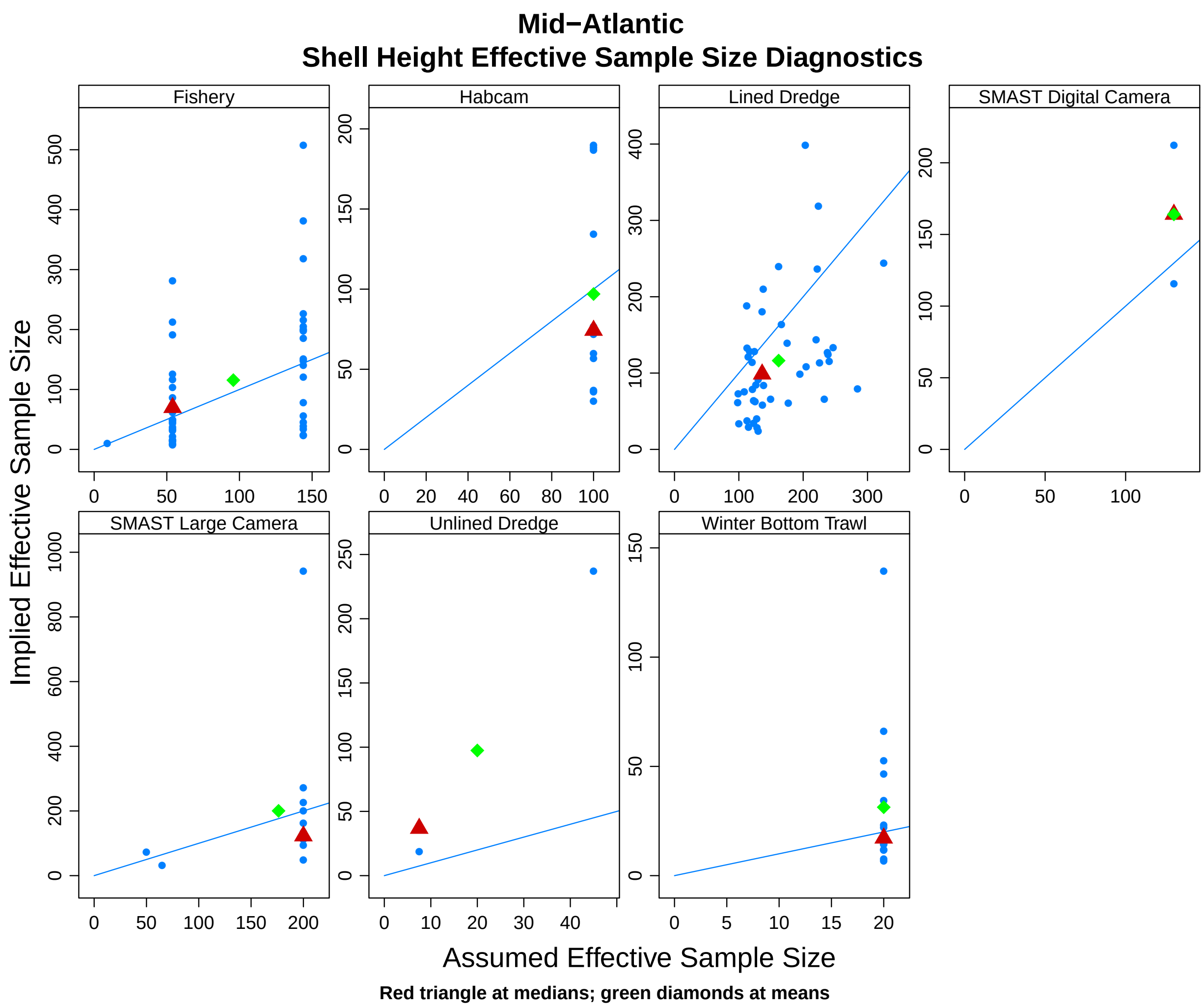


Figure 4.11: Assumed and model implied effective sample sizes for SMAST digital camera, lined dredge, Habcam, SMAST large camera, unlined dredge, and winter bottom trawl surveys, and the fishery shell height compositions for Mid-Atlantic areas. The triangle is the median and the diamond is the mean.

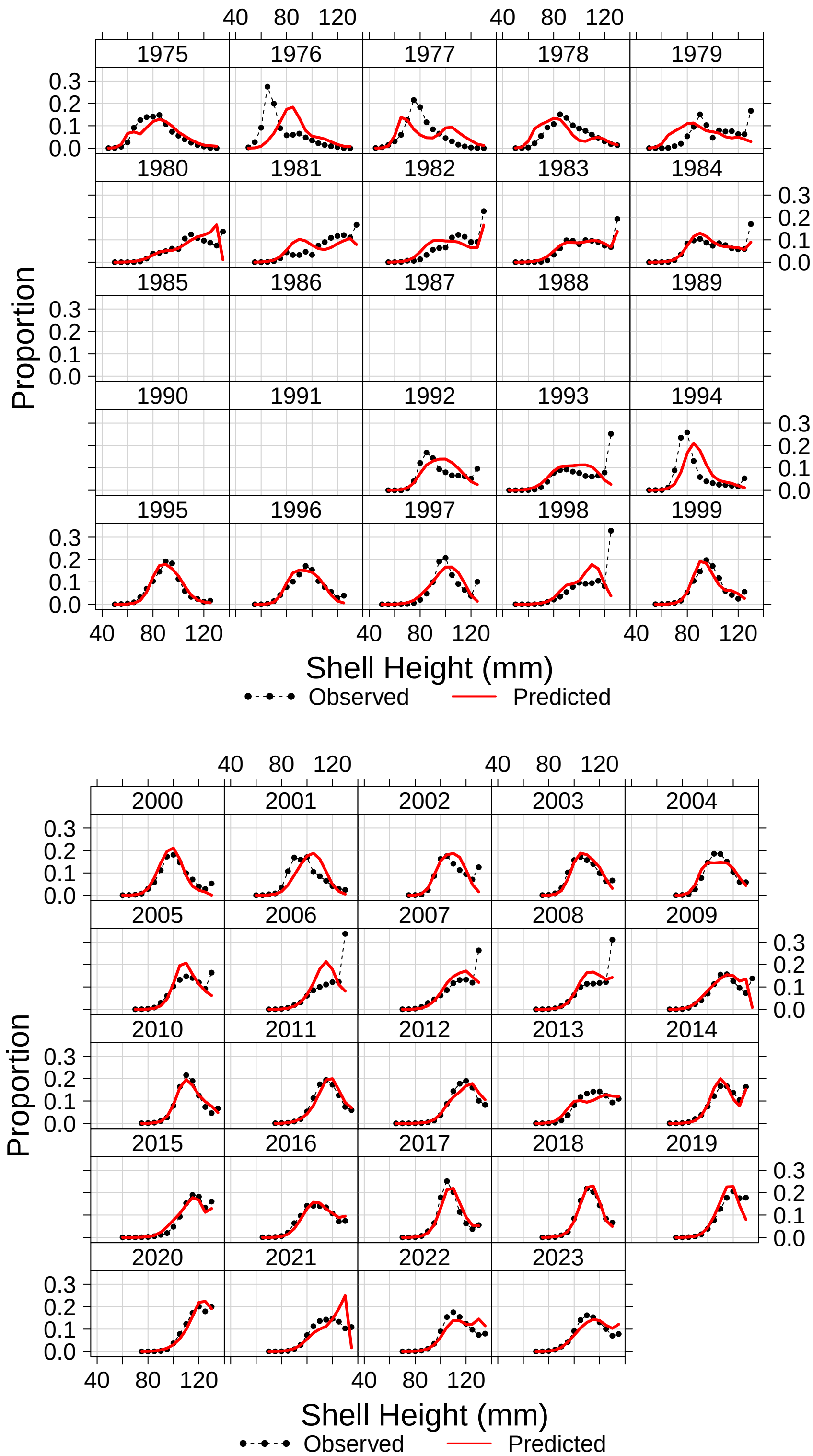


Figure 4.12: Comparison of observed fishery shell height proportions (solid circles) and model estimated fishery shell height proportions (lines) for Mid-Atlantic areas.

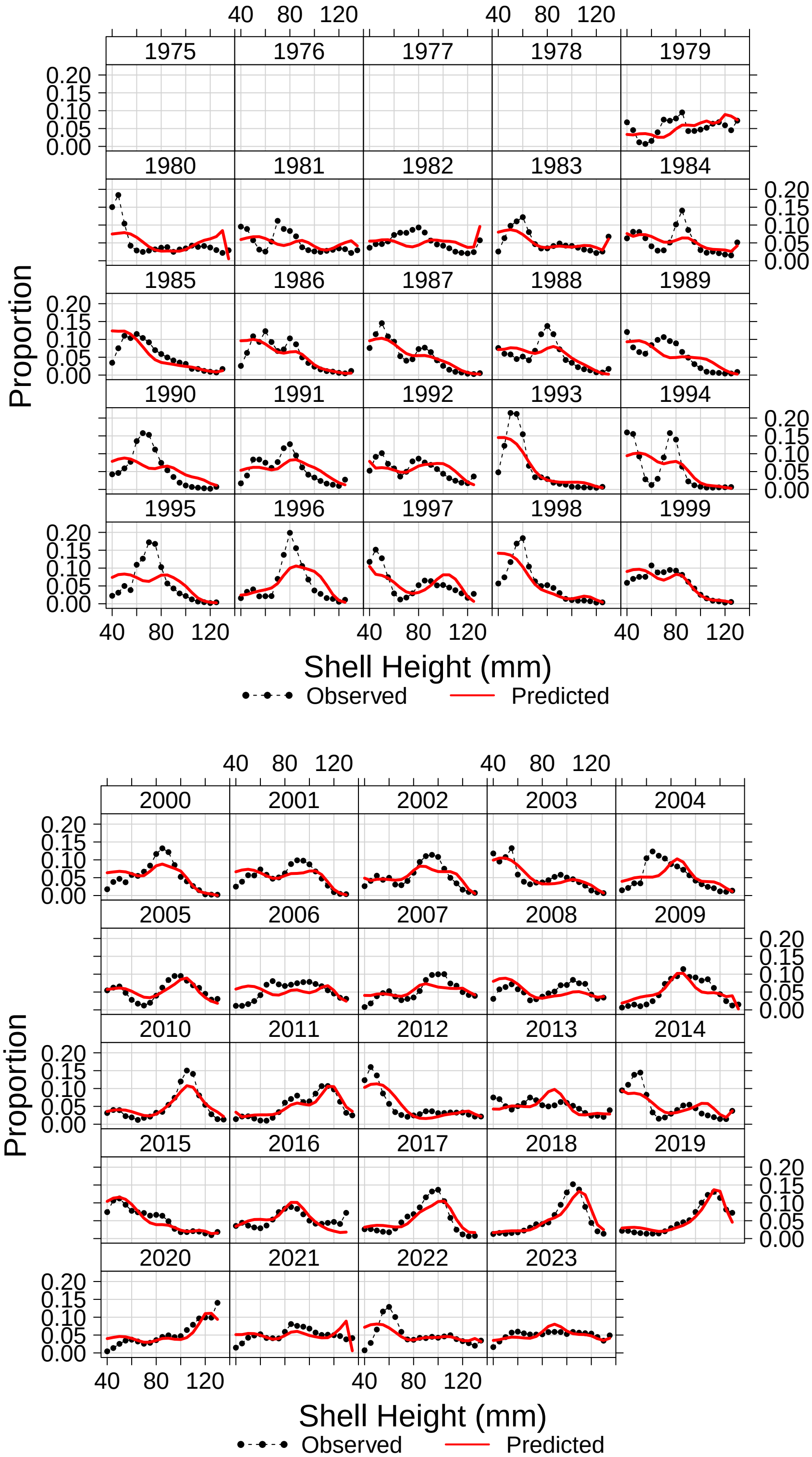
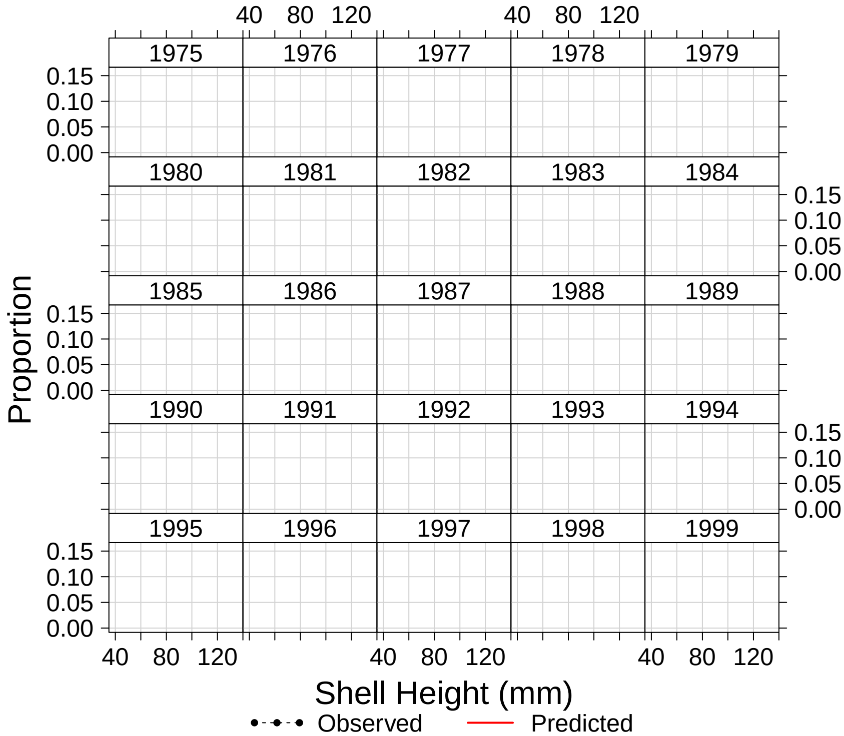


Figure 4.13: Comparison of lined dredge survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Mid-Atlantic areas.



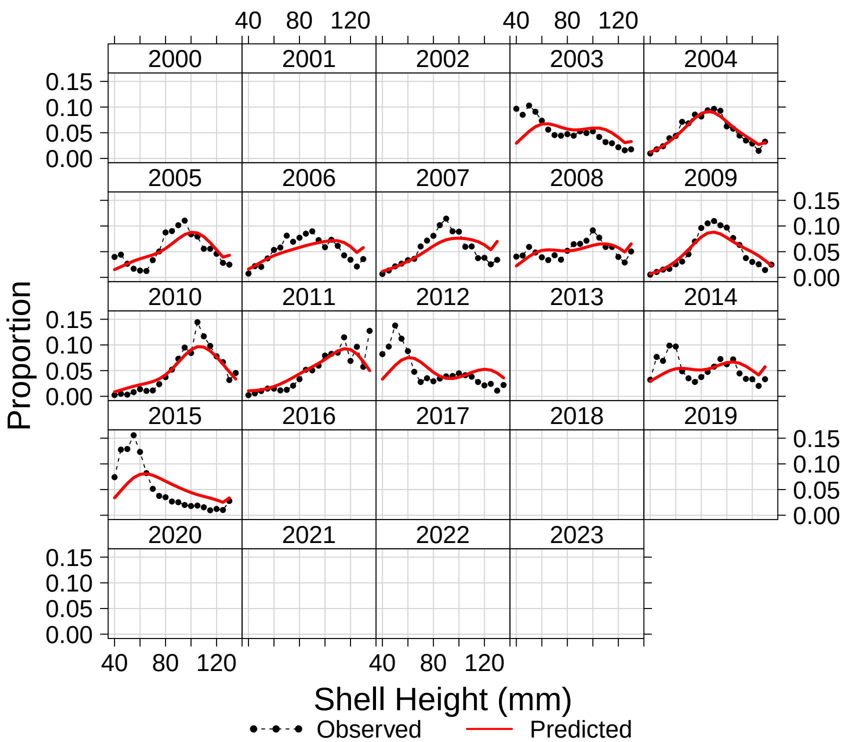


Figure 4.14: Comparison of SMAST large camera survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Mid-Atlantic areas.

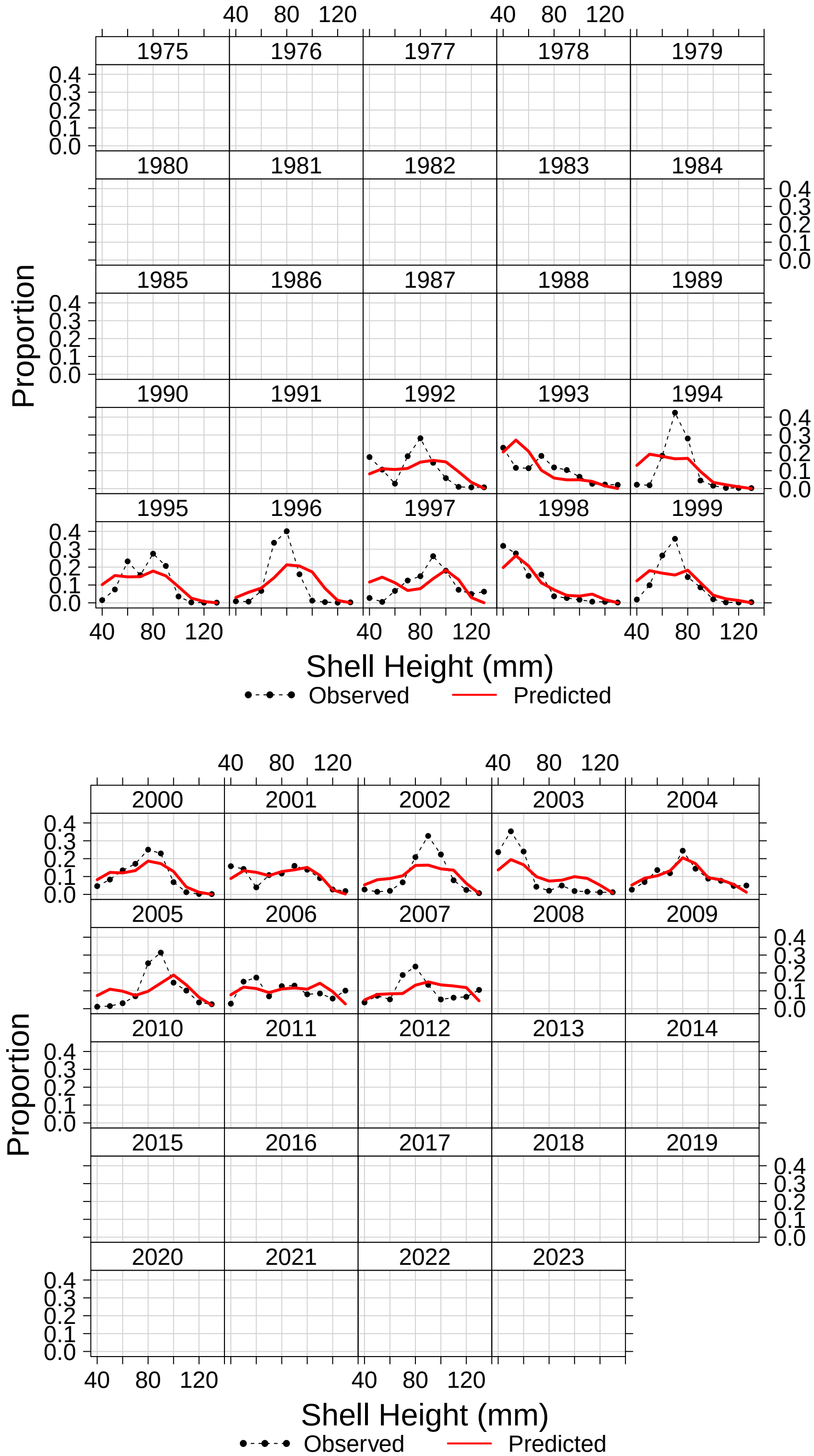


Figure 4.15: Comparison of winter bottom trawl survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Mid-Atlantic areas.

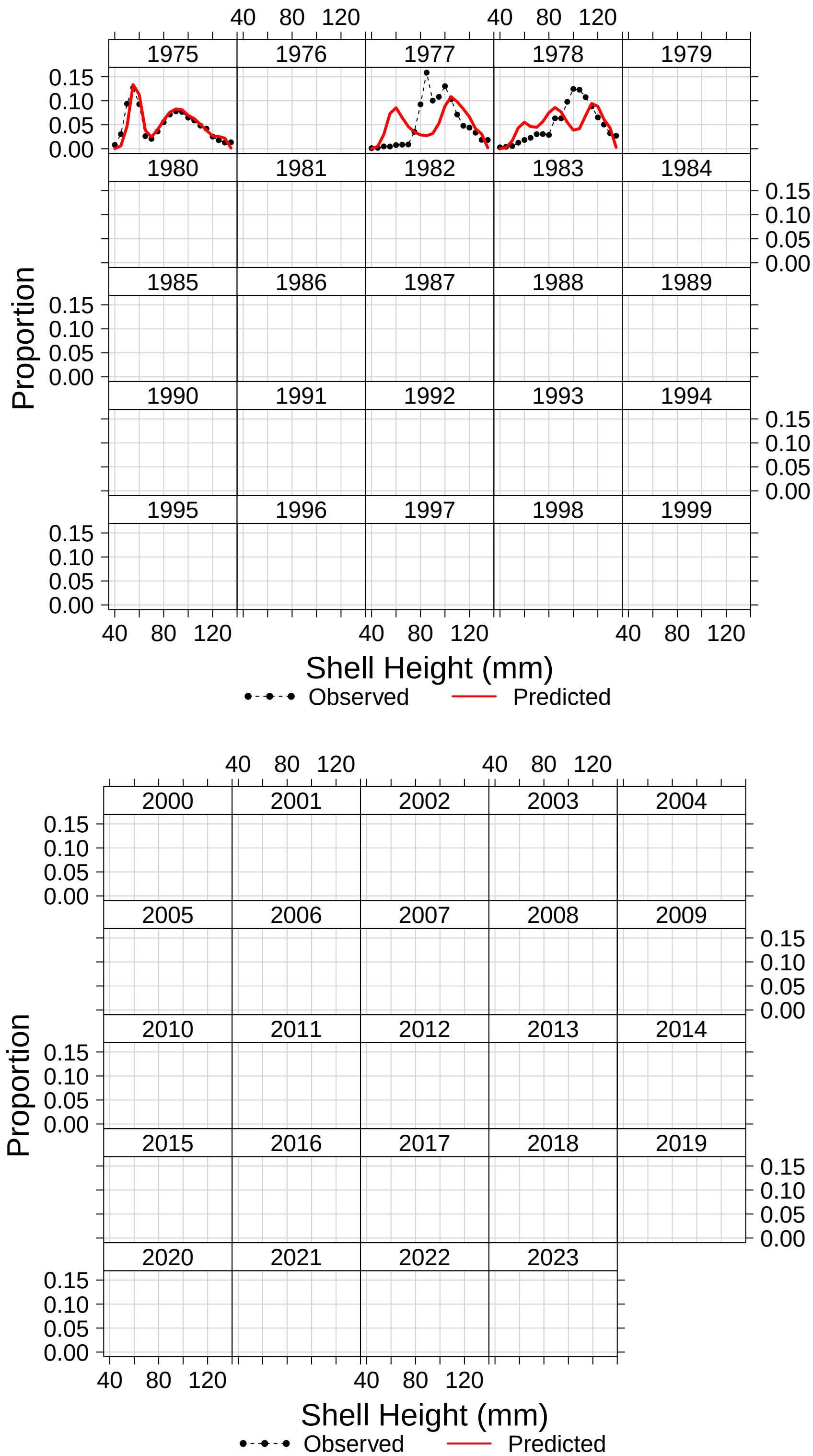


Figure 4.16: Comparison of unlined dredge survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Mid-Atlantic areas.

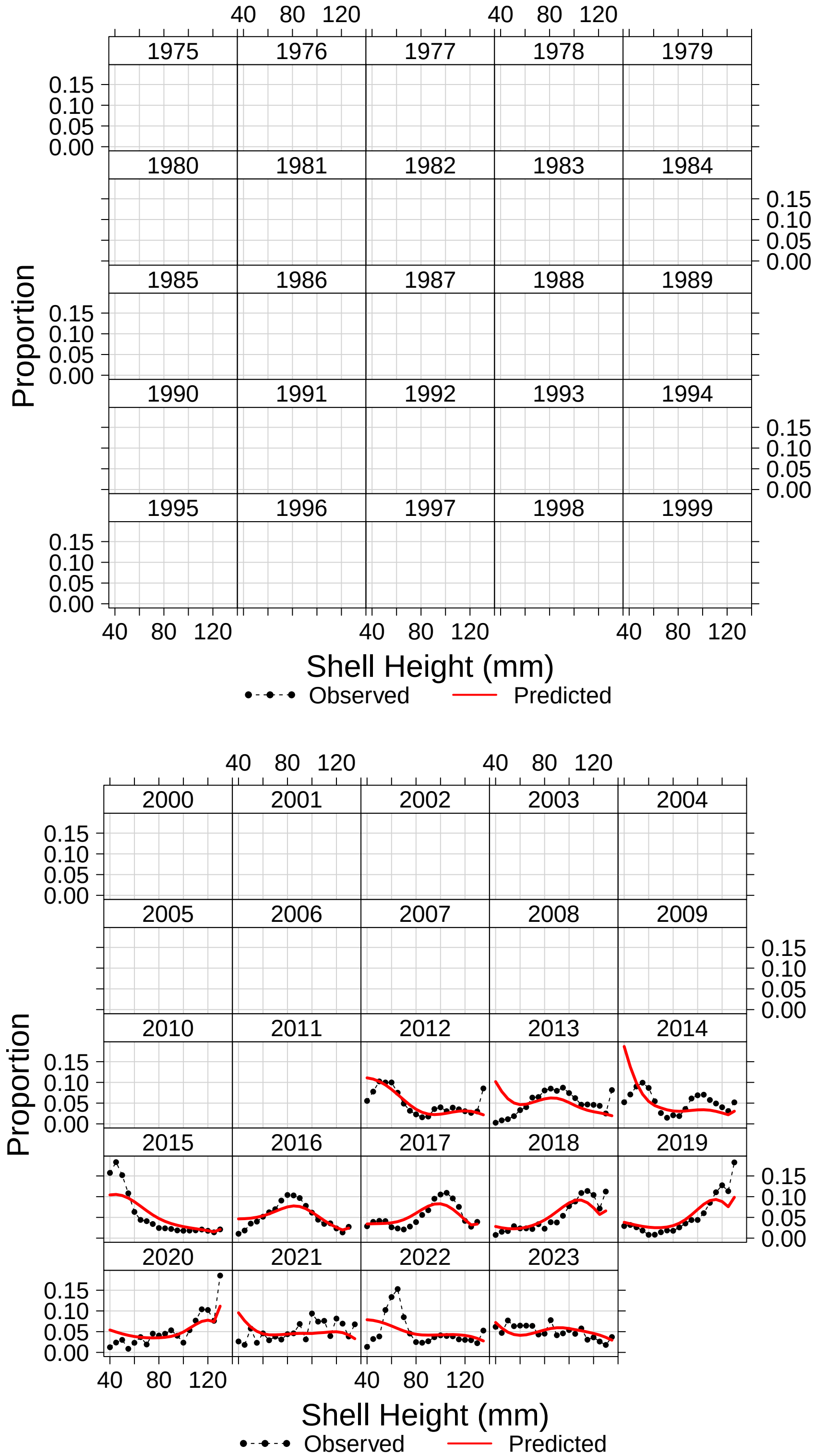


Figure 4.17: Comparison of Habcam survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Mid-Atlantic areas.

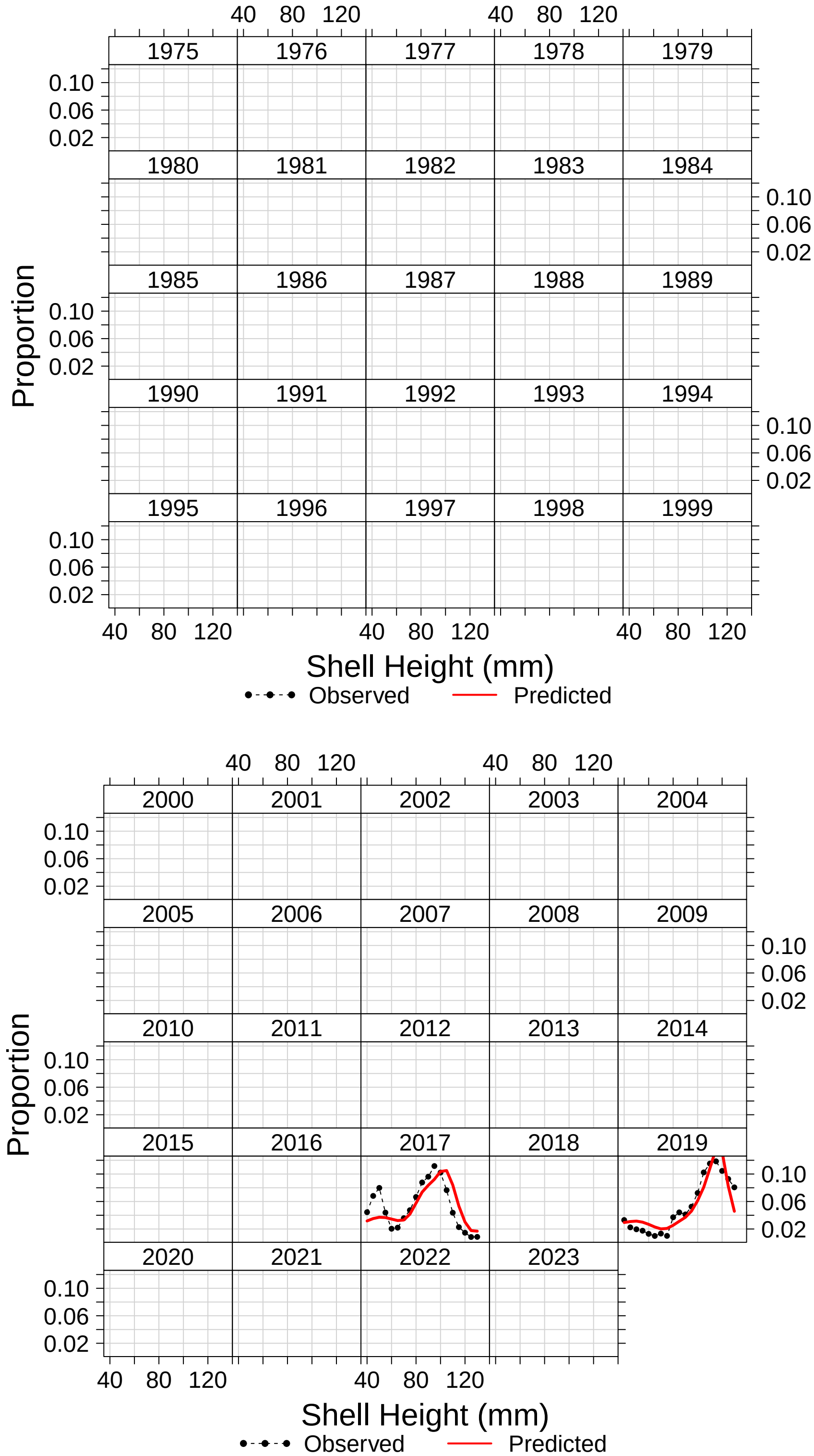


Figure 4.18: Comparison of SMAST digital camera survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Mid-Atlantic areas.

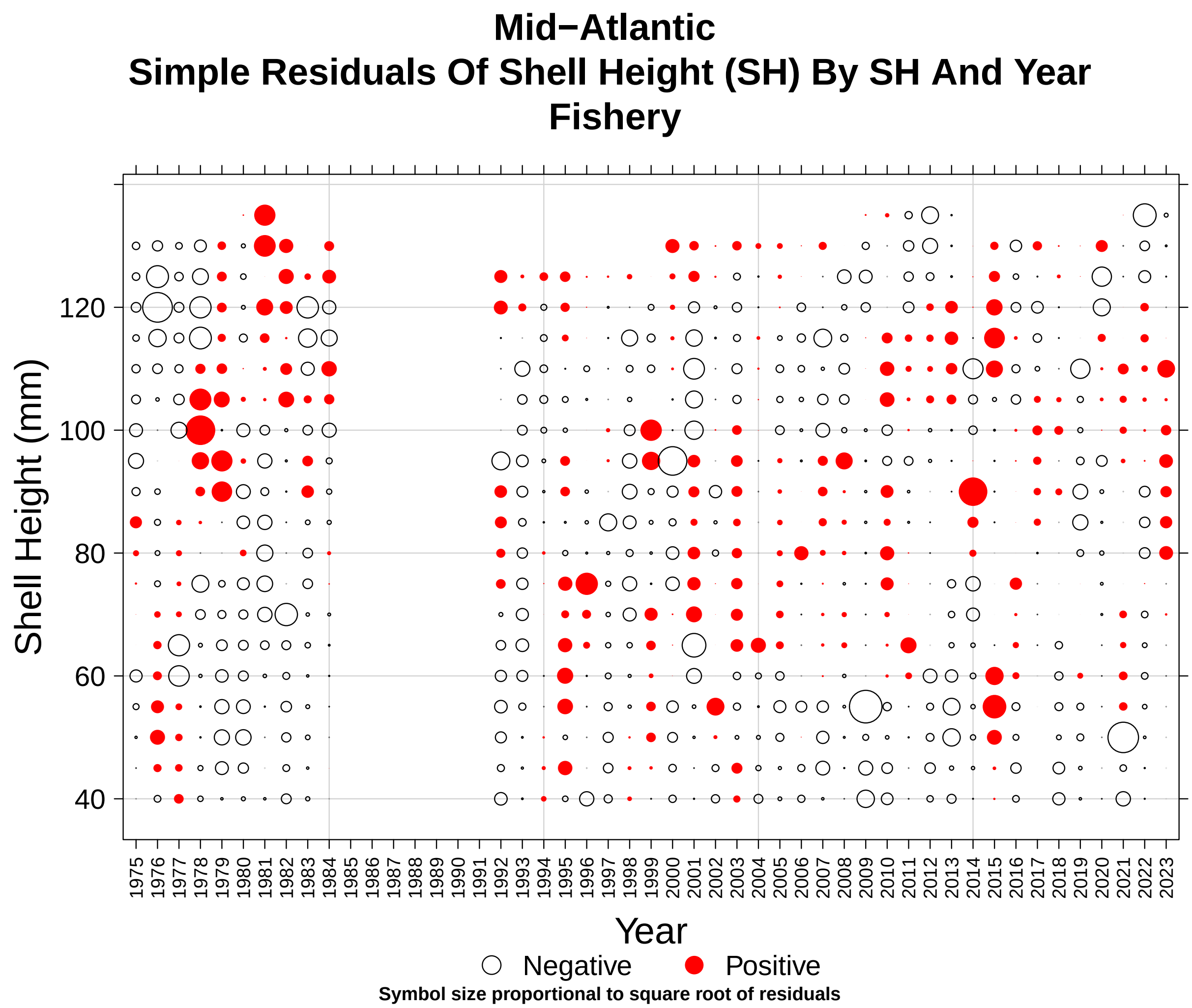


Figure 4.19: Simple residuals of fishery shell height proportions for Mid-Atlantic areas. Symbol areas are proportional to residual.

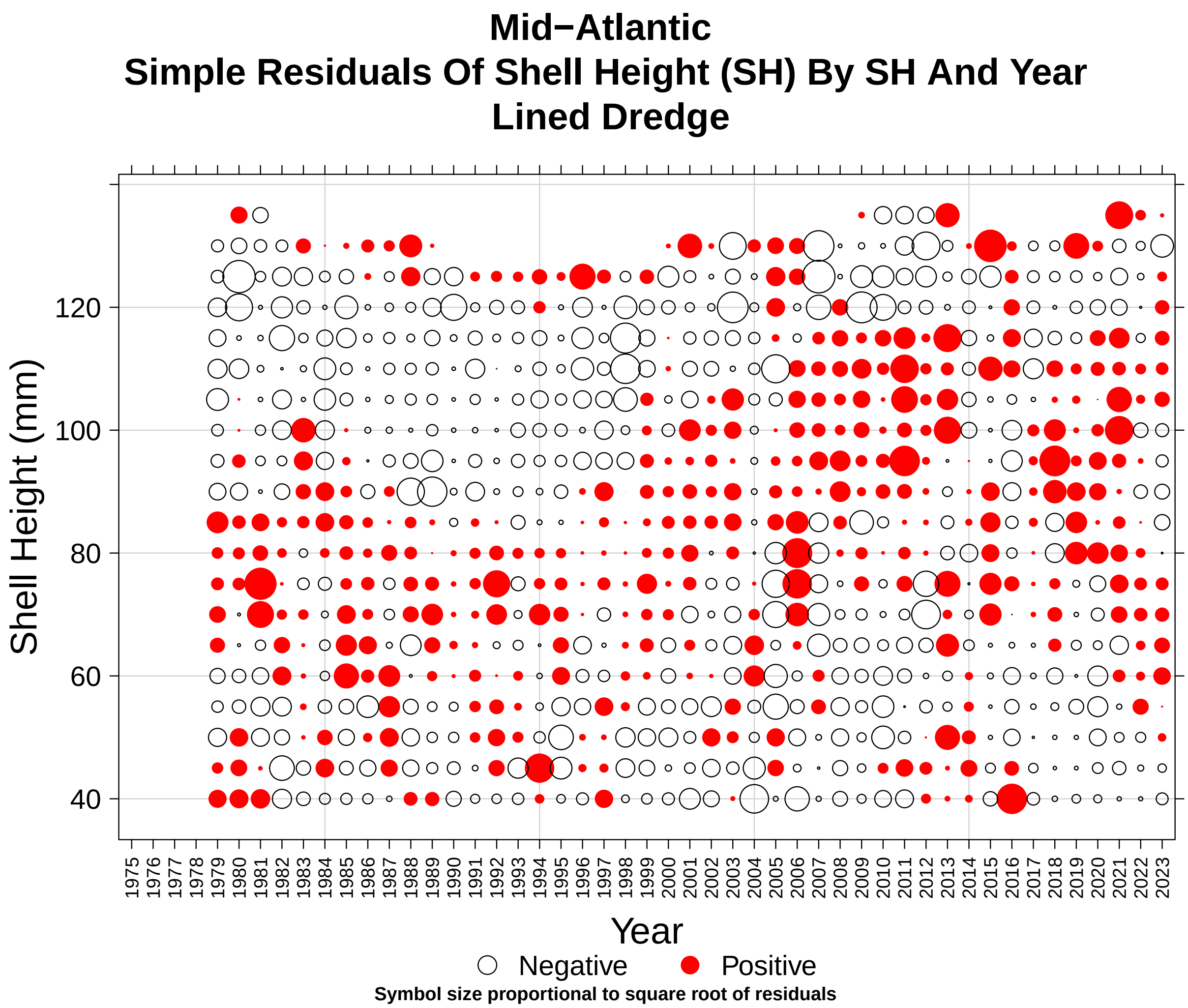


Figure 4.20: Simple residuals of lined dredge survey shell height proportions for Mid-Atlantic areas. Symbol areas are proportional to residual.

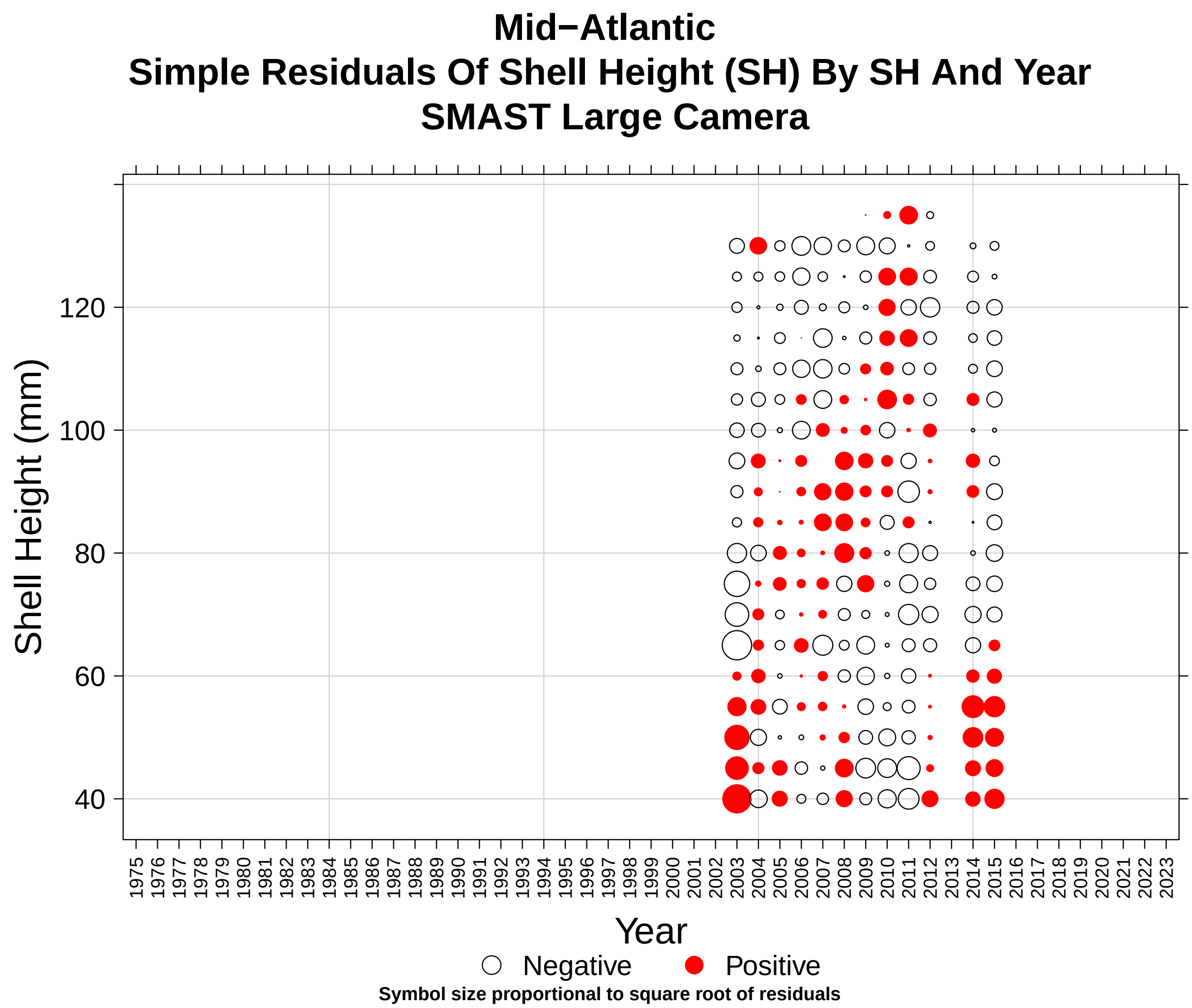


Figure 4.21: Simple residuals of SMAST large camera survey shell height proportions for Mid-Atlantic areas. Symbol areas are proportional to residual.

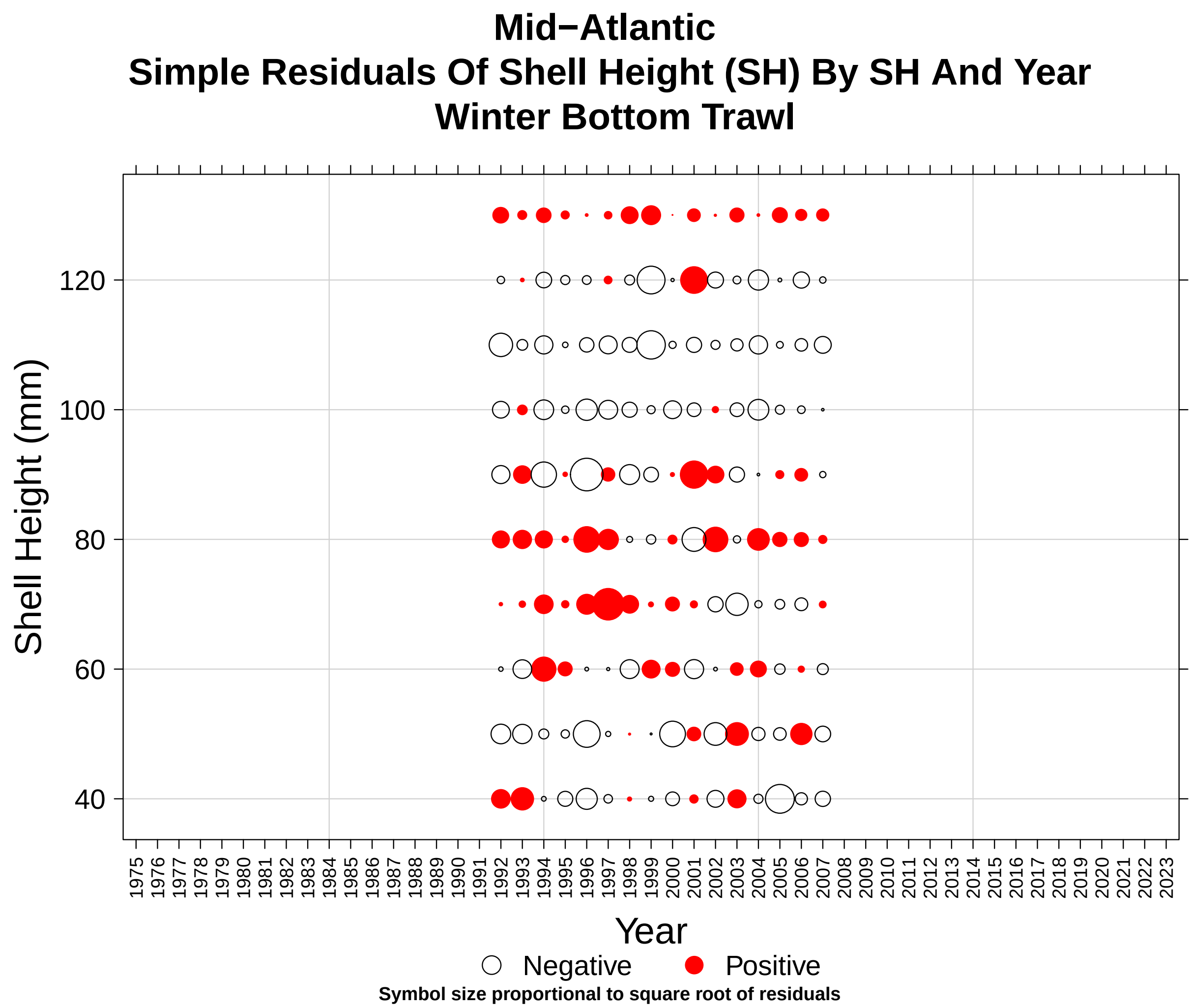


Figure 4.22: Simple residuals of winter bottom trawl survey shell height proportions for Mid-Atlantic areas. Symbol areas are proportional to residual.

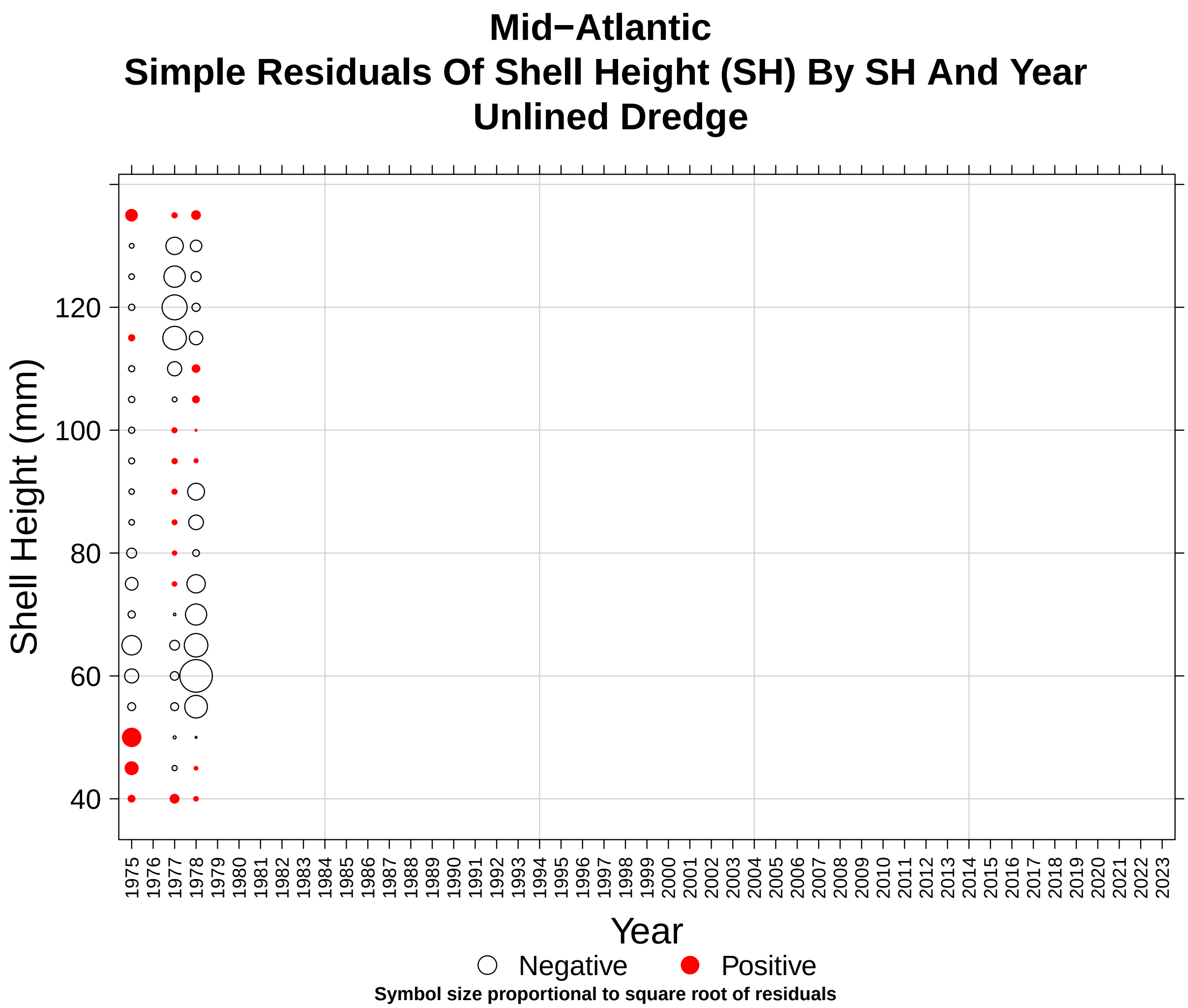


Figure 4.23: Simple residuals of unlined dredge survey shell height proportions for Mid-Atlantic areas. Symbol areas are proportional to residual.

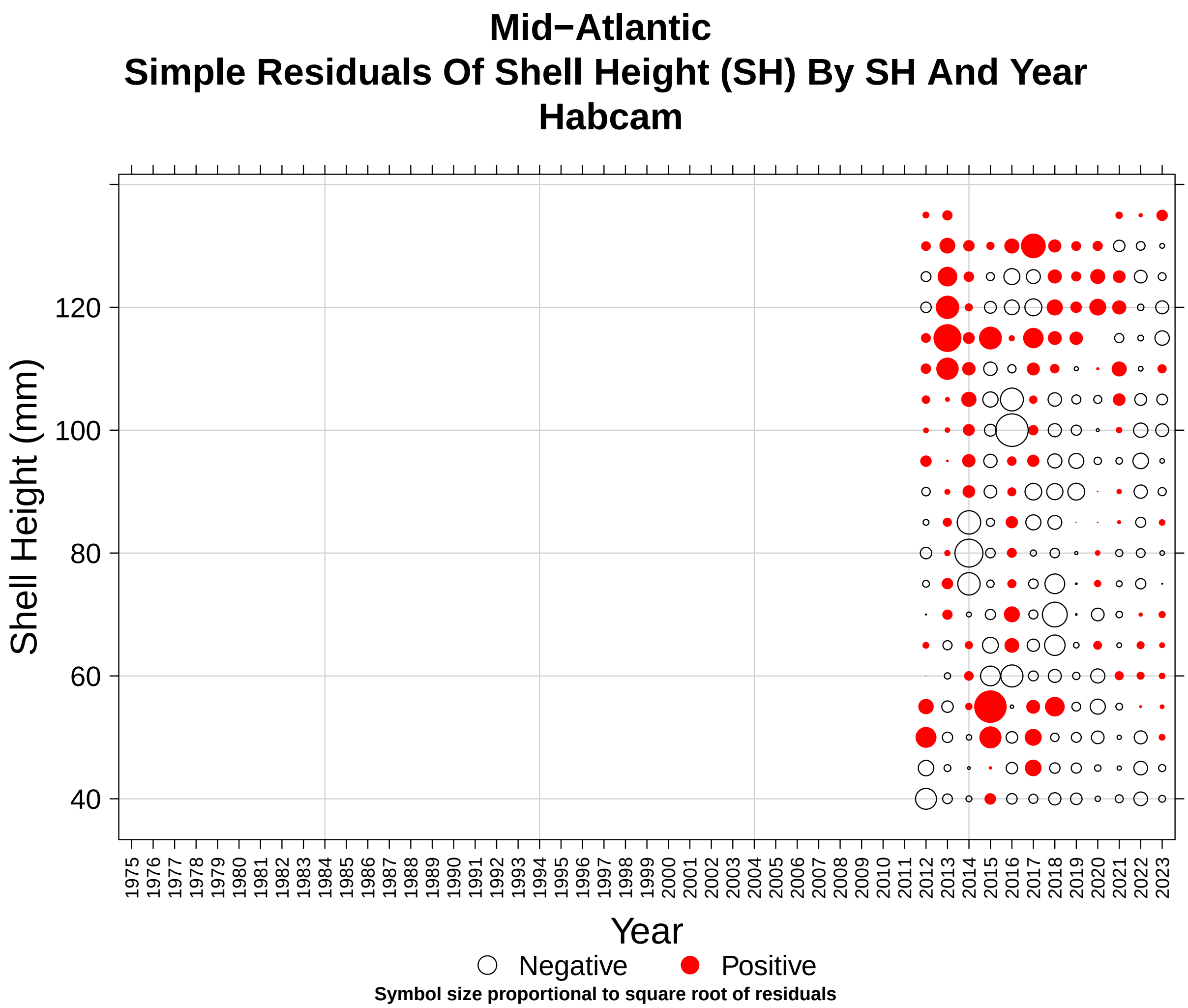


Figure 4.24: Simple residuals of Habcam survey shell height proportions for Mid-Atlantic areas. Symbol areas are proportional to residual.

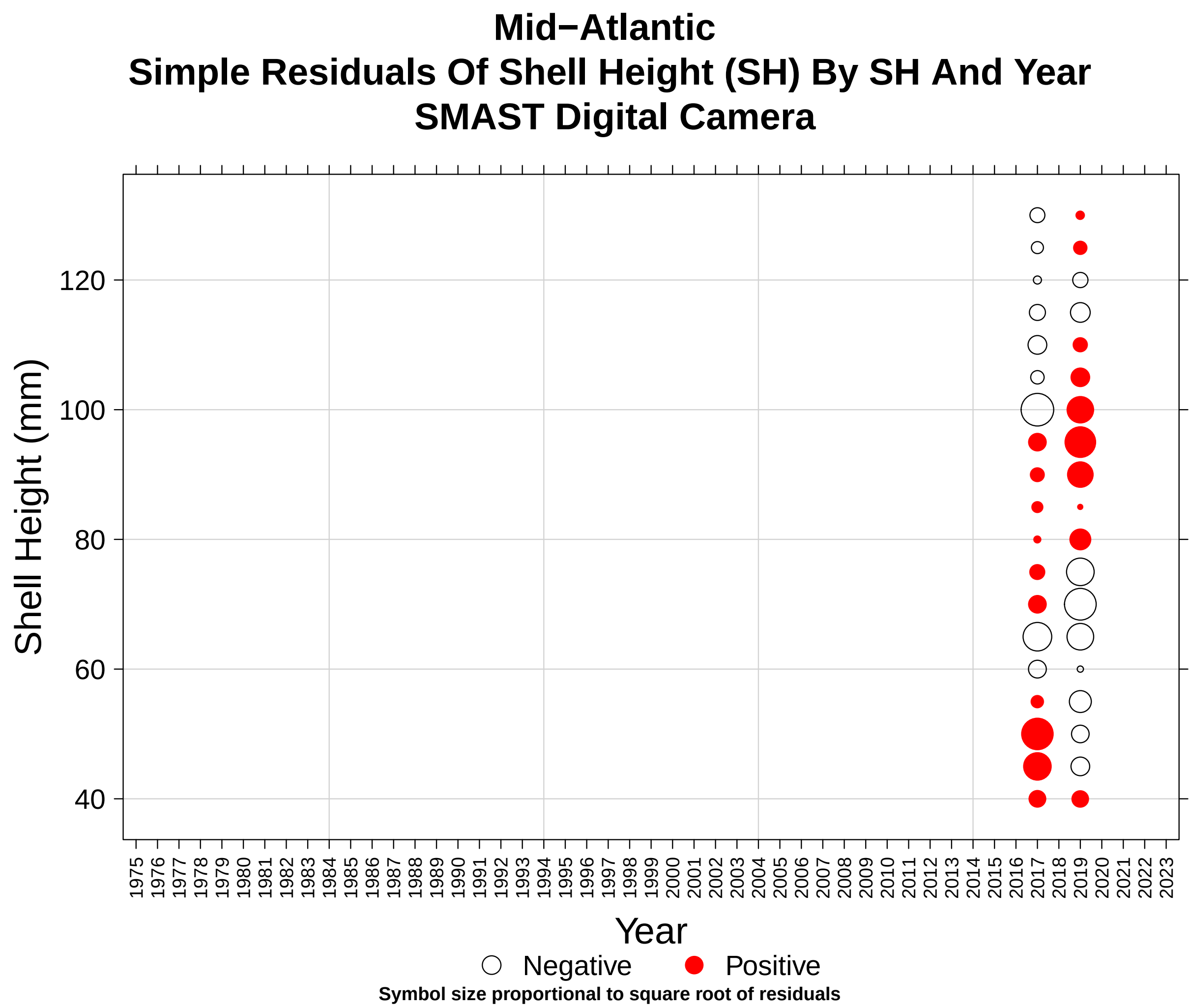


Figure 4.25: Simple residuals of SMAST digital camera survey shell height proportions for Mid-Atlantic areas. Symbol areas are proportional to residual.

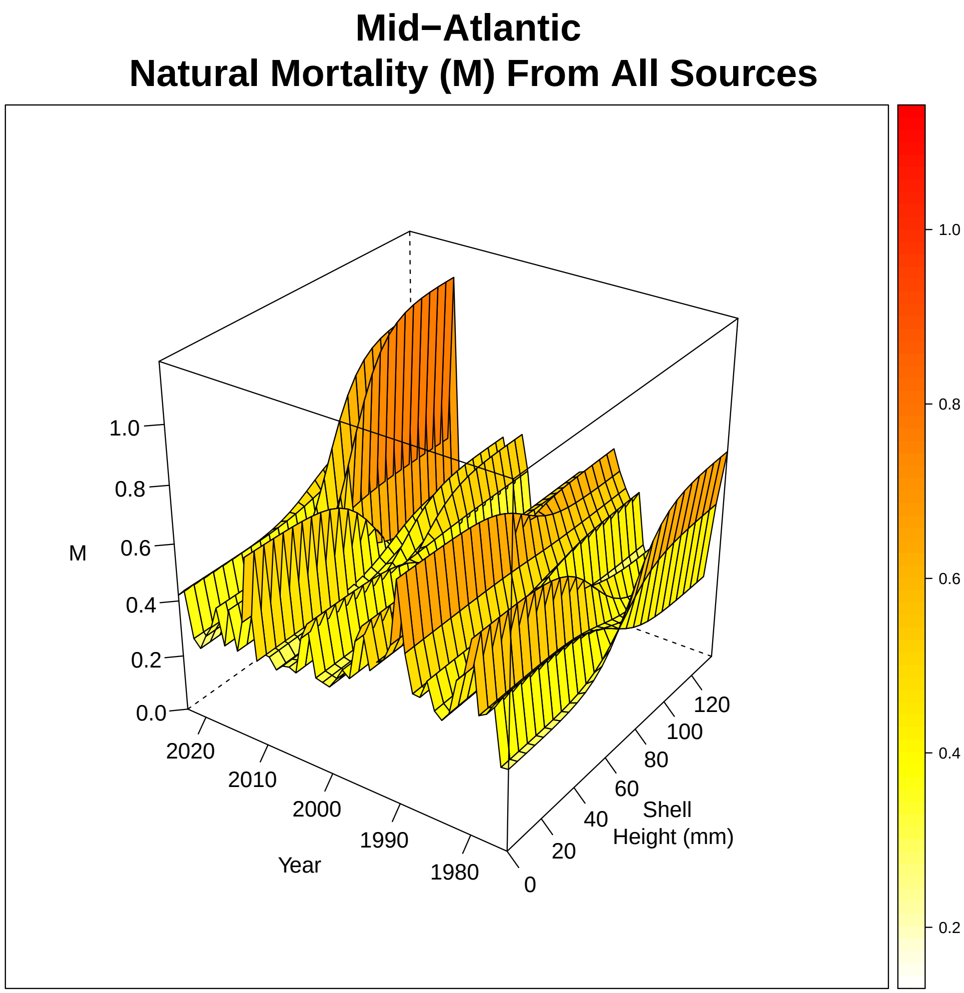


Figure 4.26: Estimated natural mortality by size from 1975 to 2023 for Mid-Atlantic areas.

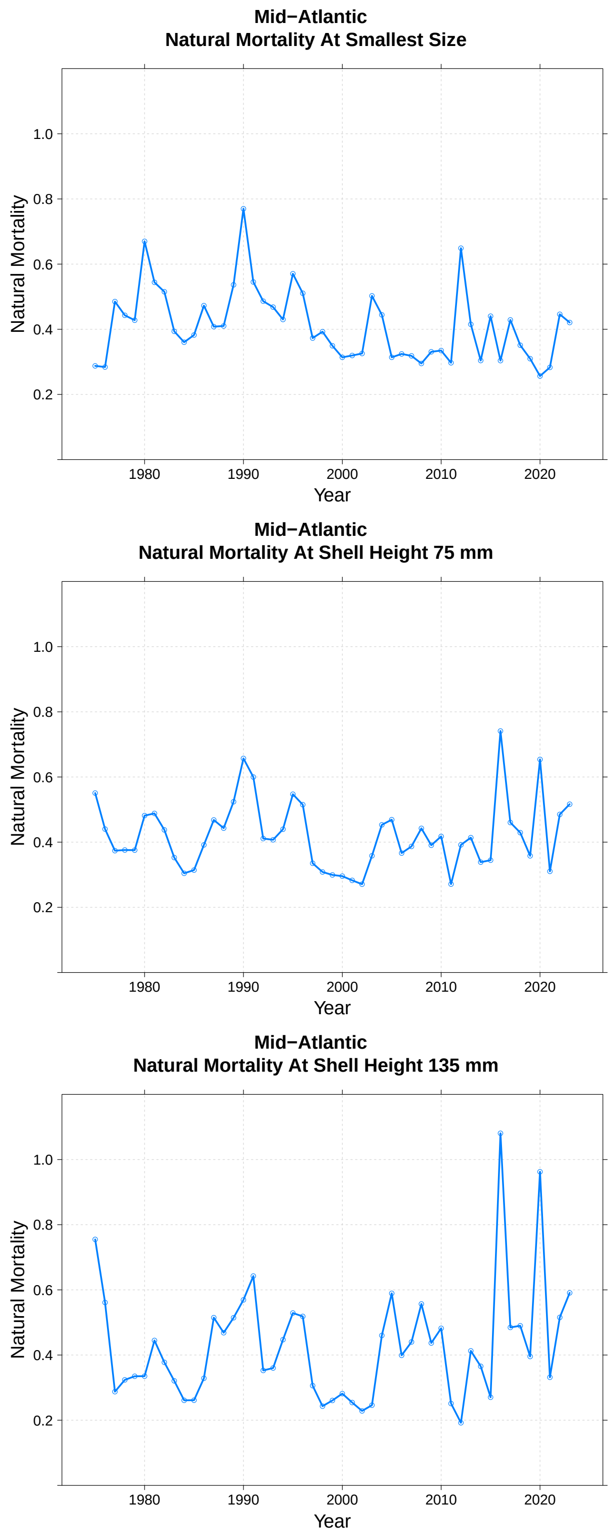


Figure 4.27: Estimated natural mortality for 0-5 mm (top), 75-80 mm (middle), and 135+ mm (bottom) scallops from 1975 to 2023 for Mid-Atlantic areas.

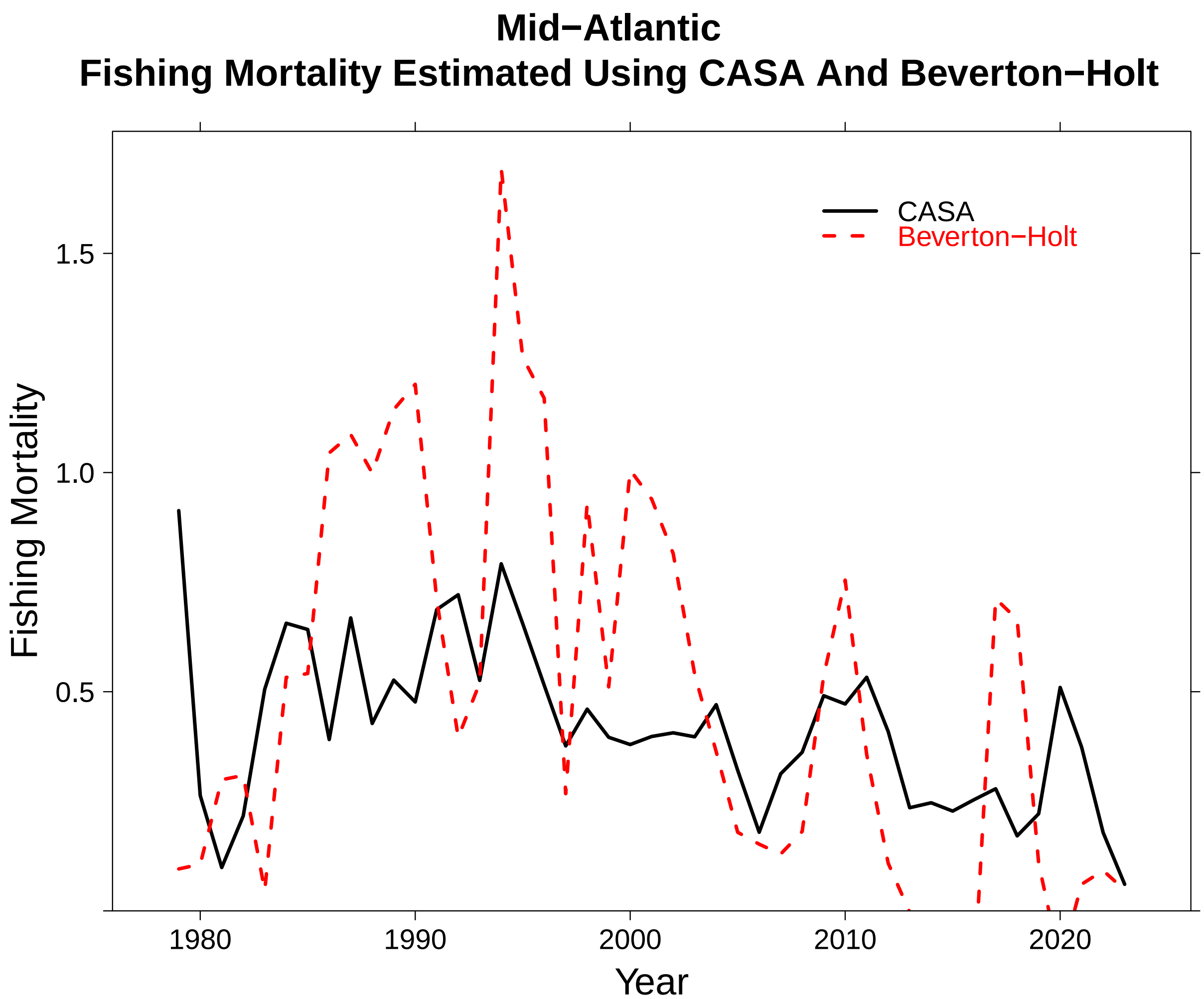


Figure 4.28: Comparison of fully recruited CASA fishing mortality with those calculated from the Beverton-Holt equilibrium length based estimator for Mid-Atlantic areas.

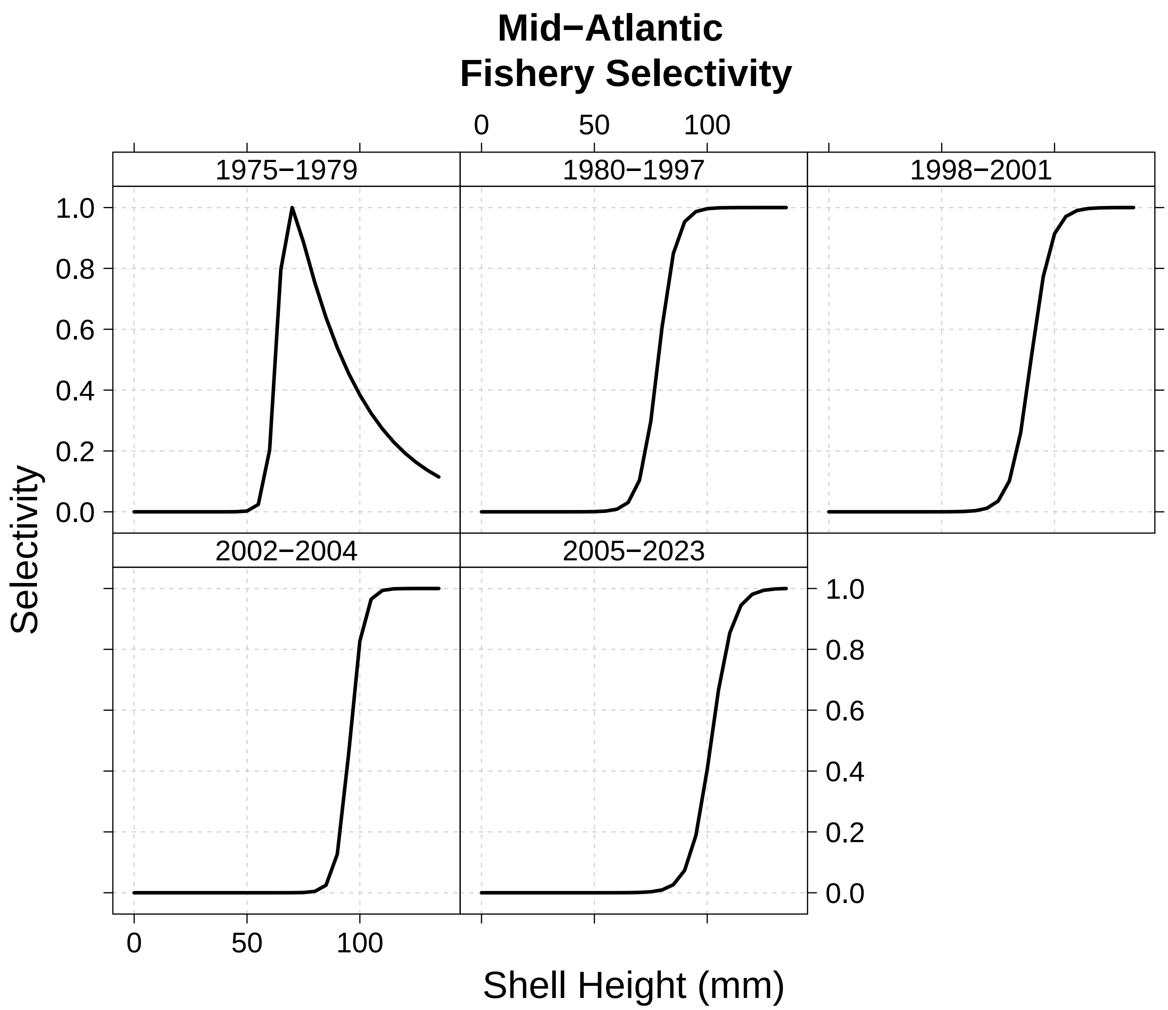


Figure 4.29: CASA model estimated fishery selectivity curves for Mid-Atlantic areas.

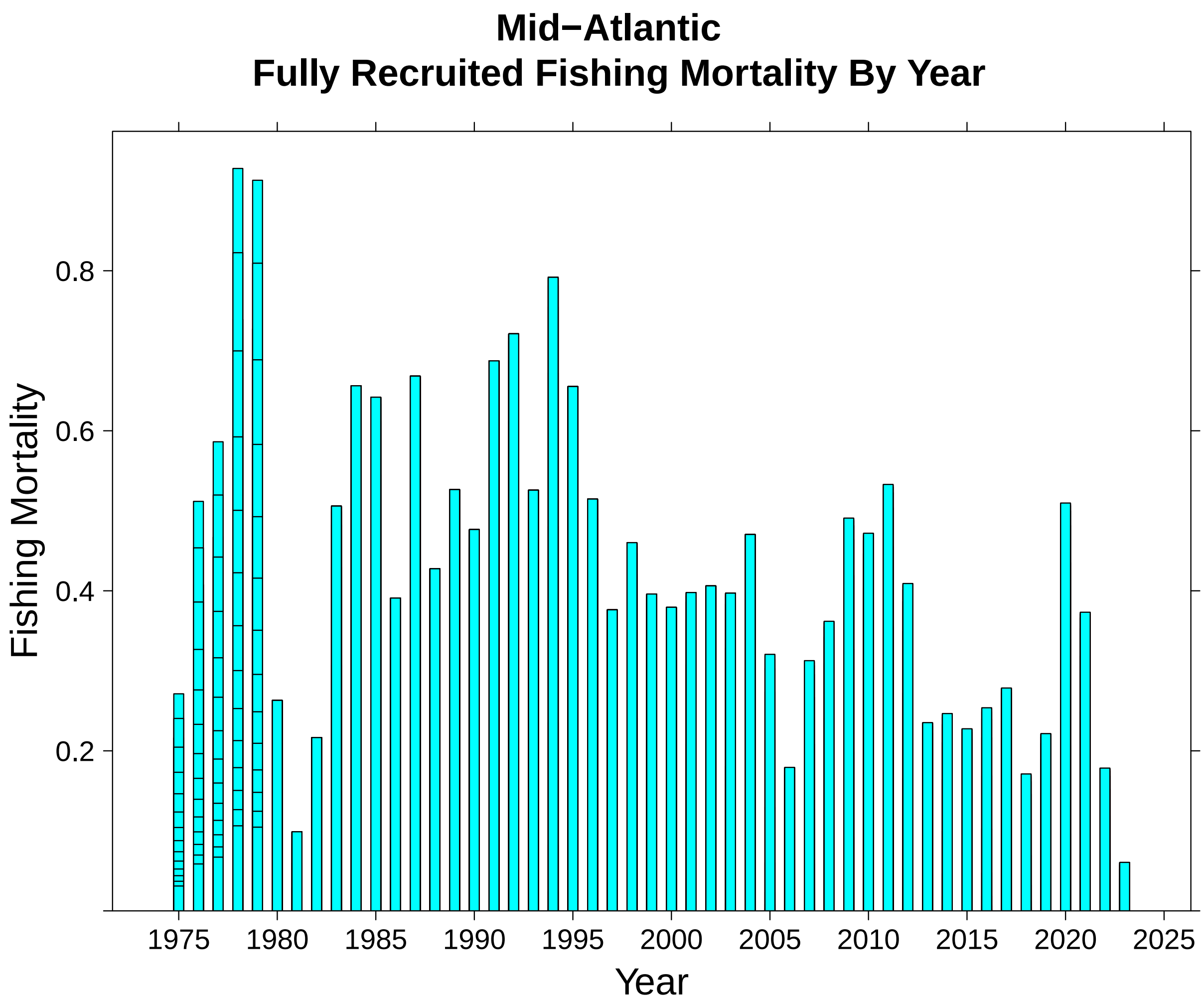


Figure 4.30: CASA model estimated fully recruited fishing mortality for Mid-Atlantic areas.

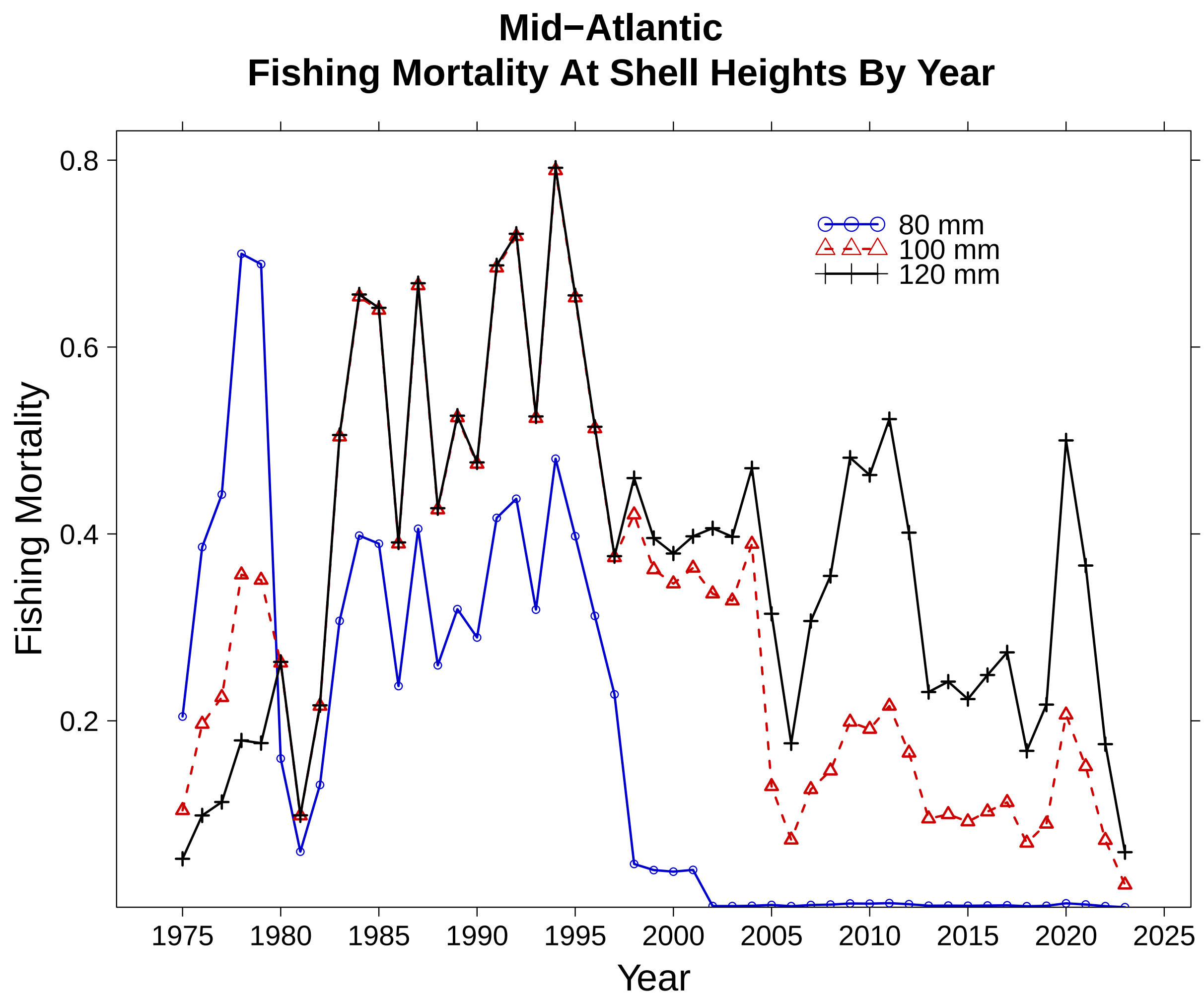


Figure 4.31: CASA model estimated fishing mortality at 80 mm (solid line with circles), 100 mm (dashed line with triangles), and 120 mm SH (dashed line with crosses) for Mid-Atlantic areas.

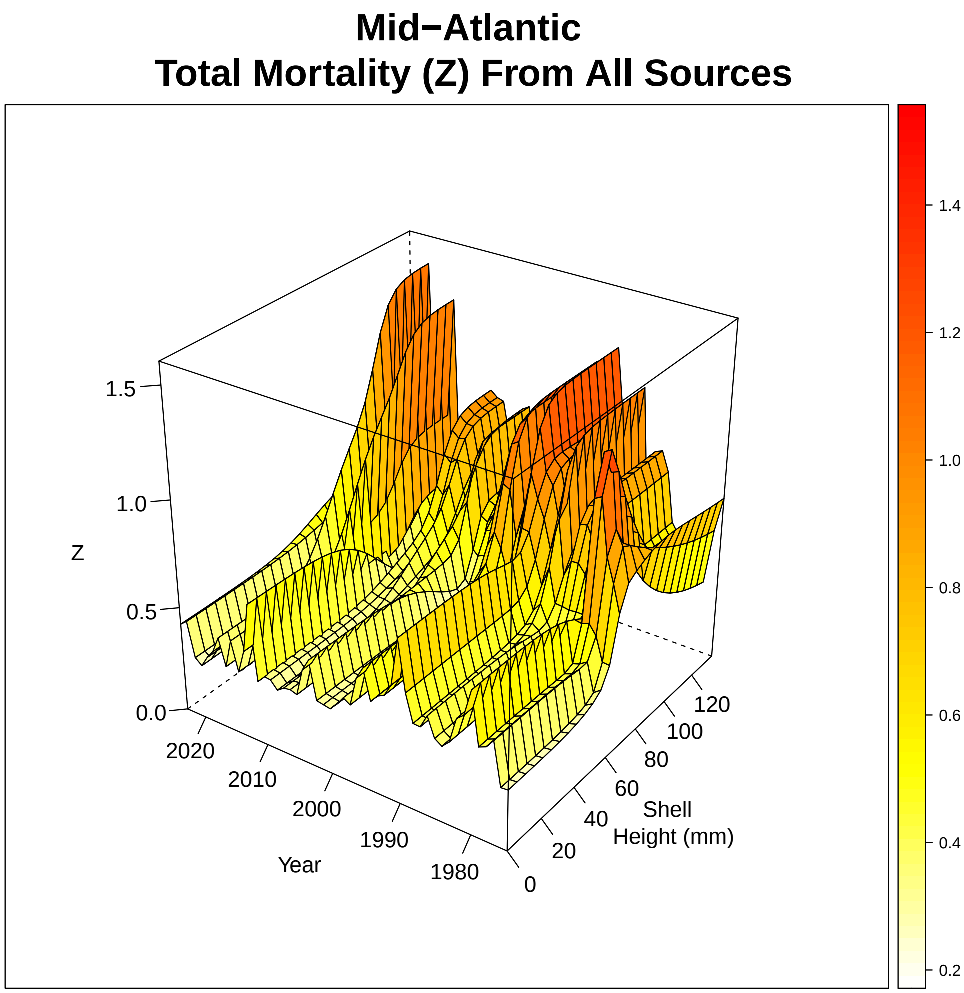


Figure 4.32: Estimated total mortality by size from 1975 to 2023 for Mid-Atlantic areas.

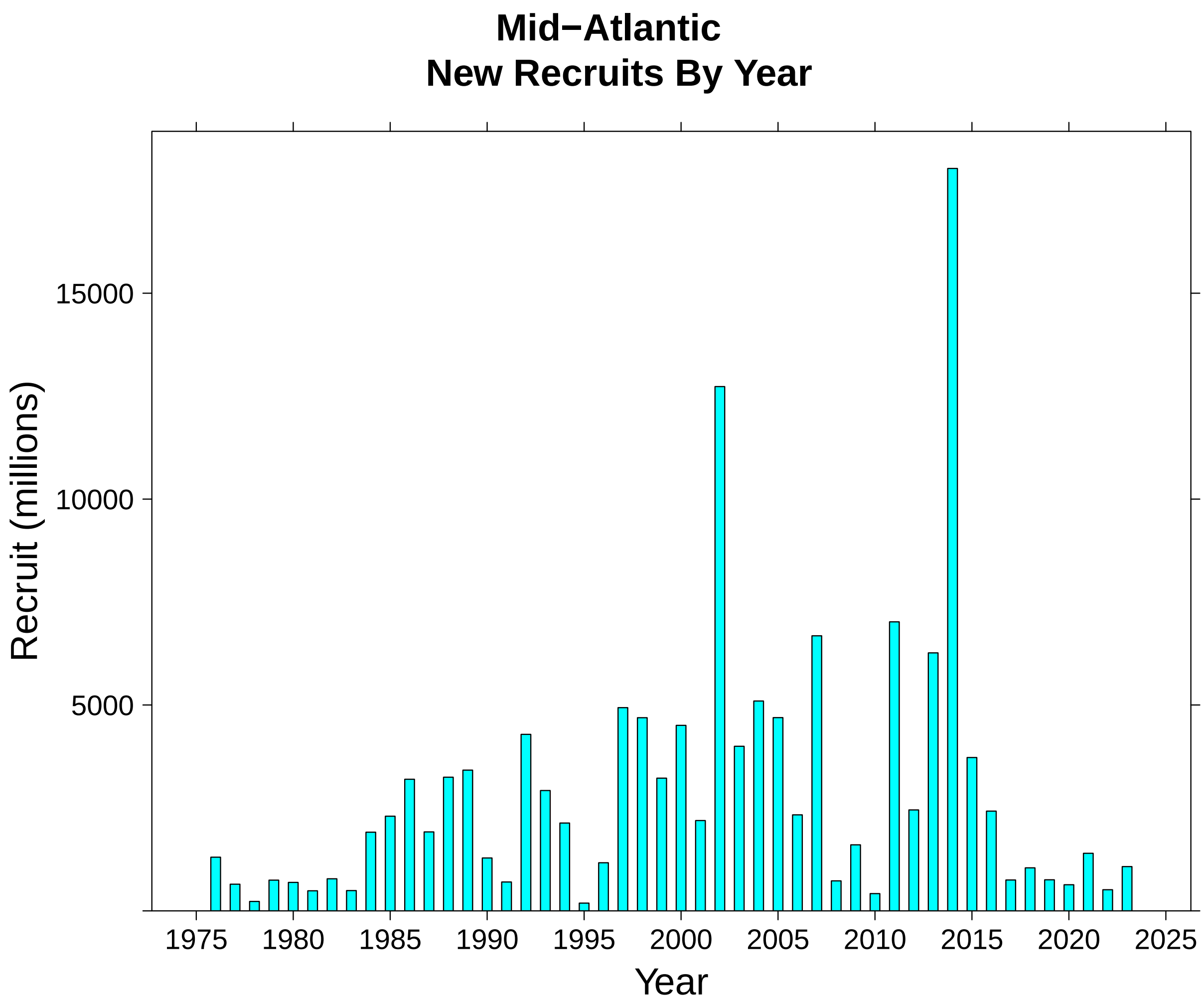


Figure 4.33: CASA model estimated recruitment for Mid-Atlantic areas.

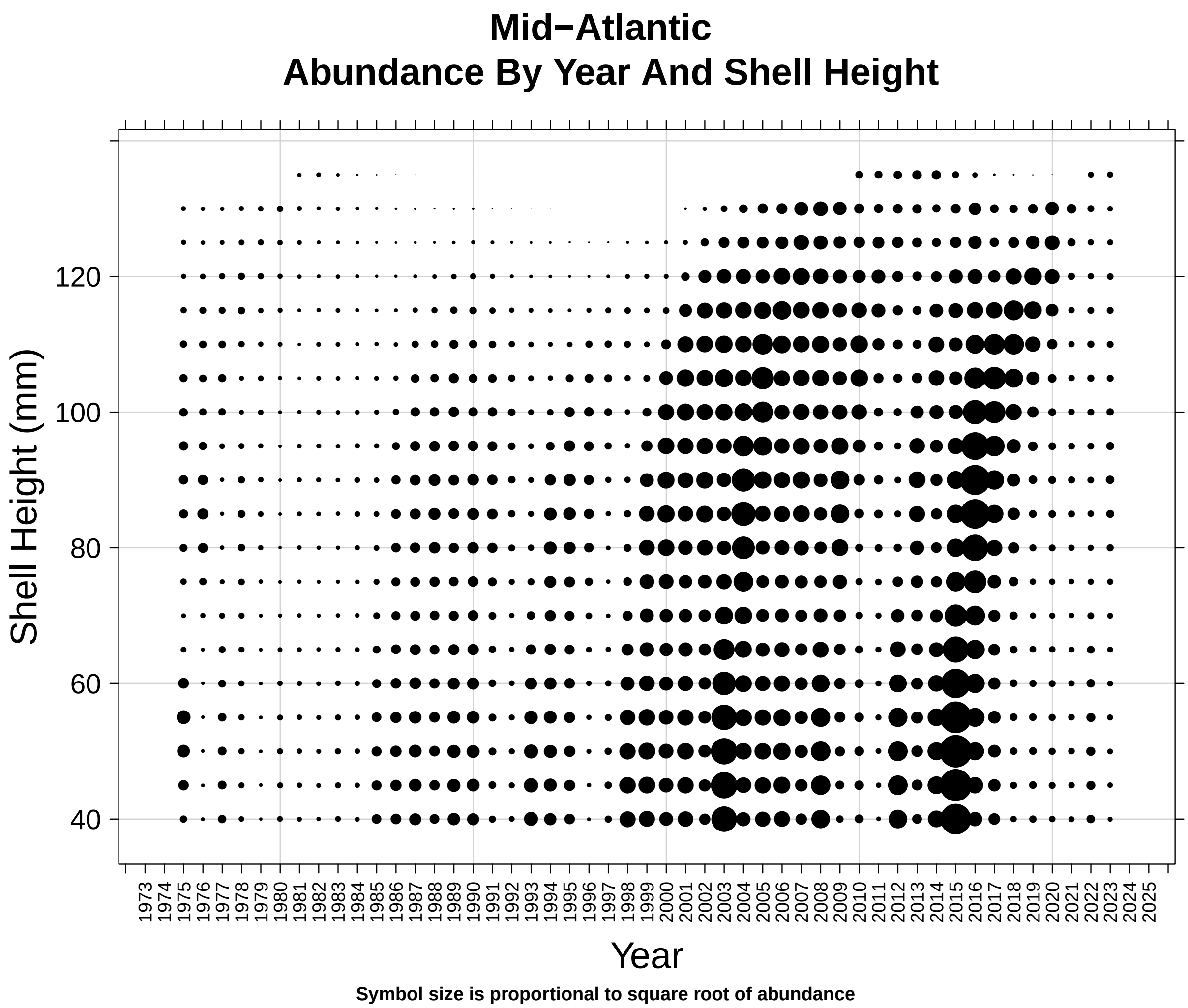


Figure 4.34: CASA model estimated abundances at shell height for Mid-Atlantic areas. Symbol areas are proportional to abundance.

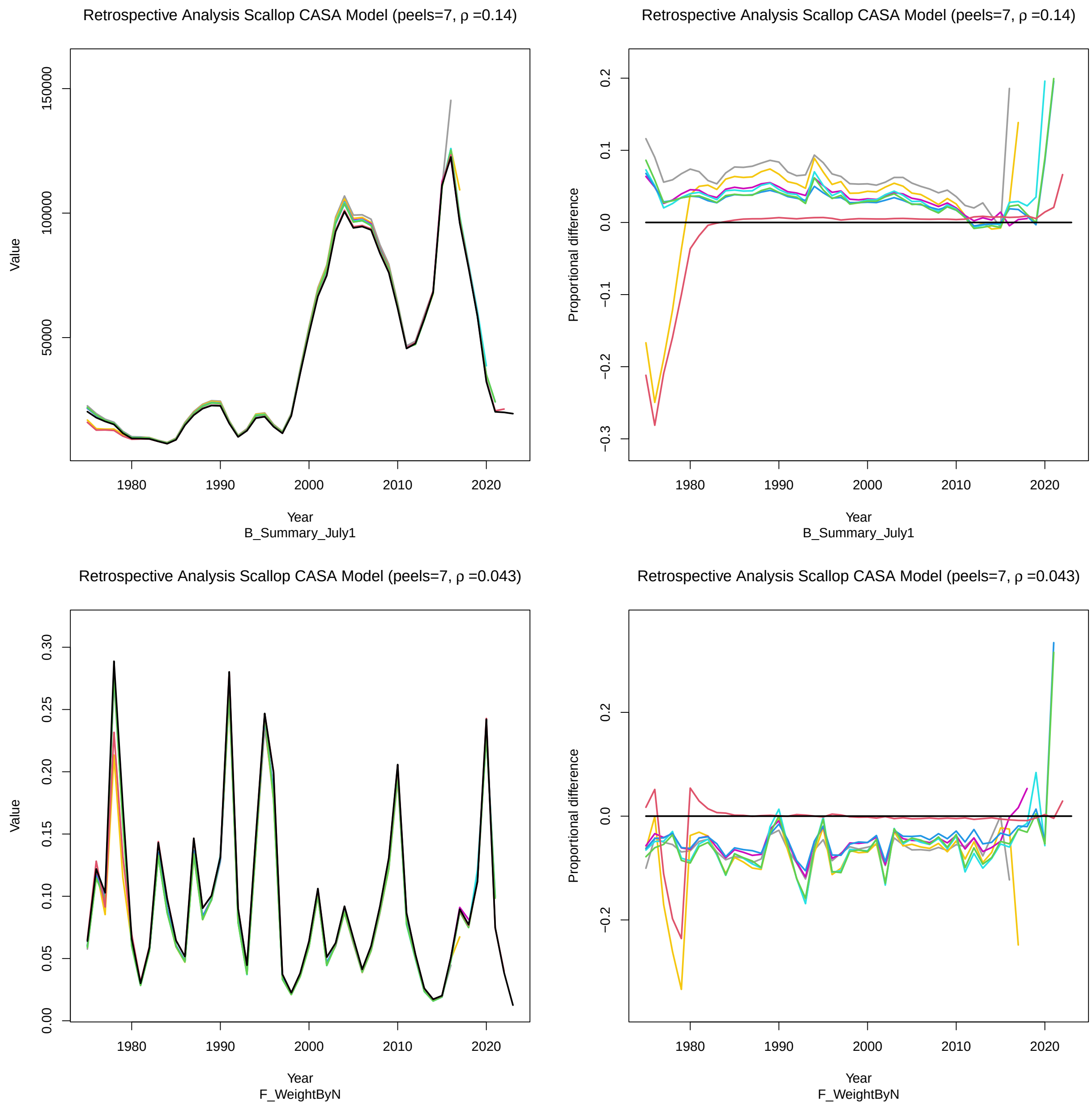


Figure 4.35: Retrospective plots for biomass and fishing mortality for Mid-Atlantic areas. Retrospectives are shown on both absolute and relative scales.

Figure 4.36: Total negative log-likelihood surface from profiling model starting size, mean natural mortality for juveniles and adults, and h_0. The box indicated the run with the smallest total likelihood.

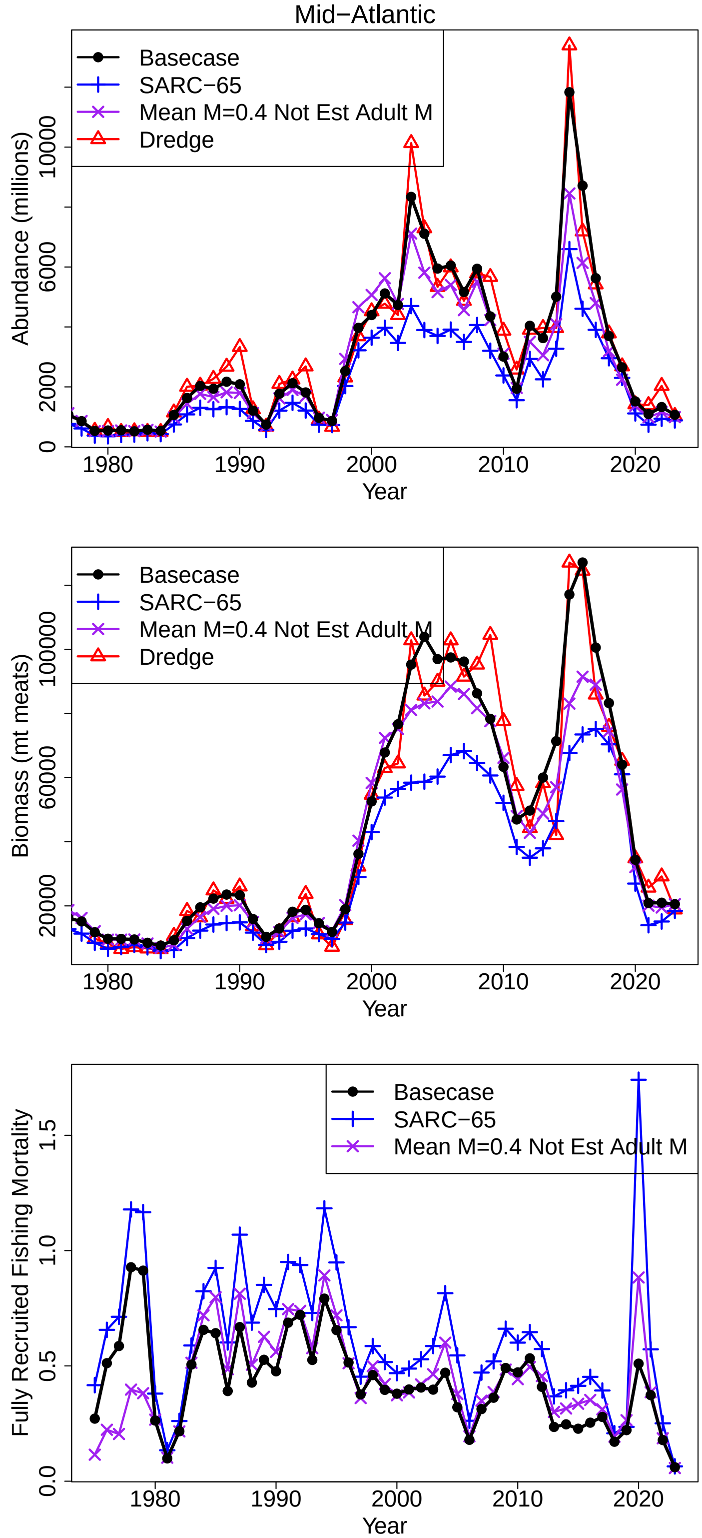


Figure 4.37: Comparison of estimated abundance (millions), biomass (mt meats), and fully recruited fishing mortality from current and SARC-65 CASA model configurations, and lined dredge survey for Mid-Atlantic areas.

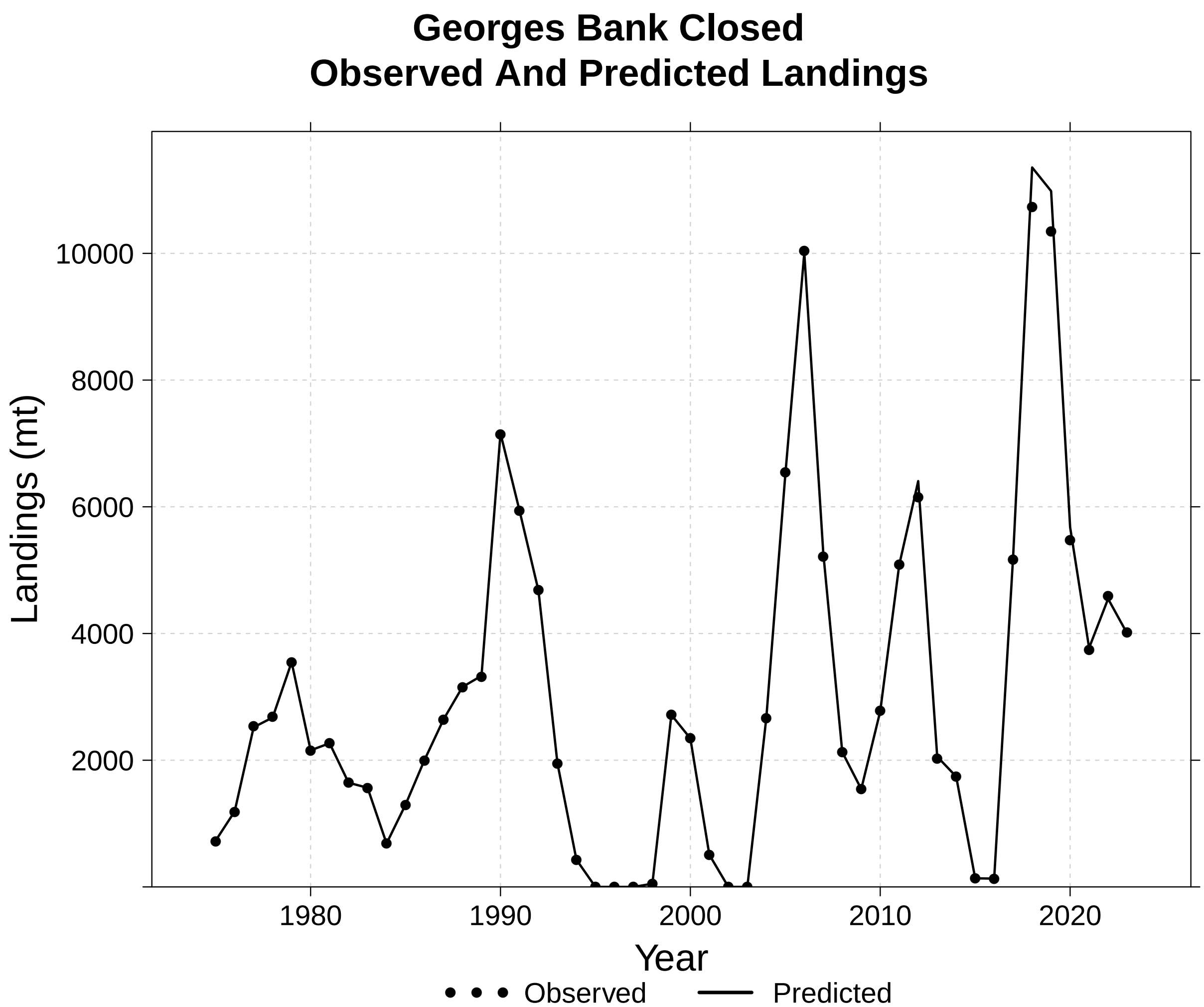


Figure 4.38: Observed catch (mt meats, solid circles) and corresponding model estimates (lines) by year in Georges Bank closed areas.

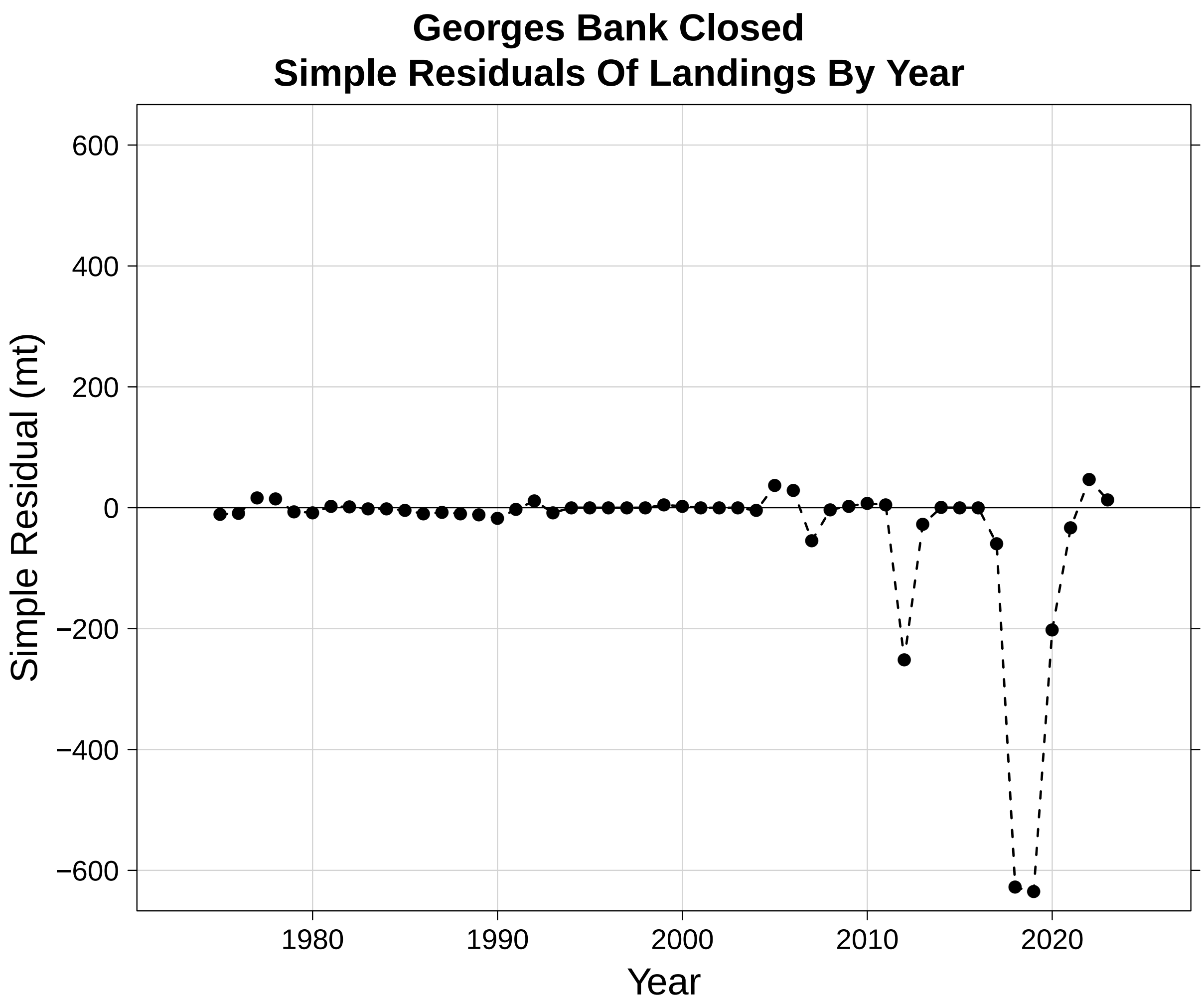


Figure 4.39: Simple residuals of catch (mt meats) by year in Georges Bank closed areas.

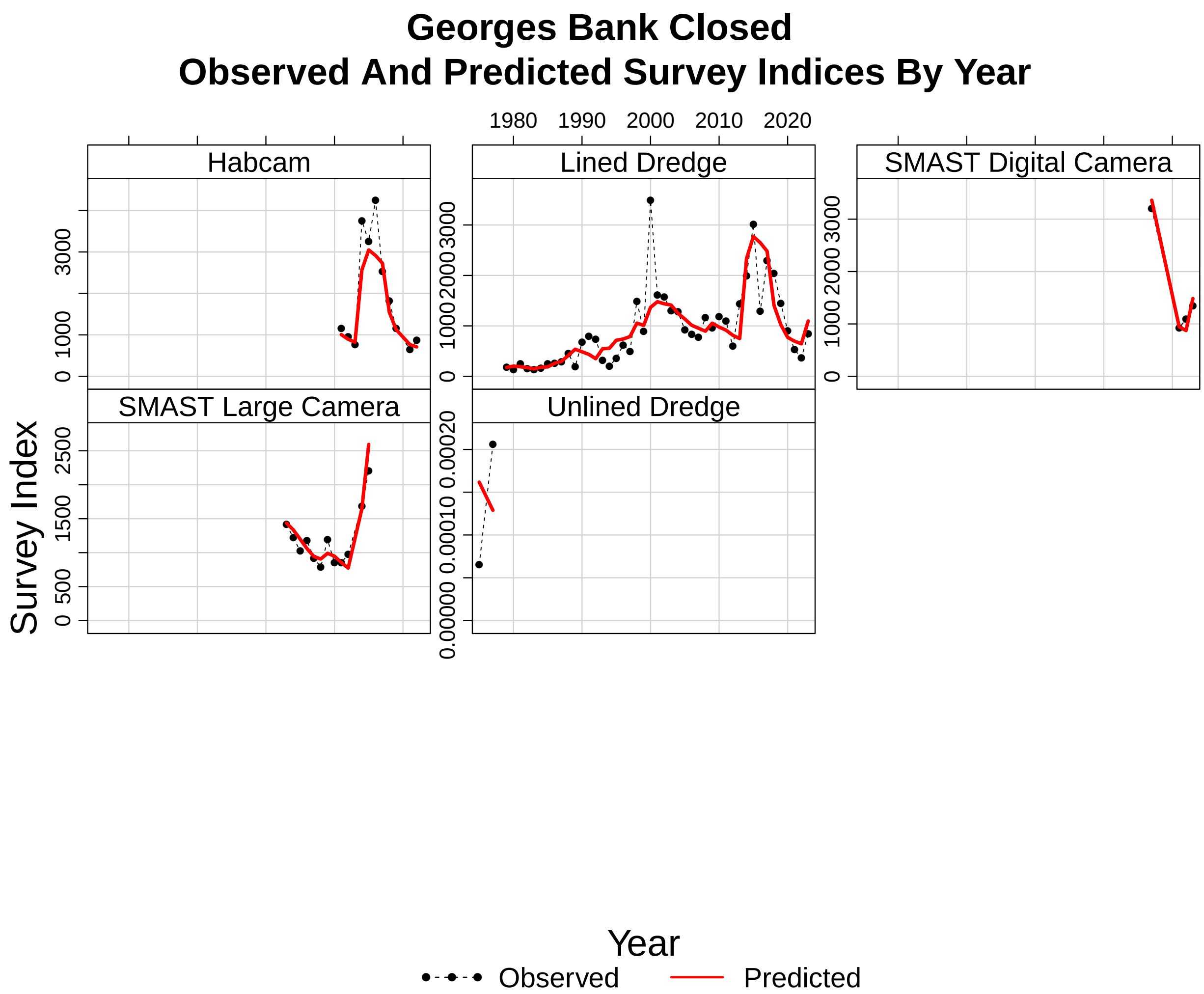


Figure 4.40: Observed survey trend and corresponding model estimates for the SMAST digital camera, lined dredge, Habcam, SMAST large camera, and unlined dredge surveys in Georges Bank closed areas.

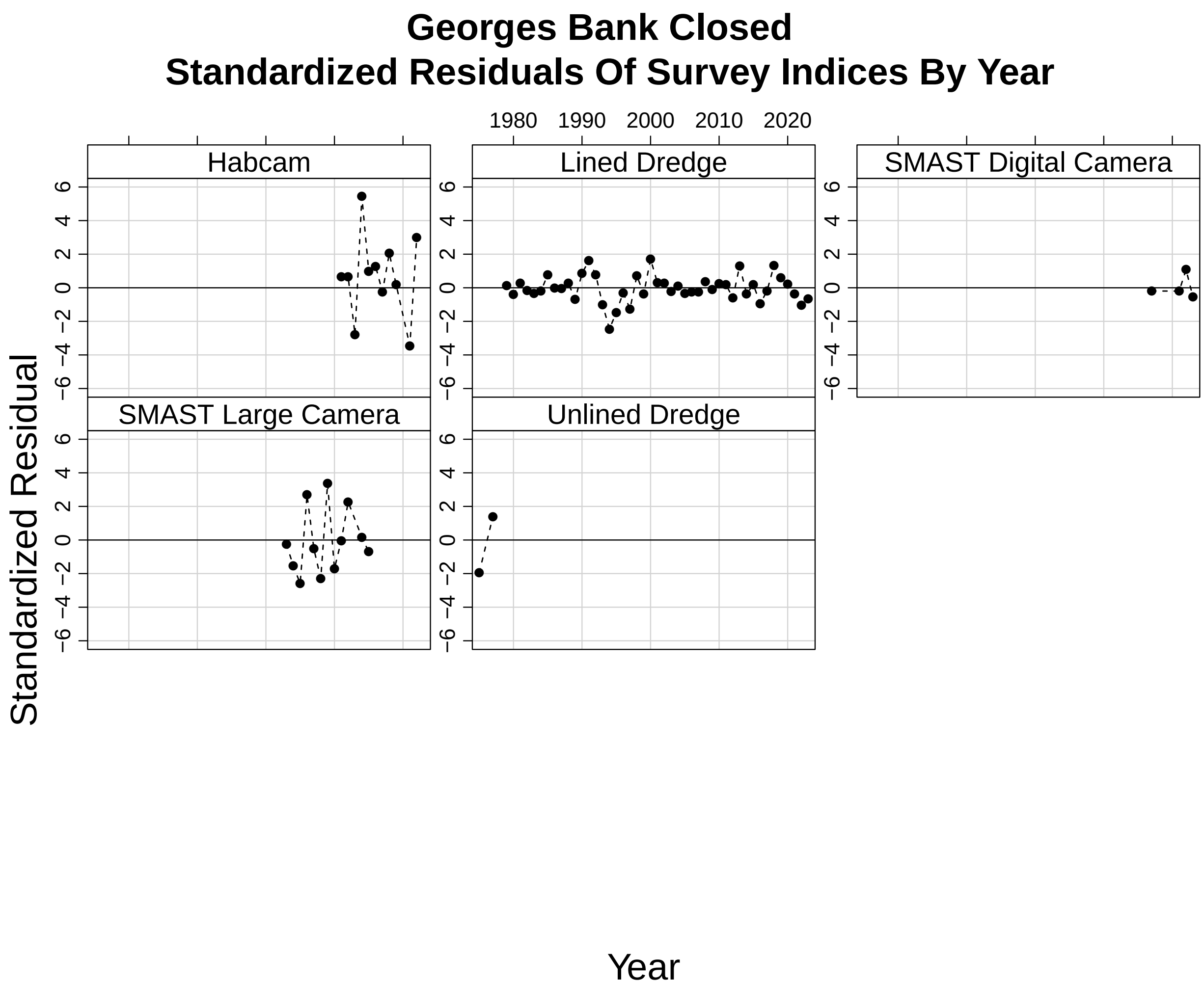


Figure 4.41: Standardized residuals of survey indices by year for the SMAST digital camera, lined dredge, Habcam, SMAST large camera, unlined dredge, and winter bottom trawl surveys in Georges Bank closed areas.

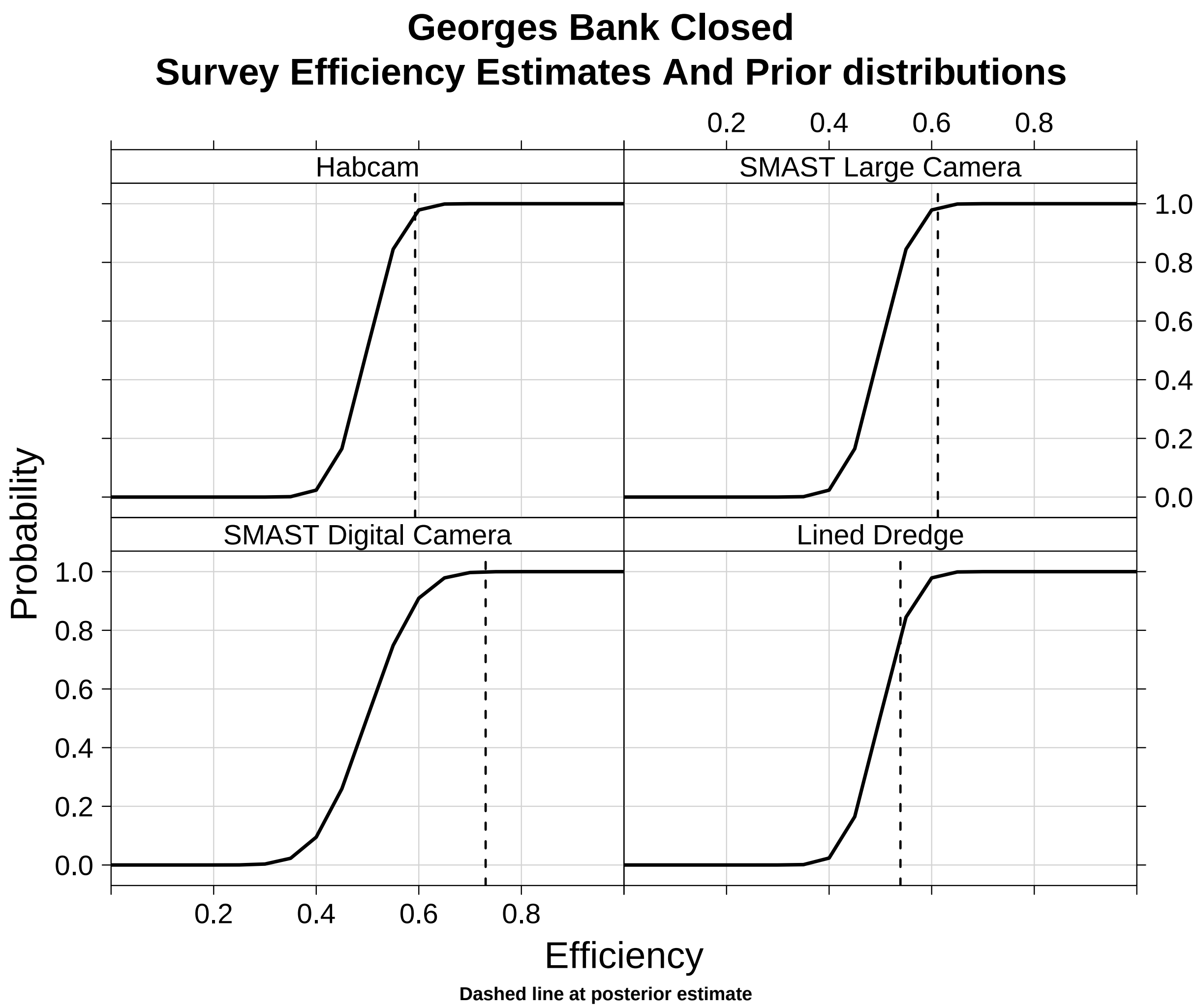


Figure 4.42: Prior cumulative distributions for catchability of Habcam, SMAST large camera, SMAST digital camera, and lined dredge surveys for Georges Bank closed areas. The dashed lines are the mean posterior estimate for survey catchability. The surveys were adjusted to have a mean prior catchability of 0.5.

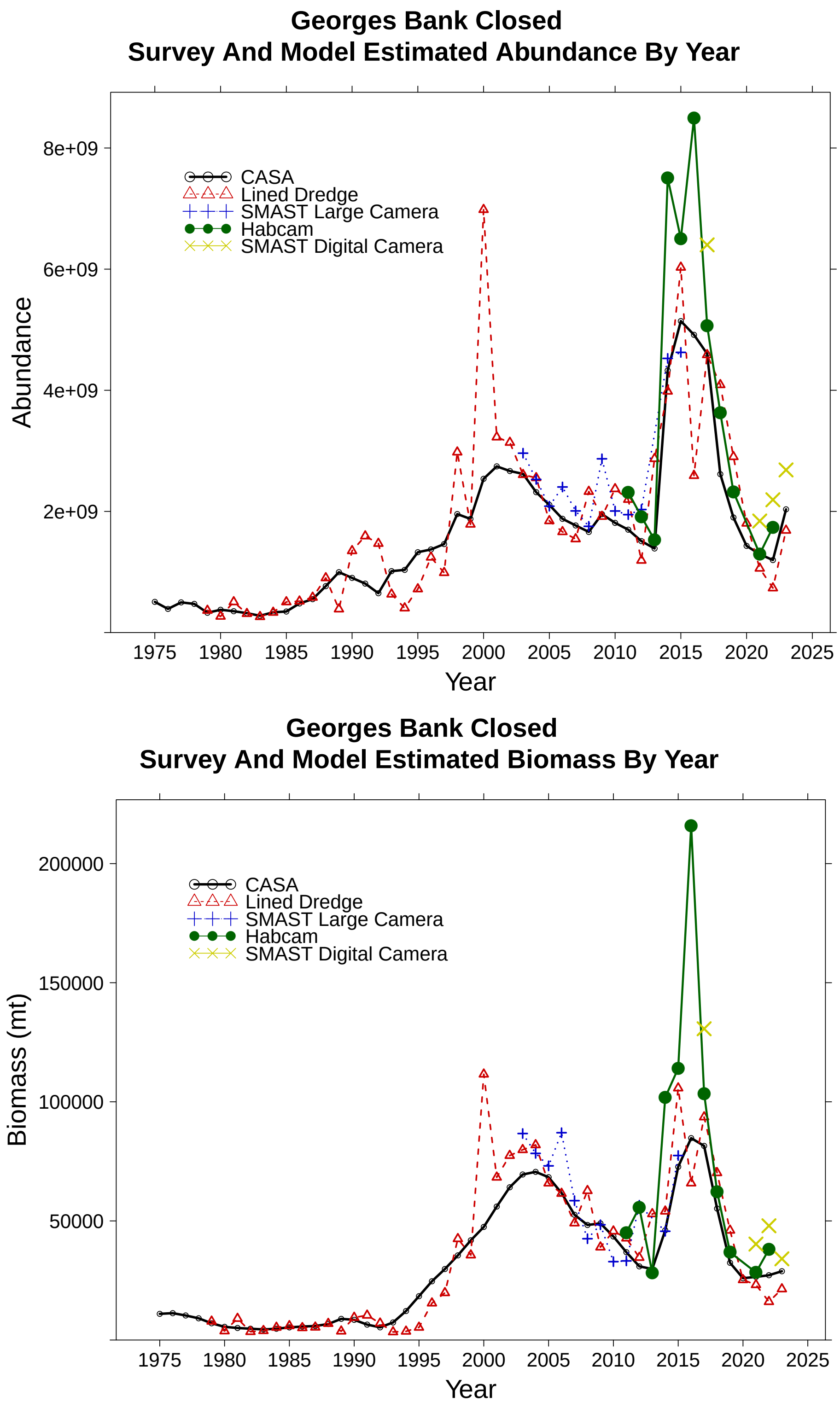


Figure 4.43: Comparison of CASA model estimated abundance (top) and biomass (bottom) with expanded estimates from the lined dredge (red triangle), SMAST large camera (blue cross), HabCam (green dots), and SMAST digital camera (light green x) for Georges Bank closed areas.

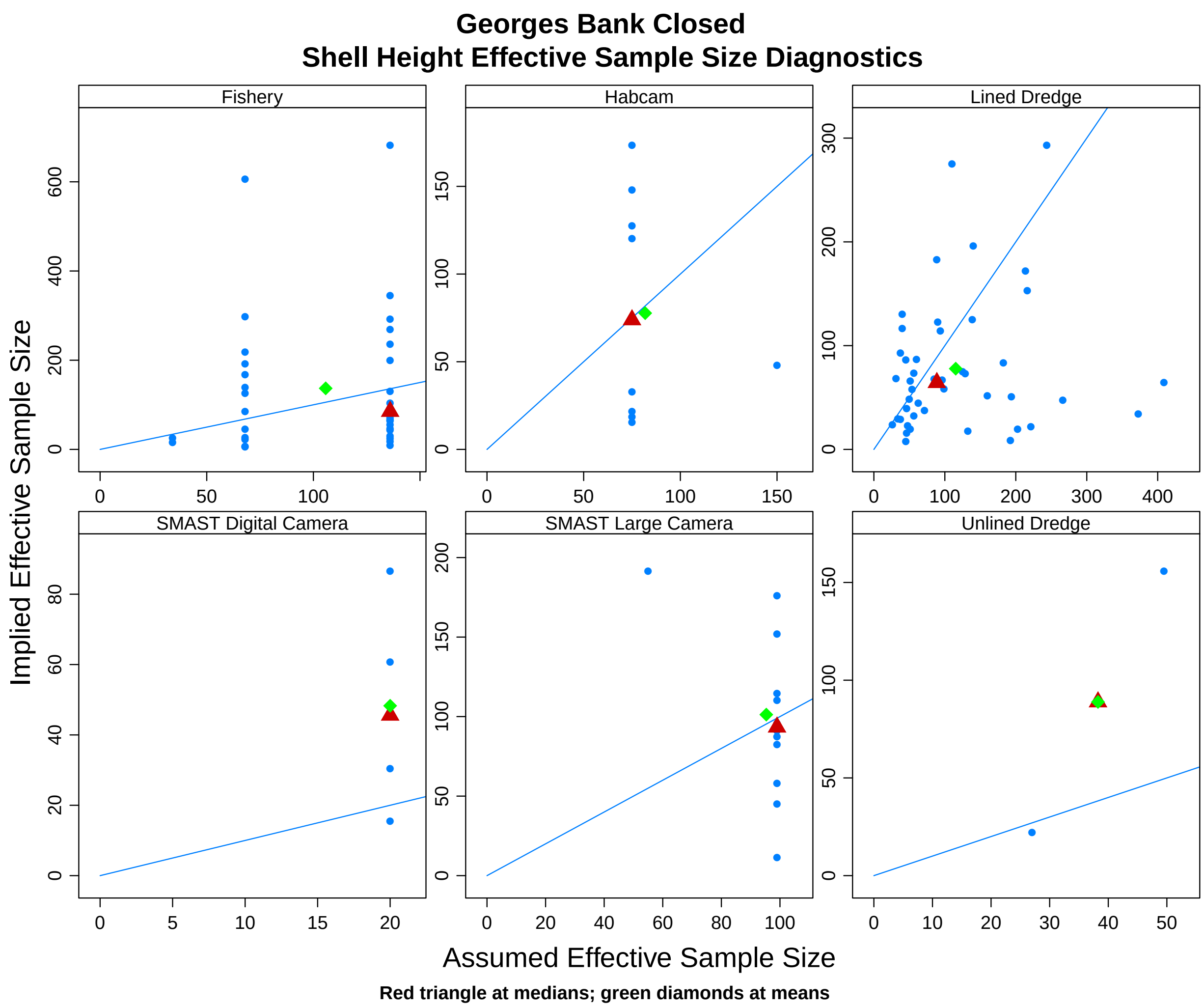


Figure 4.44: Assumed and model implied effective sample sizes for SMAST digital camera, lined dredge, Habcam, SMAST large camera, and unlined dredge surveys, and the fishery shell height compositions for Georges Bank closed areas. The triangle is the median and the diamond is the mean.

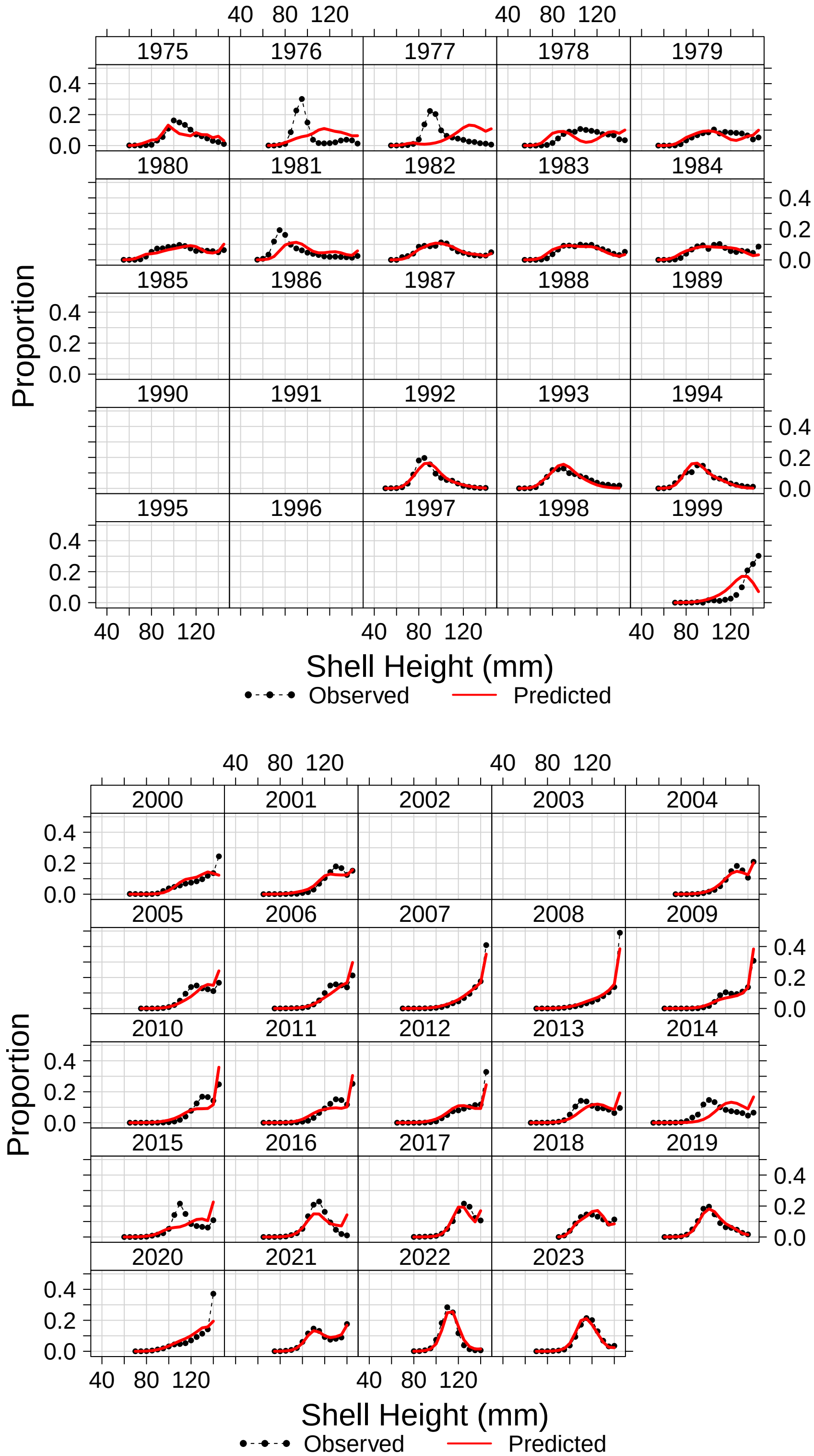


Figure 4.45: Comparison of observed fishery shell height proportions (solid circles) and model estimated fishery shell height proportions (lines) for Georges Bank closed areas.

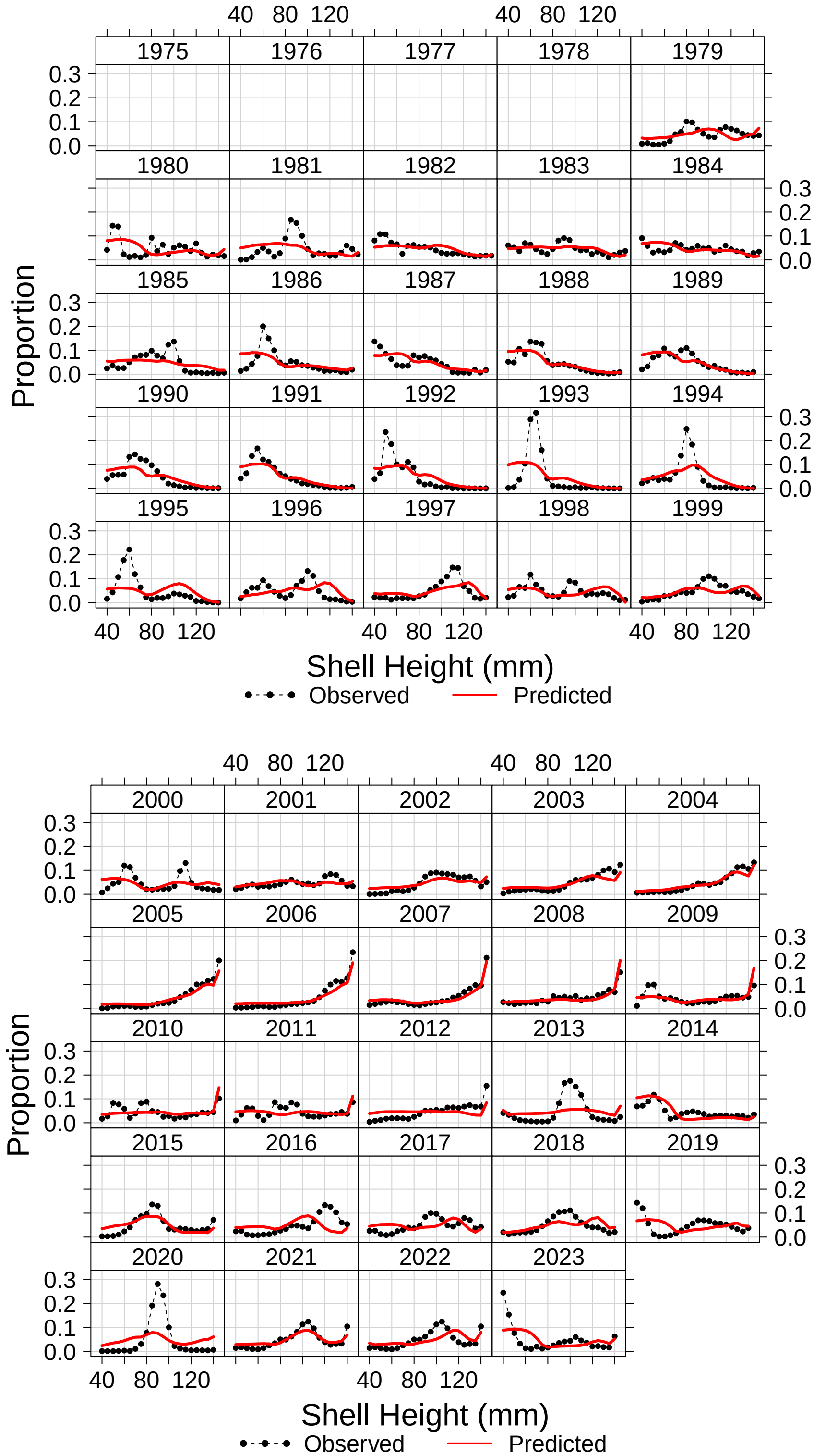
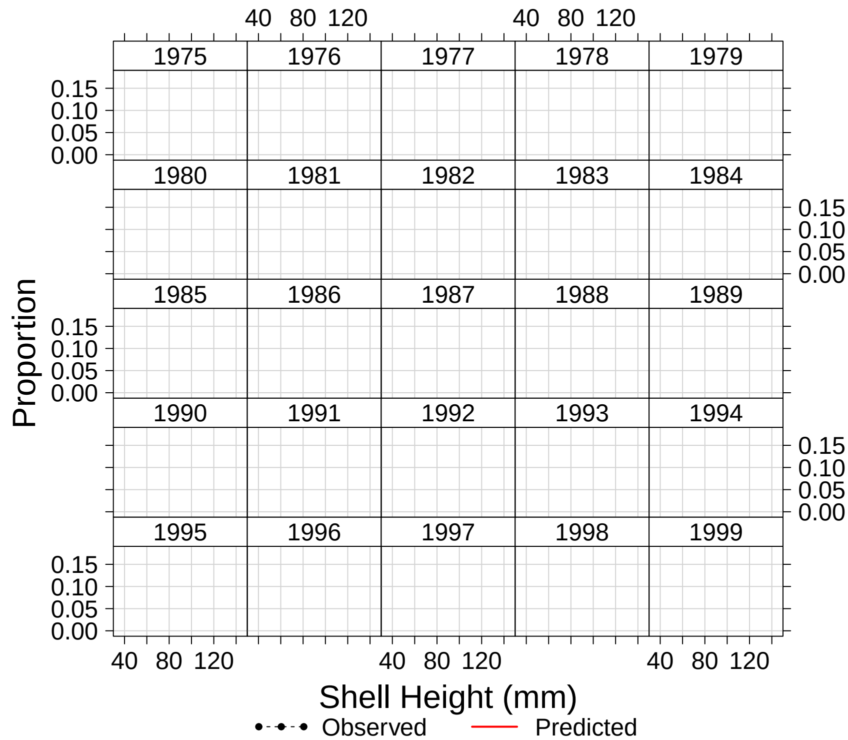


Figure 4.46: Comparison of lined dredge survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank closed areas.



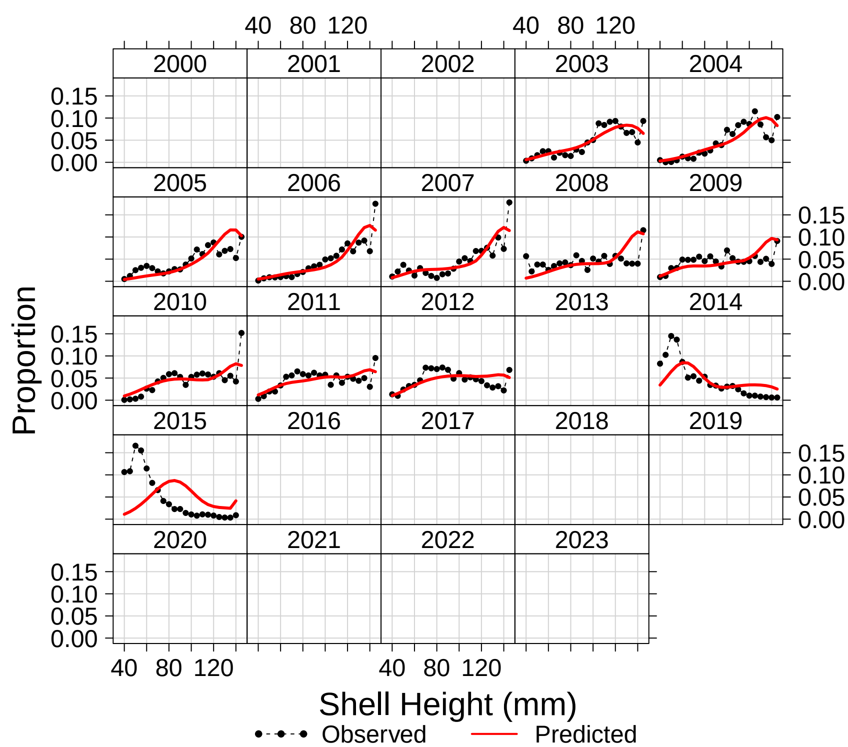
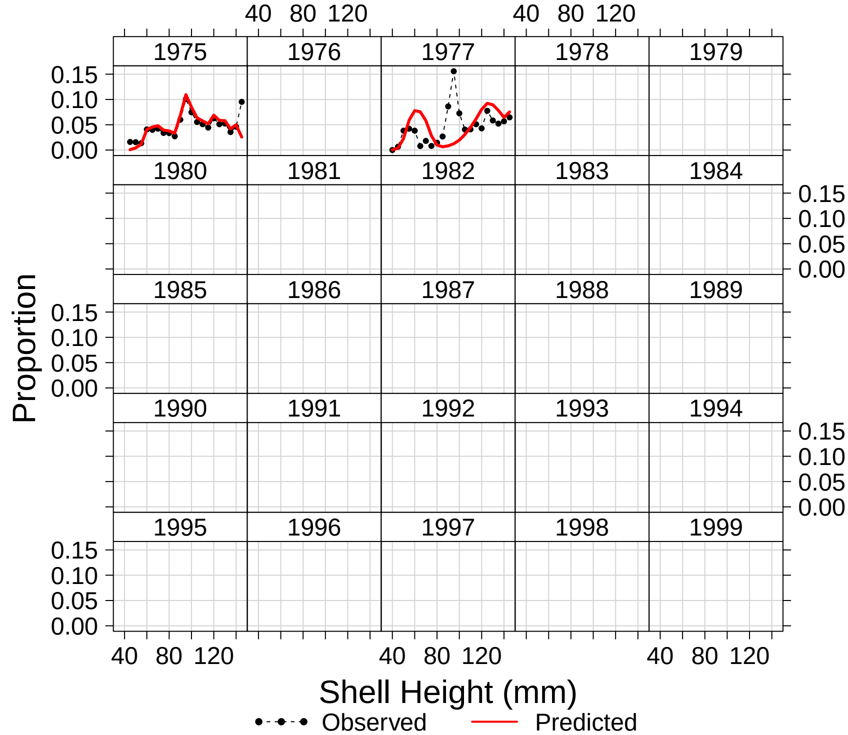


Figure 4.47: Comparison of SMAST large camera survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank closed areas.



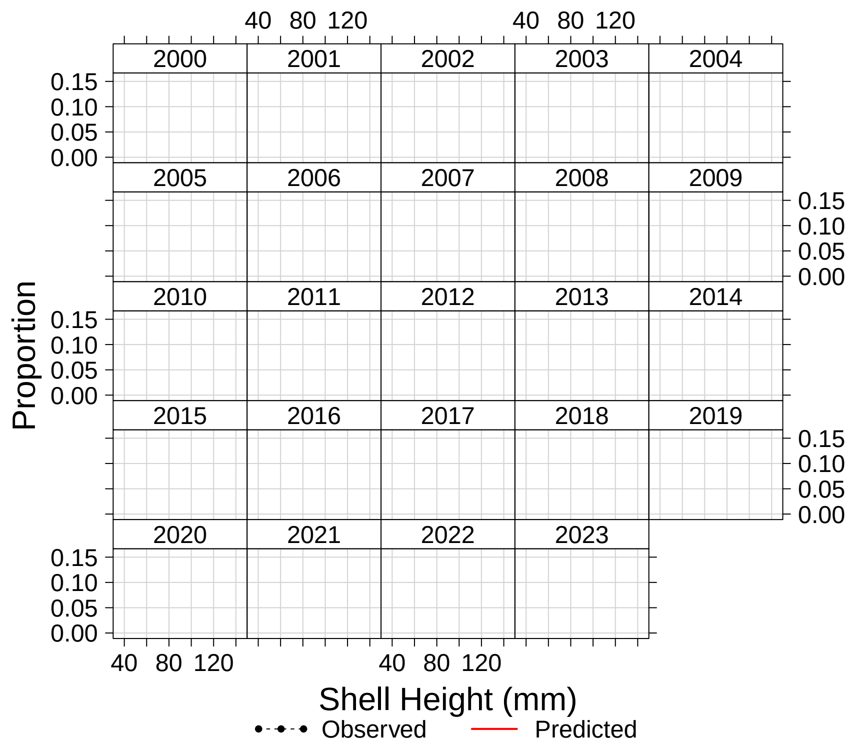
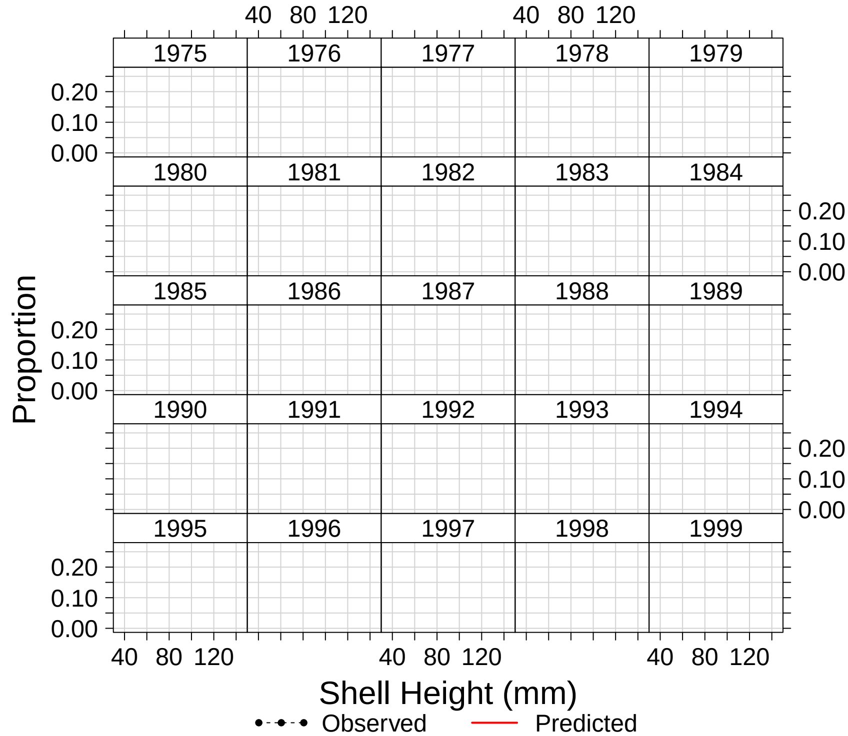


Figure 4.48: Comparison of unlined dredge survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank closed areas.



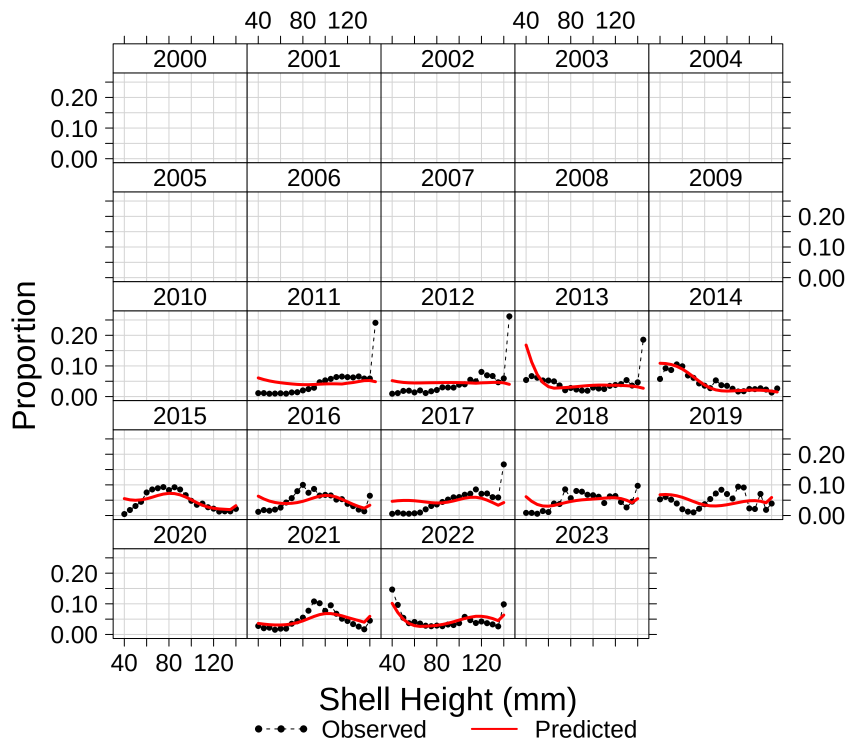
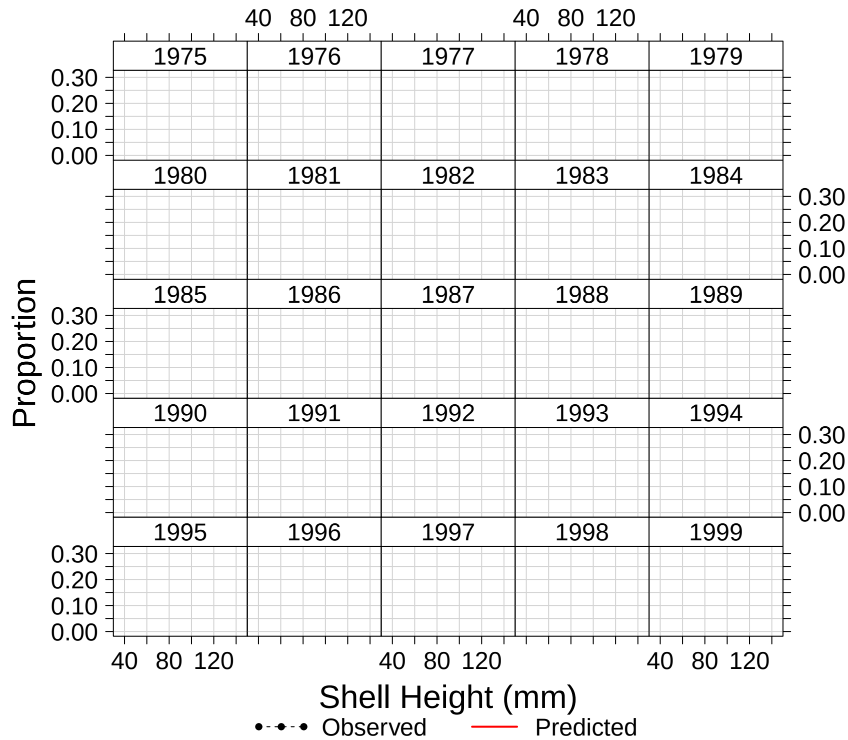


Figure 4.49: Comparison of Habcam survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank closed areas.



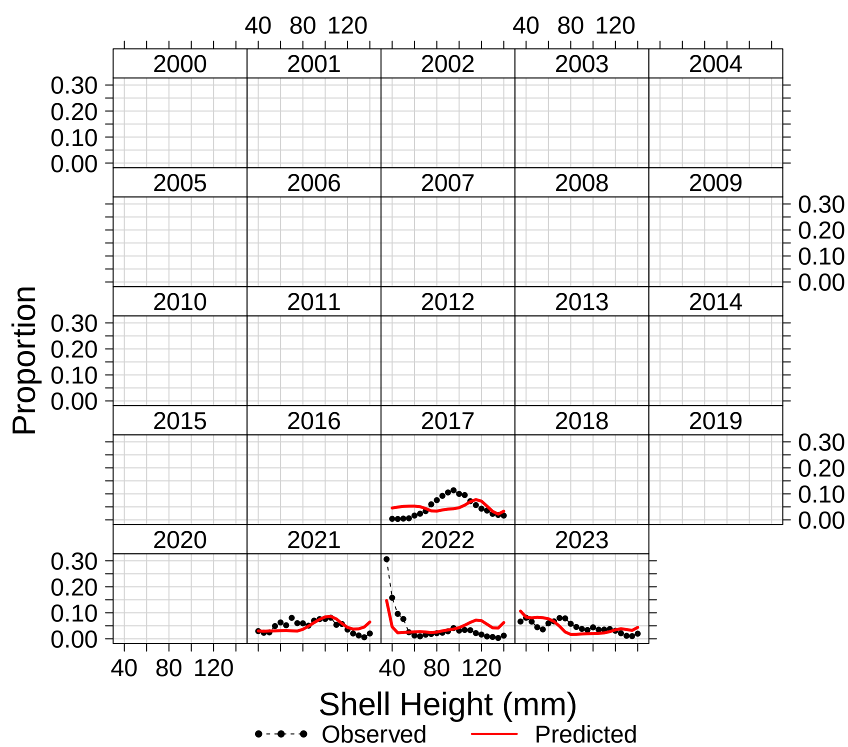


Figure 4.50: Comparison of SMAST digital camera survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank closed areas.

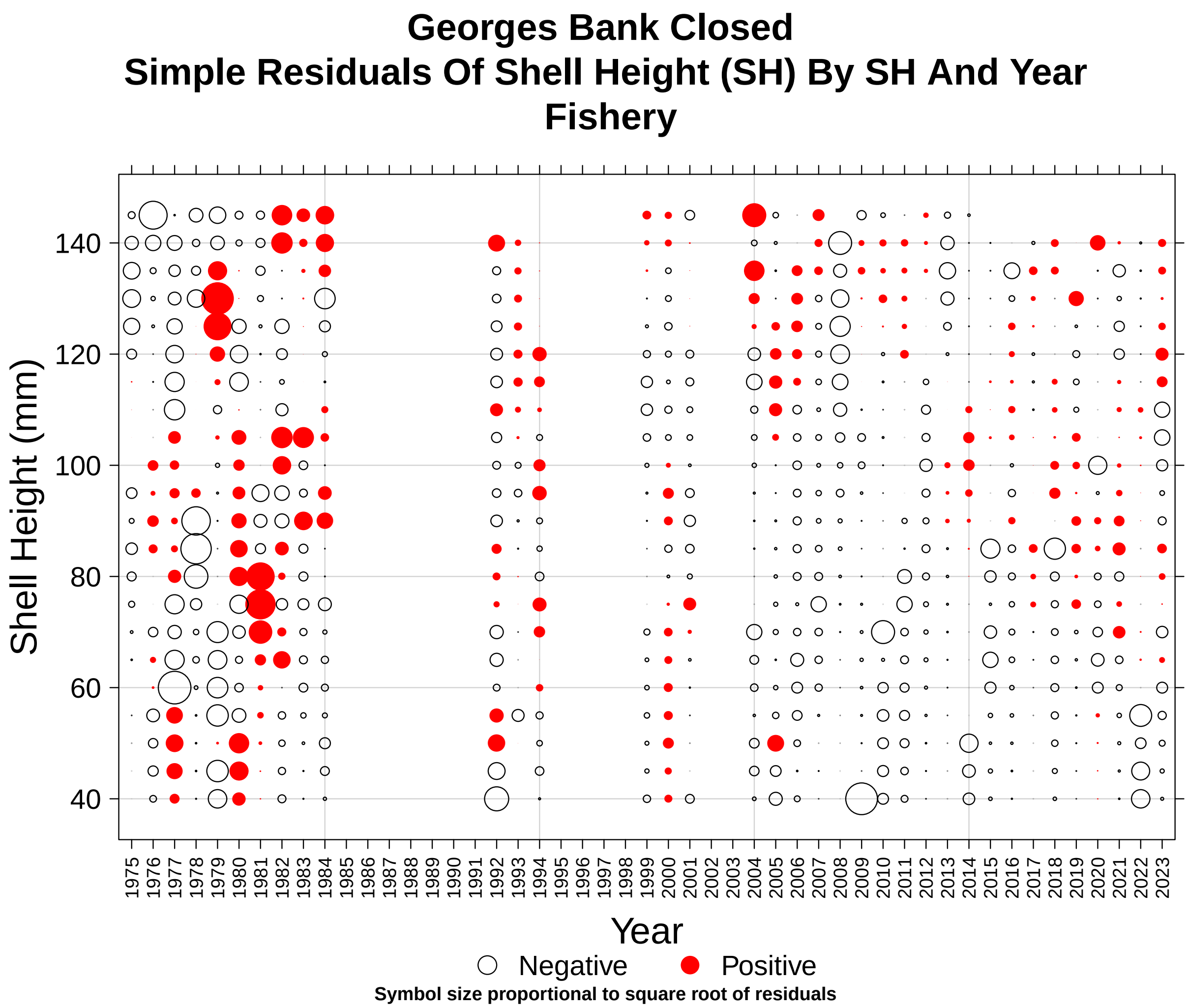


Figure 4.51: Simple residuals of fishery shell height proportions for Georges Bank closed areas. Symbol areas are proportional to residual.

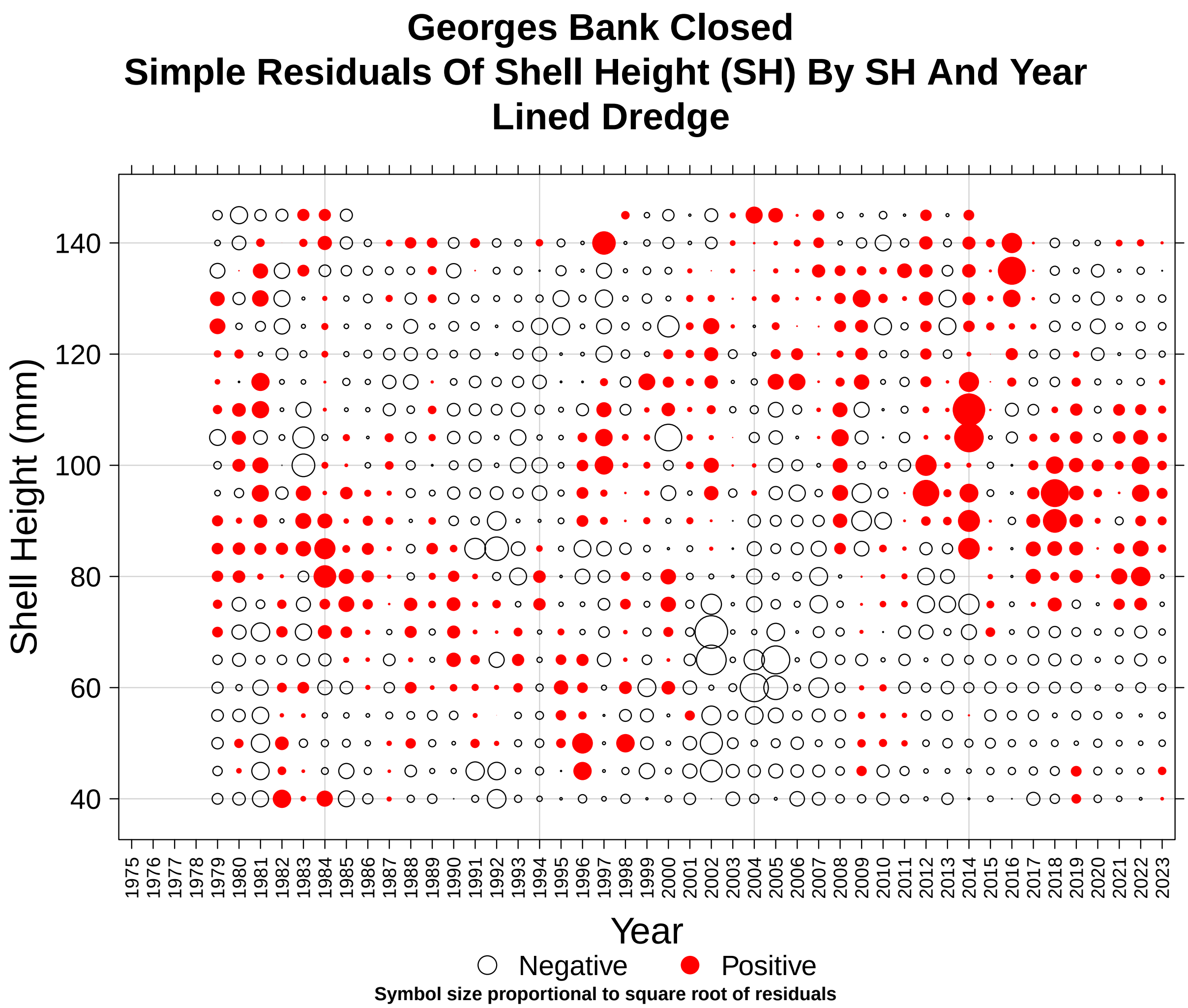


Figure 4.52: Simple residuals of lined dredge survey shell height proportions for Georges Bank closed areas. Symbol areas are proportional to residual.

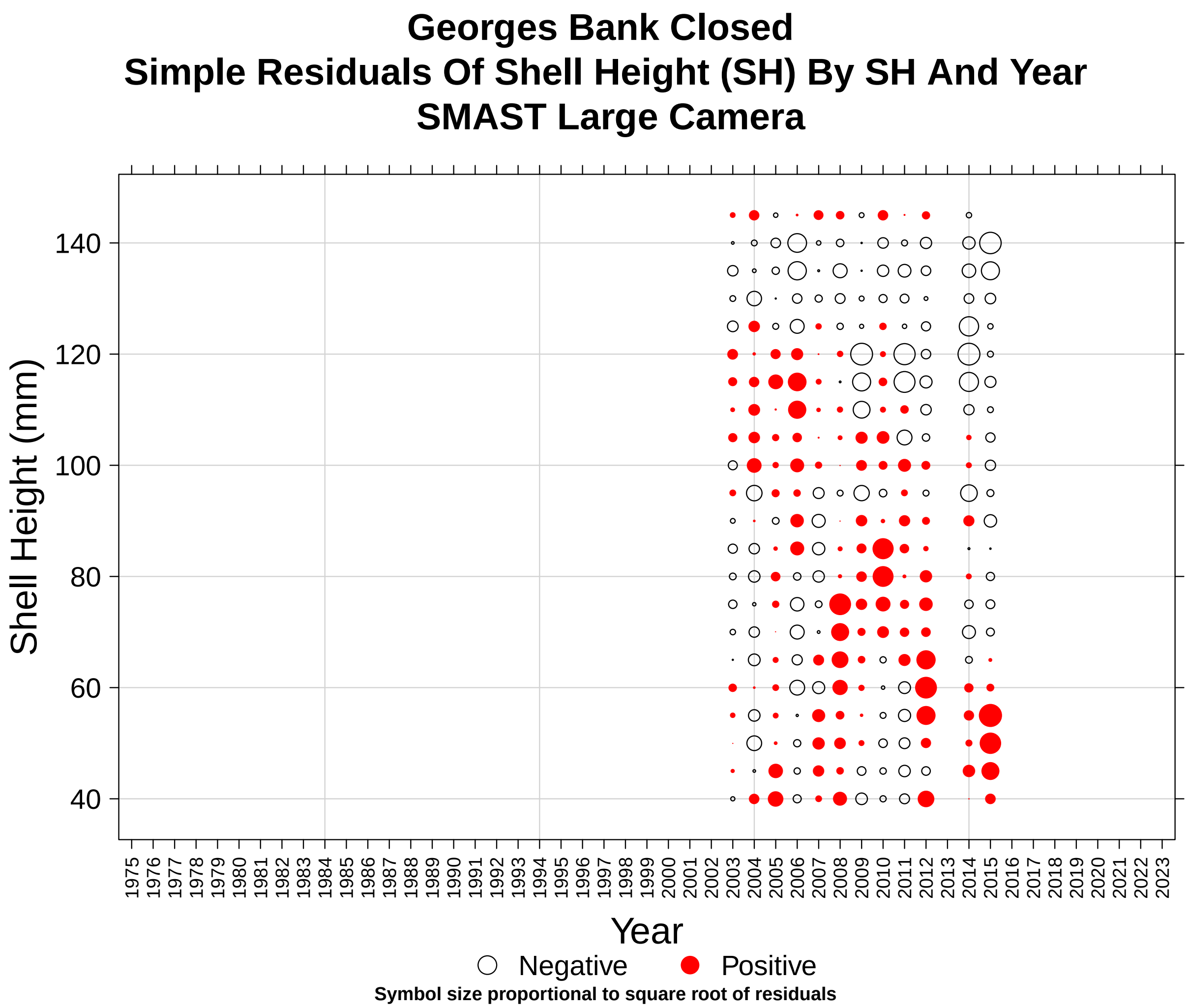


Figure 4.53: Simple residuals of SMAST large camera survey shell height proportions for Georges Bank closed areas. Symbol areas are proportional to residual.

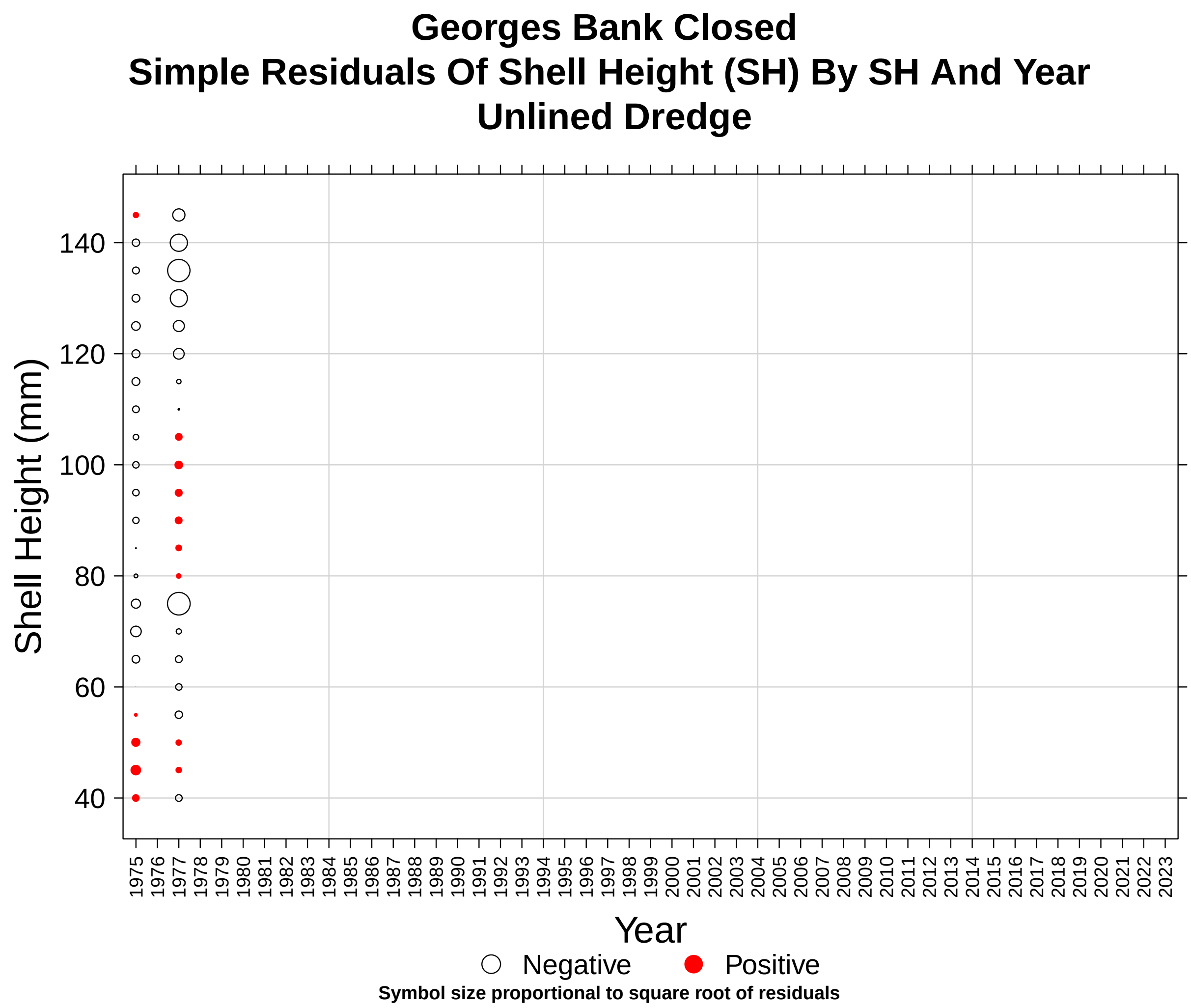


Figure 4.54: Simple residuals of unlined dredge survey shell height proportions for Georges Bank closed areas. Symbol areas are proportional to residual.

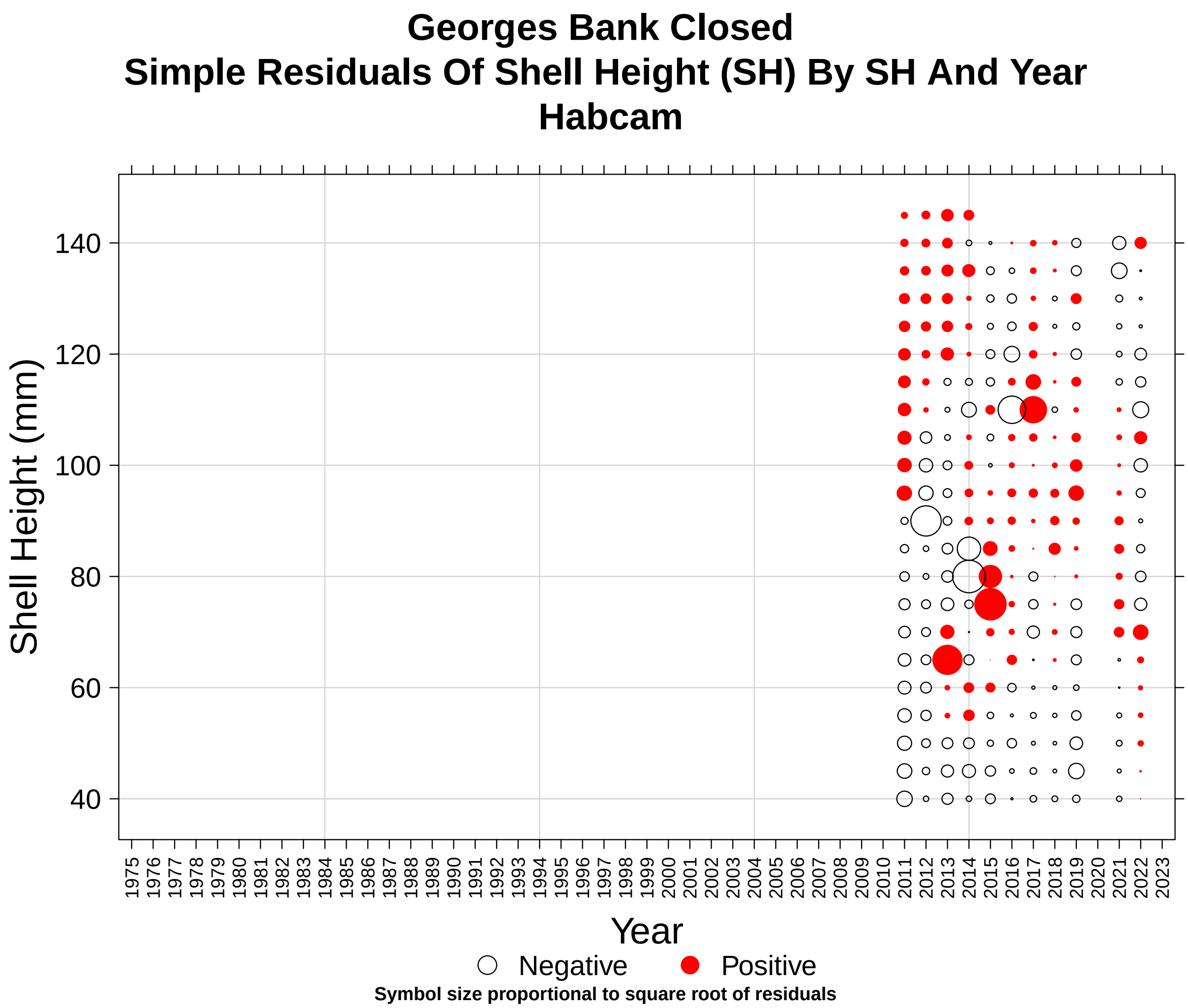


Figure 4.55: Simple residuals of Habcam survey shell height proportions for Georges Bank closed areas. Symbol areas are proportional to residual.

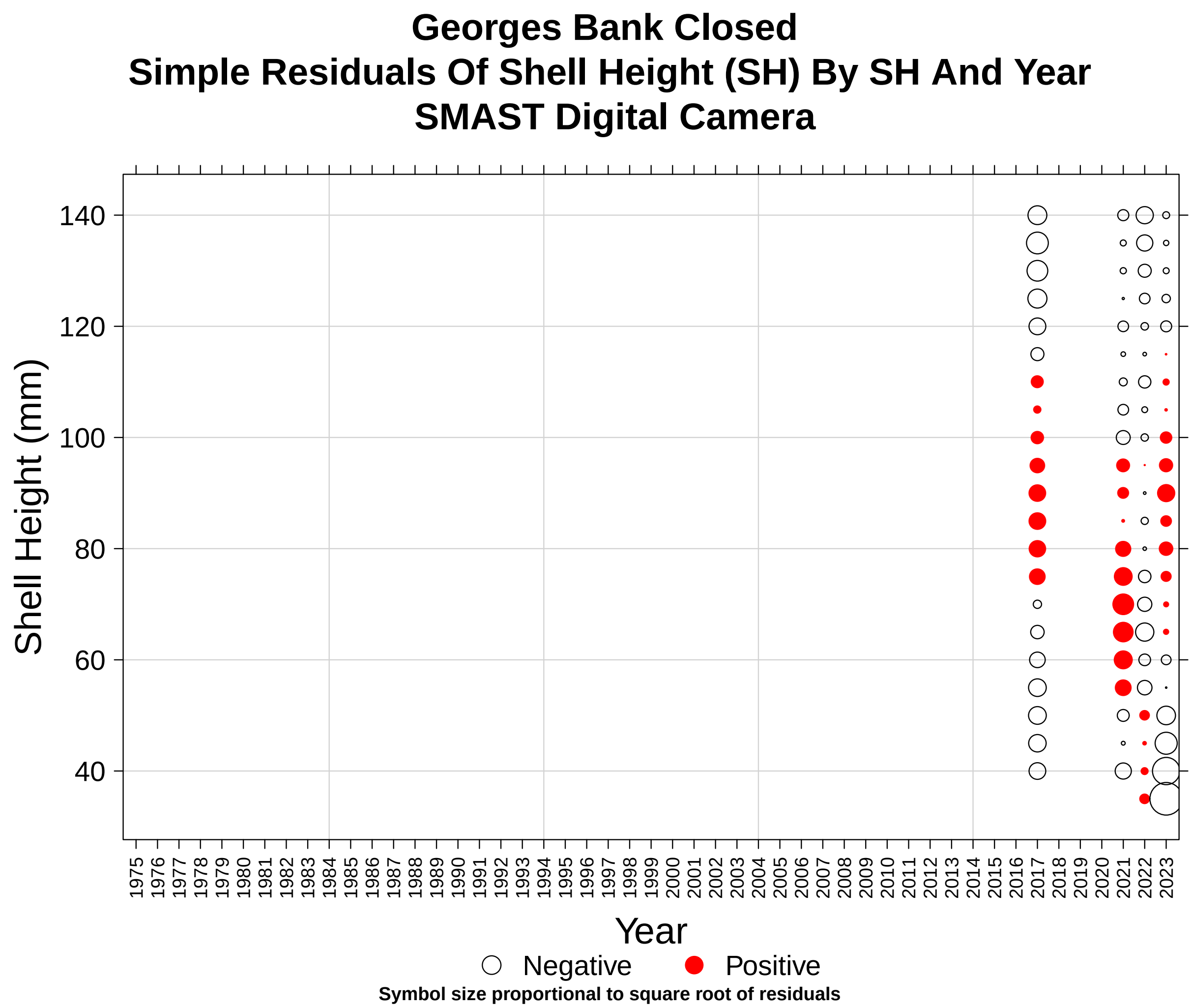
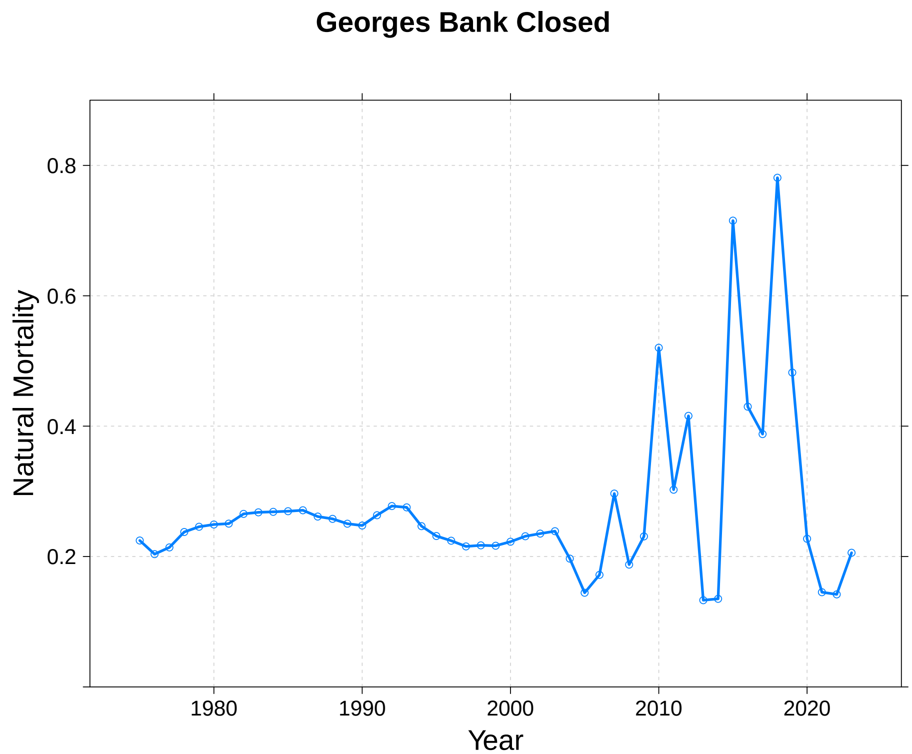


Figure 4.56: Simple residuals of SMAST digital camera survey shell height proportions for Georges Bank closed areas. Symbol areas are proportional to residual.



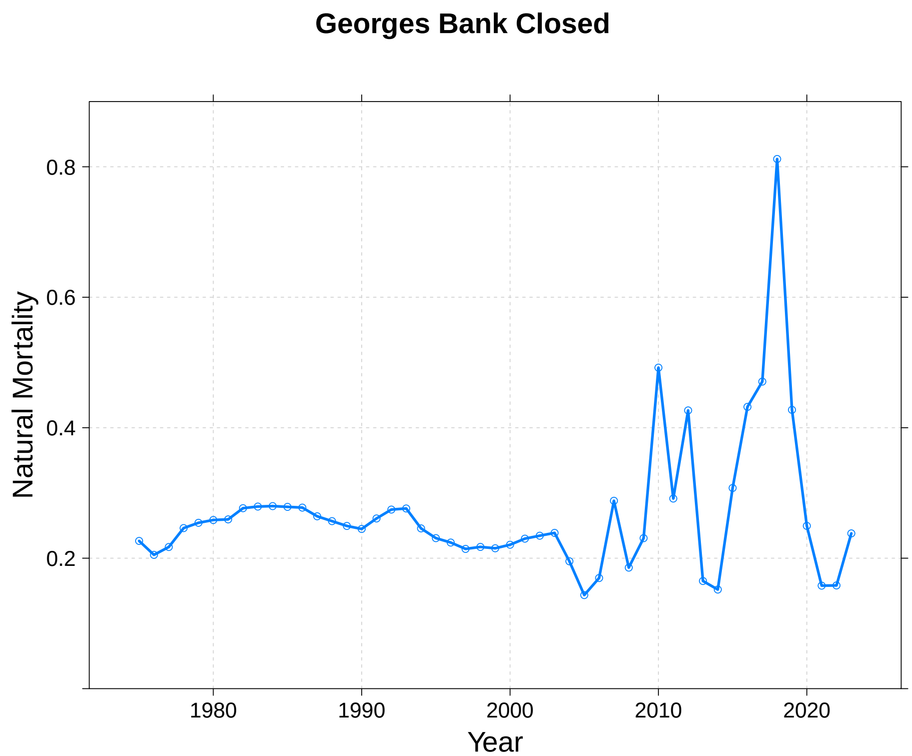


Figure 4.57: Estimated natural mortality from 1975 to 2023 from the bridge model run using SARC-65 CASA model configuration (NEFSC 2018; top) and base case model (bottom) for Georges Bank closed areas.

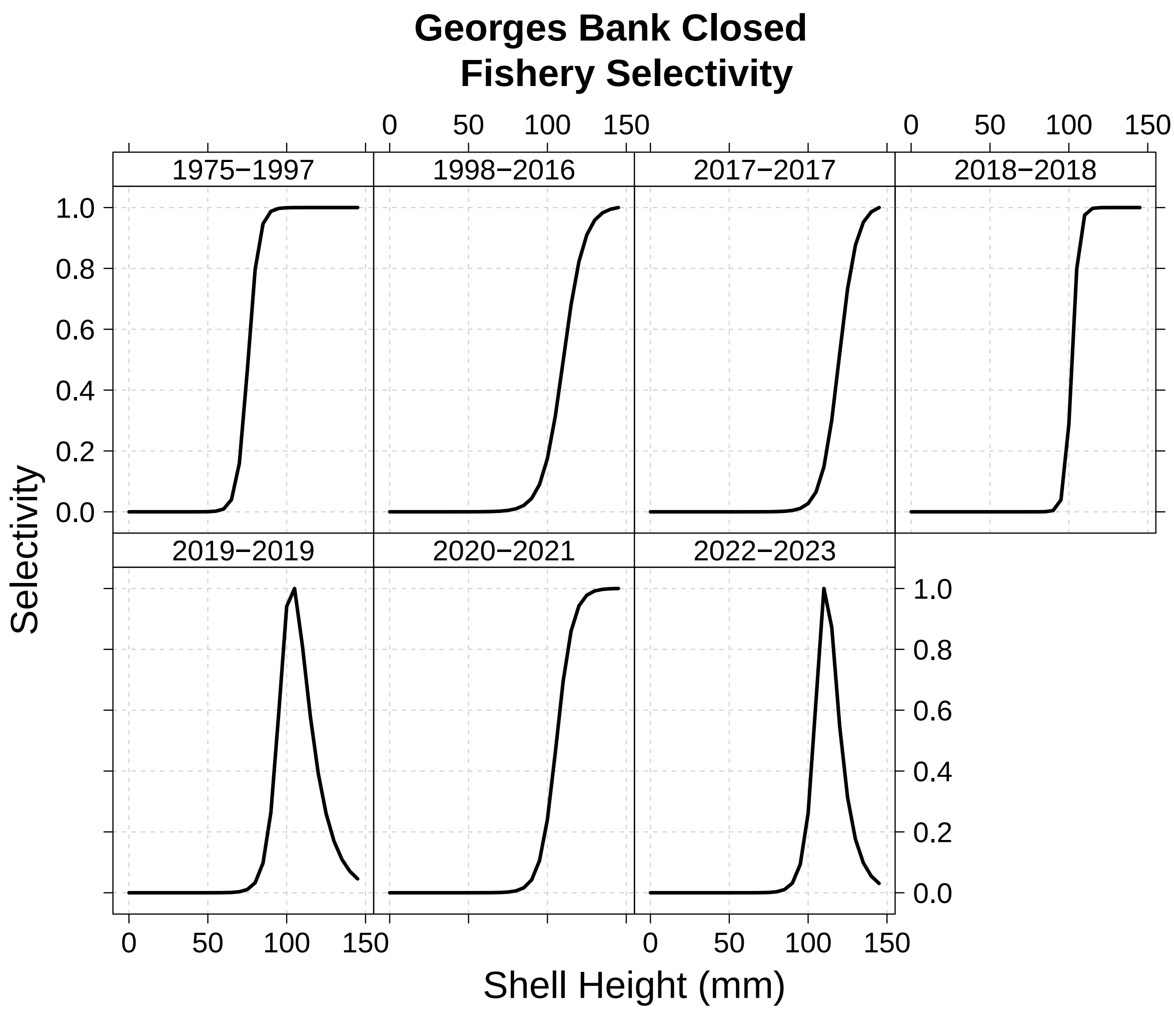


Figure 4.58: CASA model estimated fishery selectivity curves for Georges Bank closed areas.

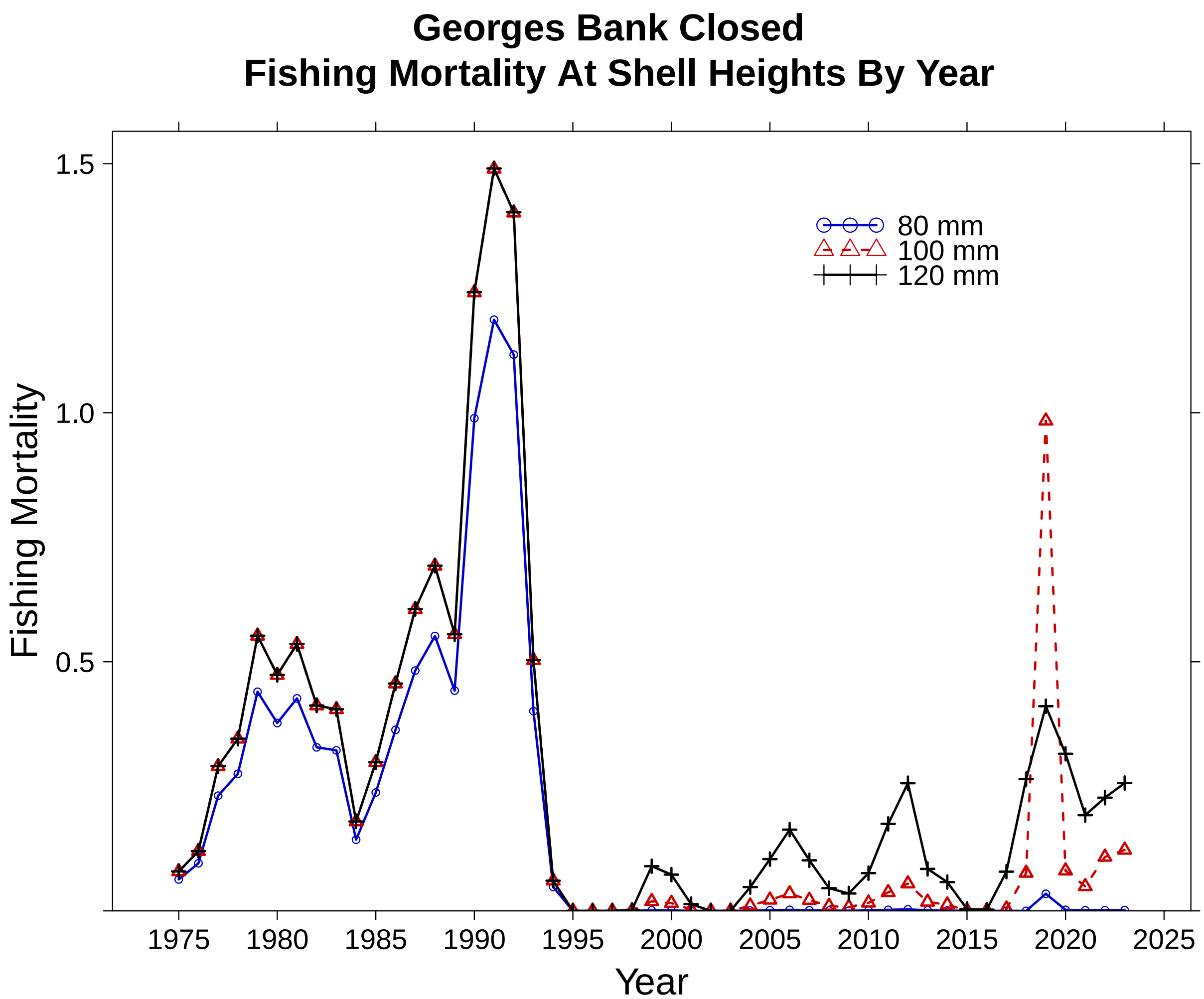


Figure 4.59: CASA model estimated fishing mortality at 80 mm (solid line with circles), 100 mm (dashed line with triangles), and 120 mm SH (dashed line with crosses) for Georges Bank closed areas.

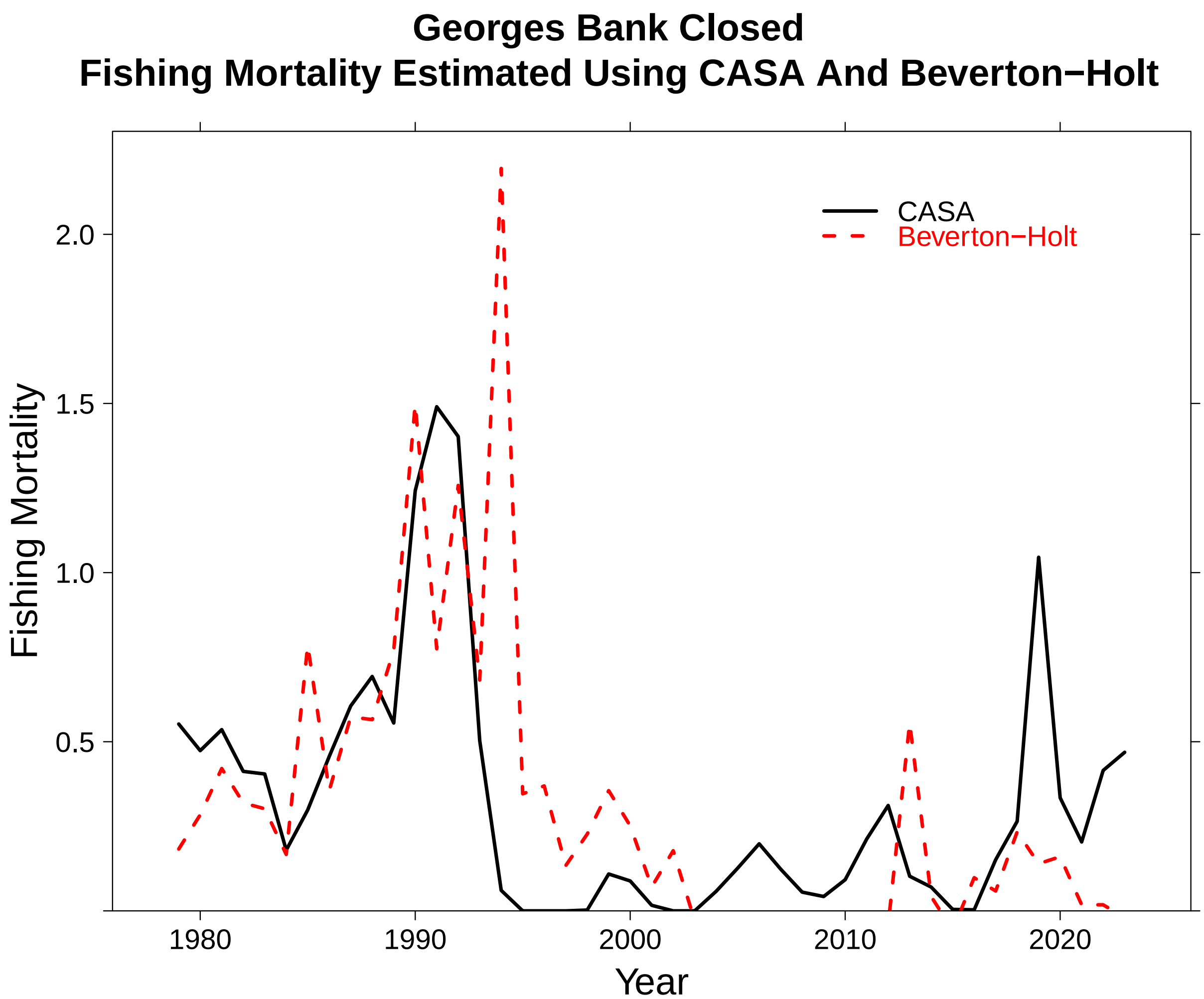


Figure 4.60: Comparison of fully recruited CASA fishing mortality with those calculated from the Beverton-Holt equilibrium length based estimator for Georges Bank closed areas.

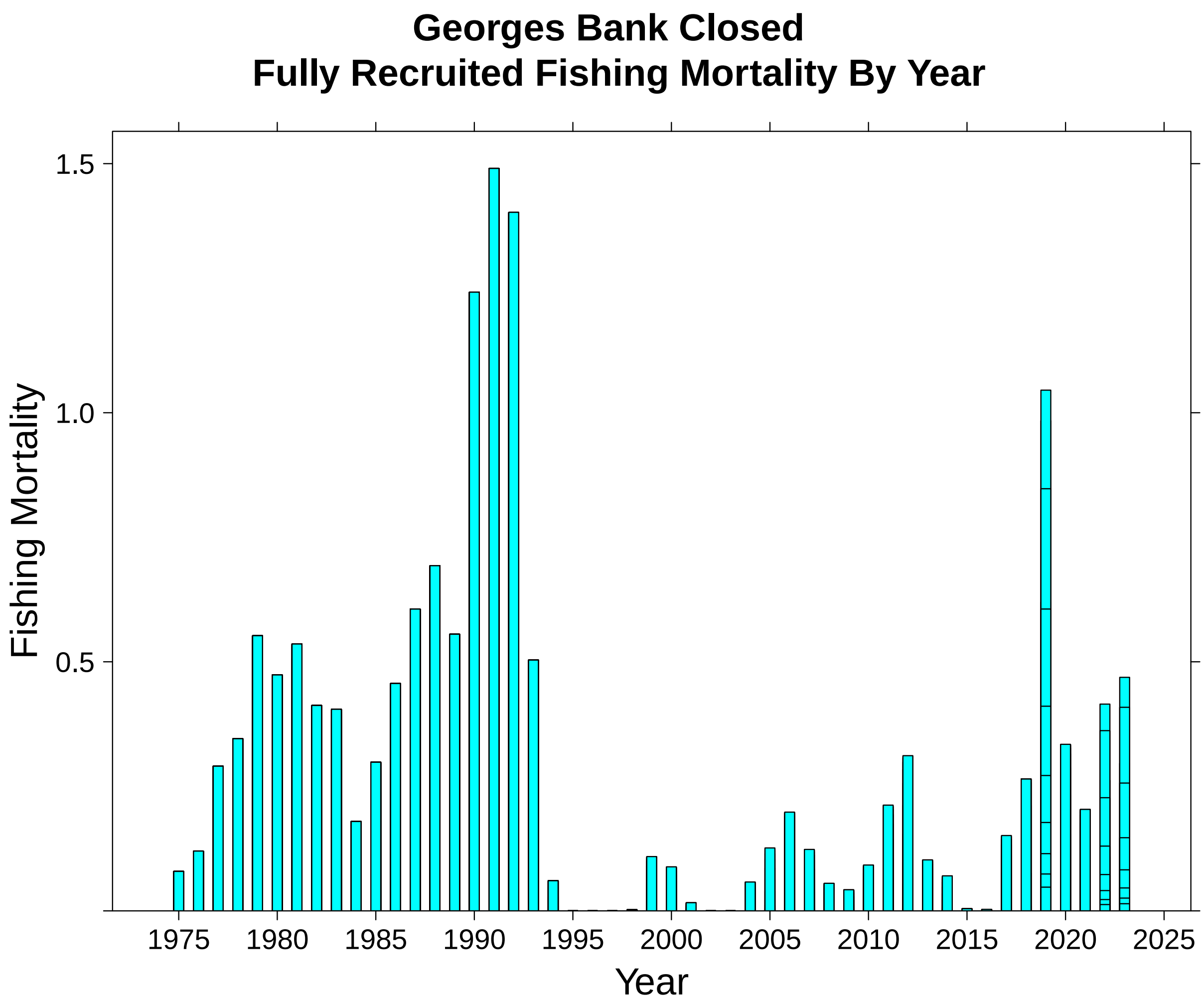


Figure 4.61: CASA model estimated fully recruited fishing mortality for Georges Bank closed areas.

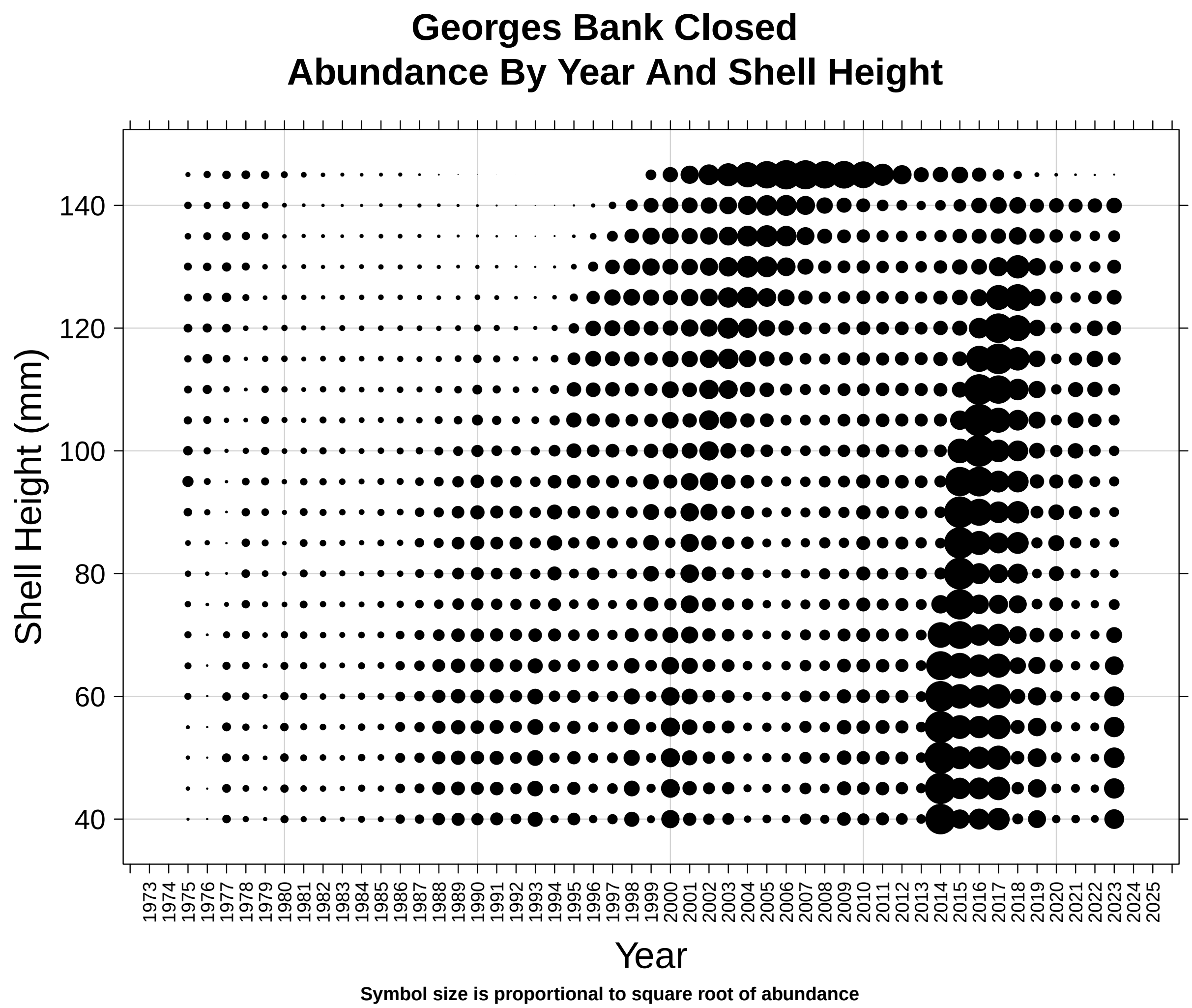


Figure 4.62: CASA model estimated abundances at shell height for Georges Bank closed areas. Symbol areas are proportional to abundance.

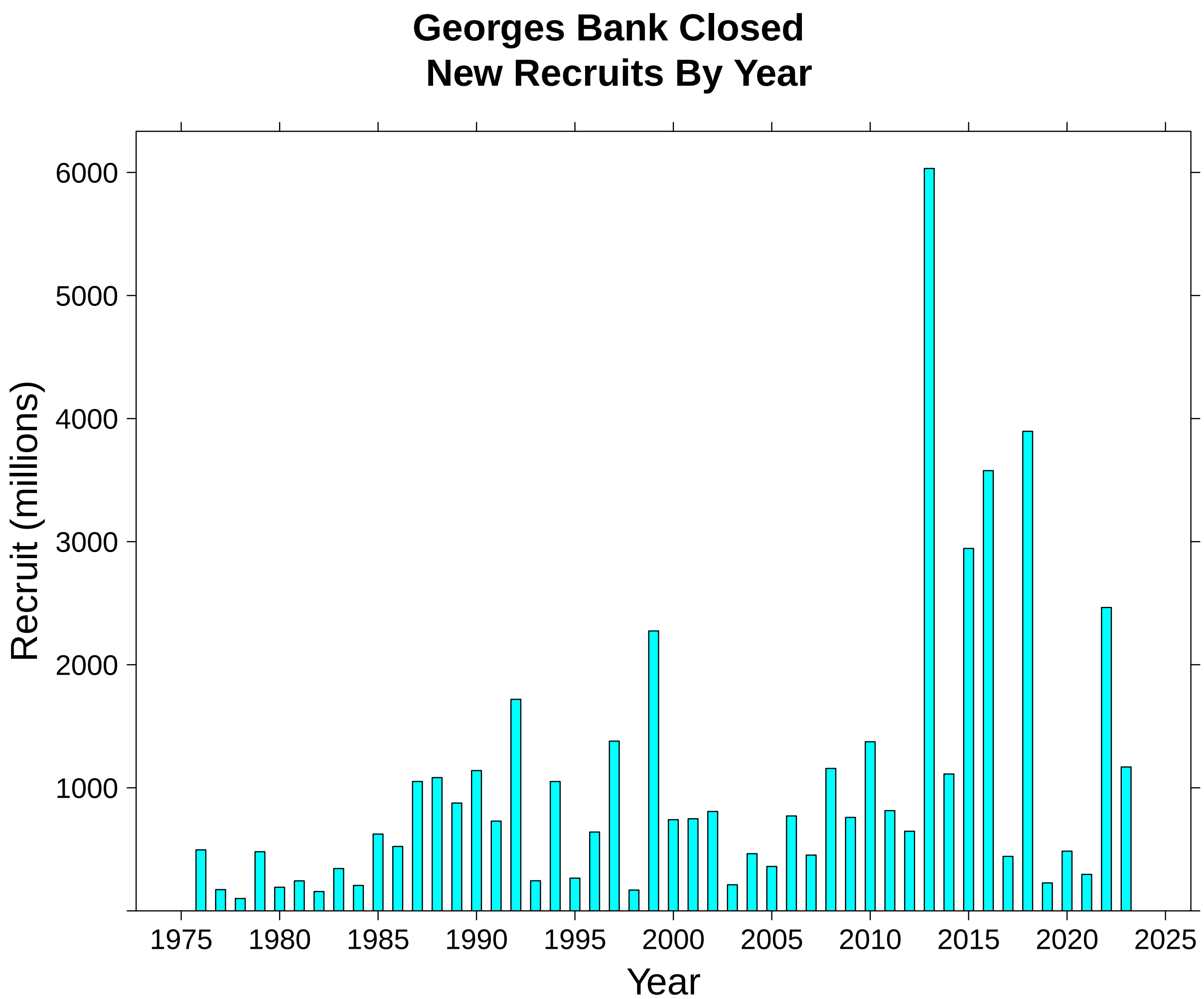


Figure 4.63: CASA model estimated recruitment for Georges Bank closed areas.

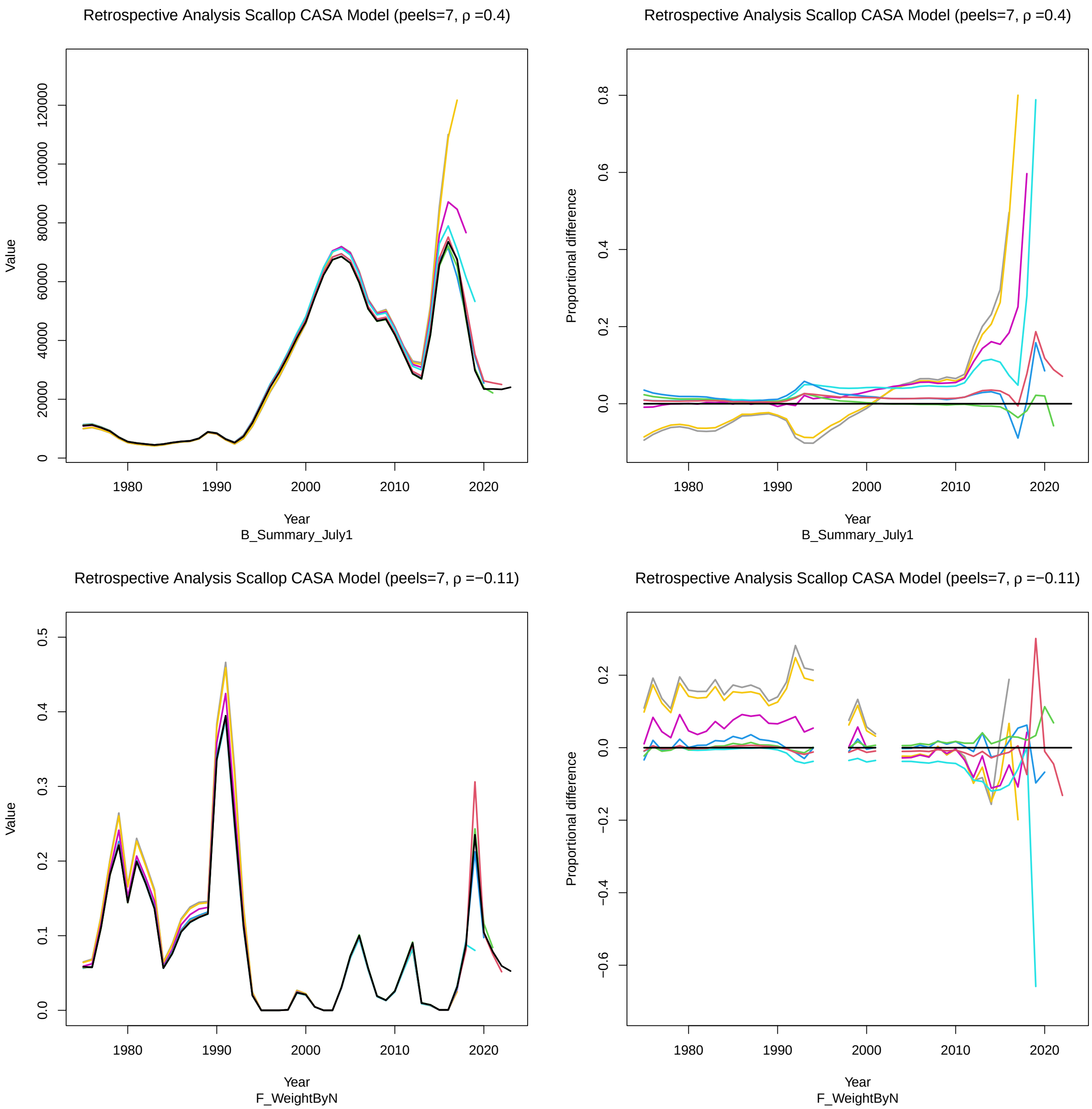


Figure 4.64: Retrospective plots for biomass and fishing mortality for Georges Bank closed areas. Retrospectives are shown on both absolute and relative scales.

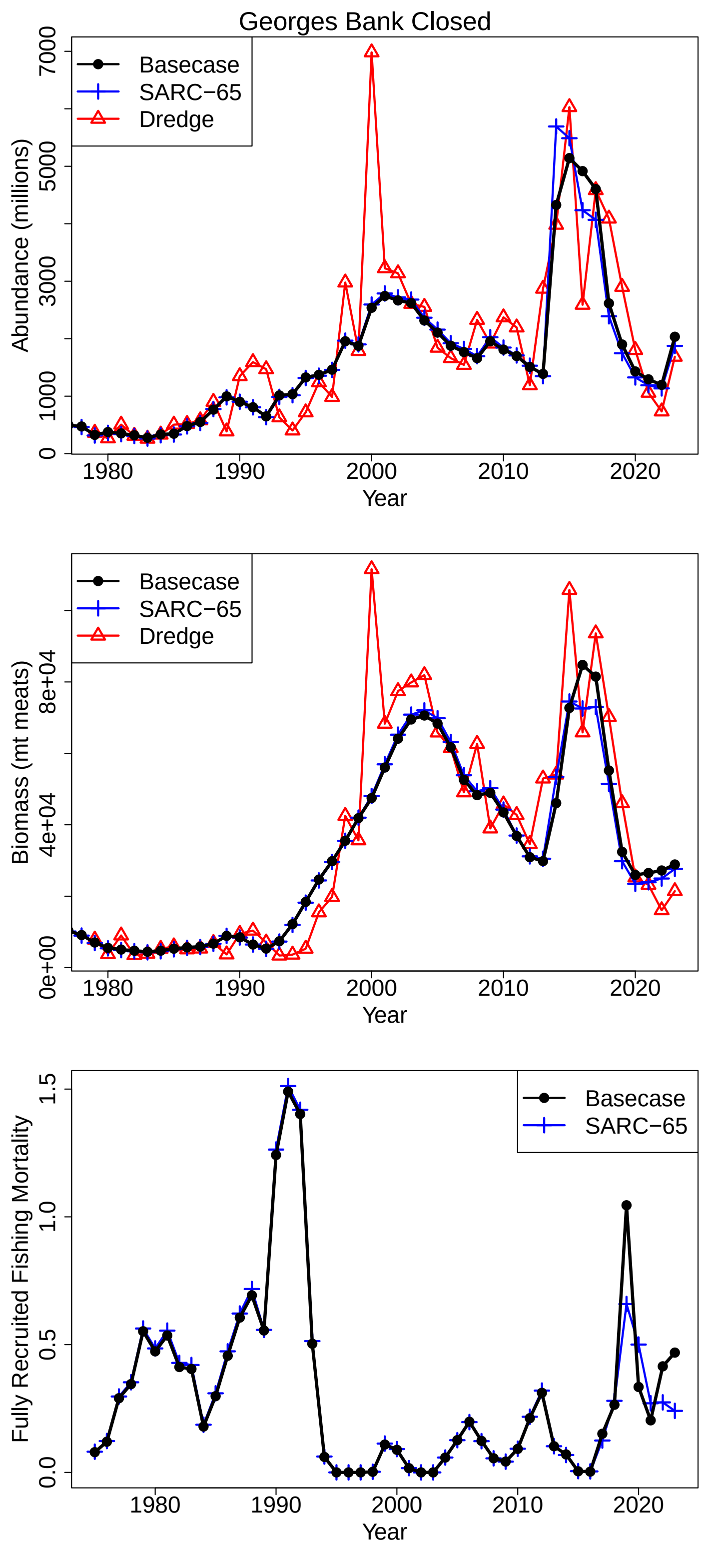
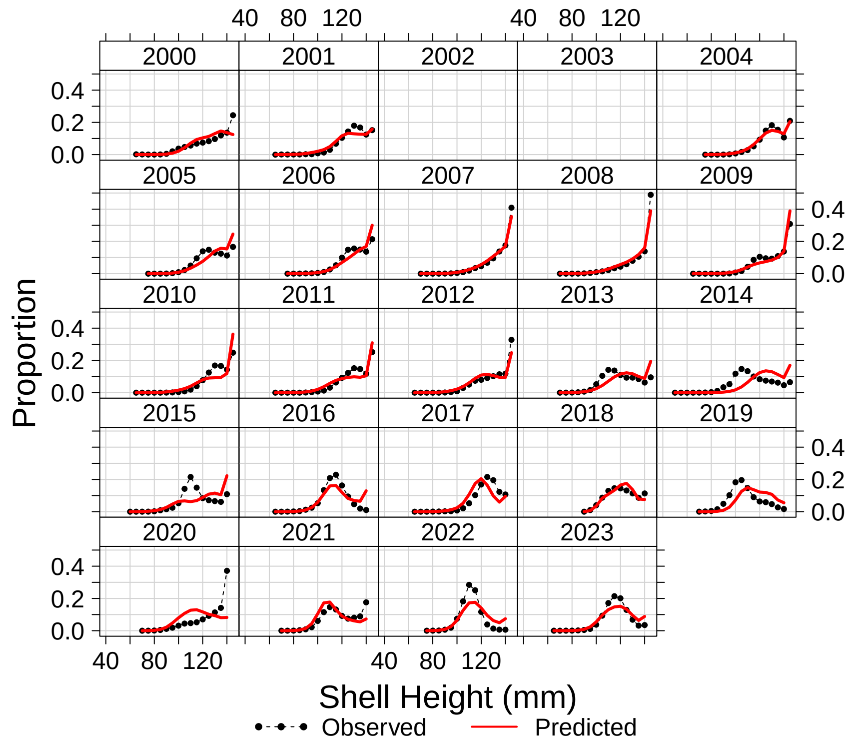


Figure 4.65: Comparison of estimated abundance (millions), biomass (mt meats), and fully recruited fishing mortality from current and SARC-65 CASA model configurations, and lined dredge survey for Georges Bank closed areas.



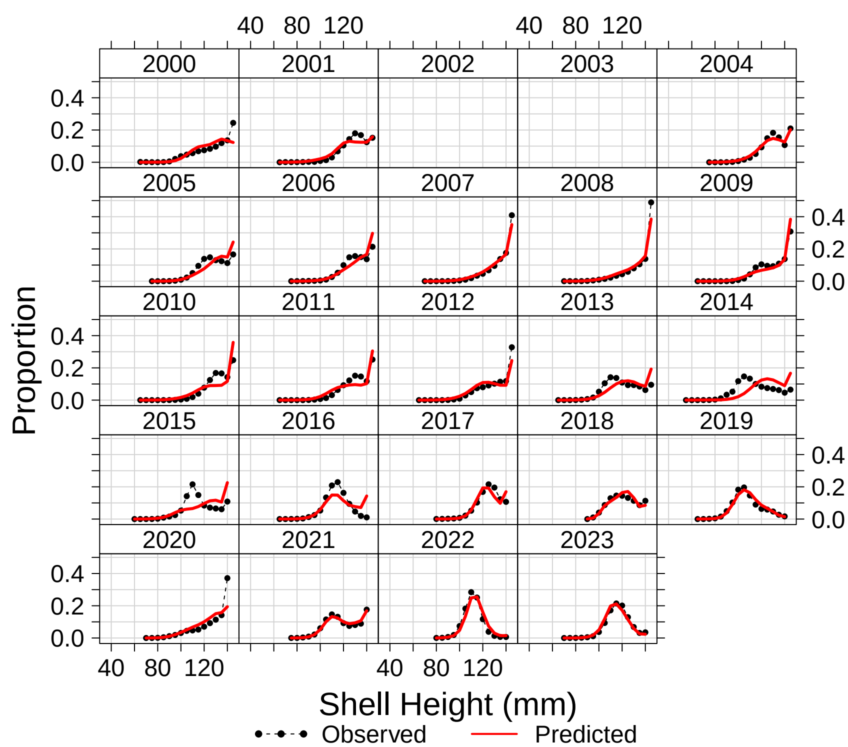


Figure 4.66: Comparison of fishery shell height proportions from the bridge model run using SARC-65 model configuration (NEFSC 2018; top) and base case model (bottom) for Georges Bank closed areas.

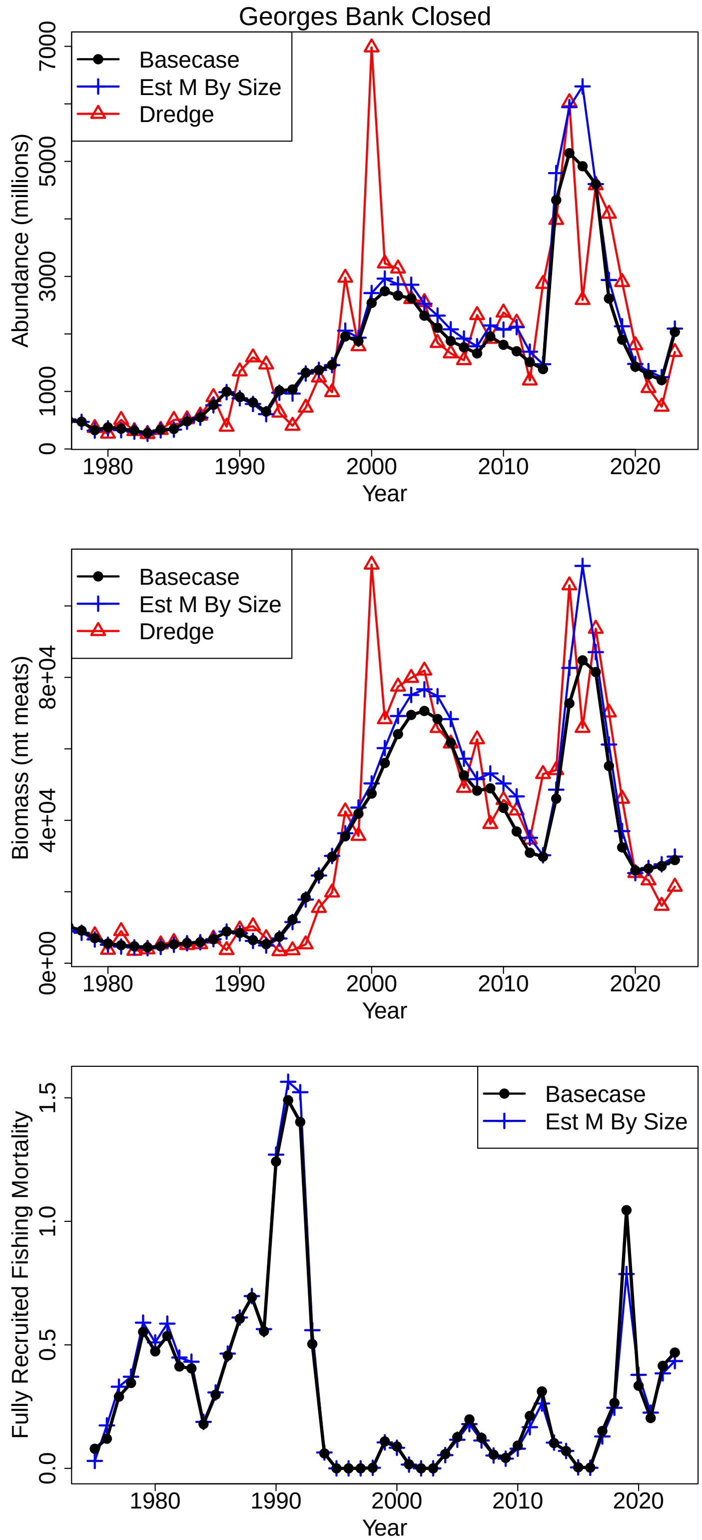


Figure 4.67: Comparison of estimated abundance (millions), biomass (mt meats), and fully recruited fishing mortality from current model, model with size-varying natural mortality, and lined dredge survey for Georges Bank closed areas.

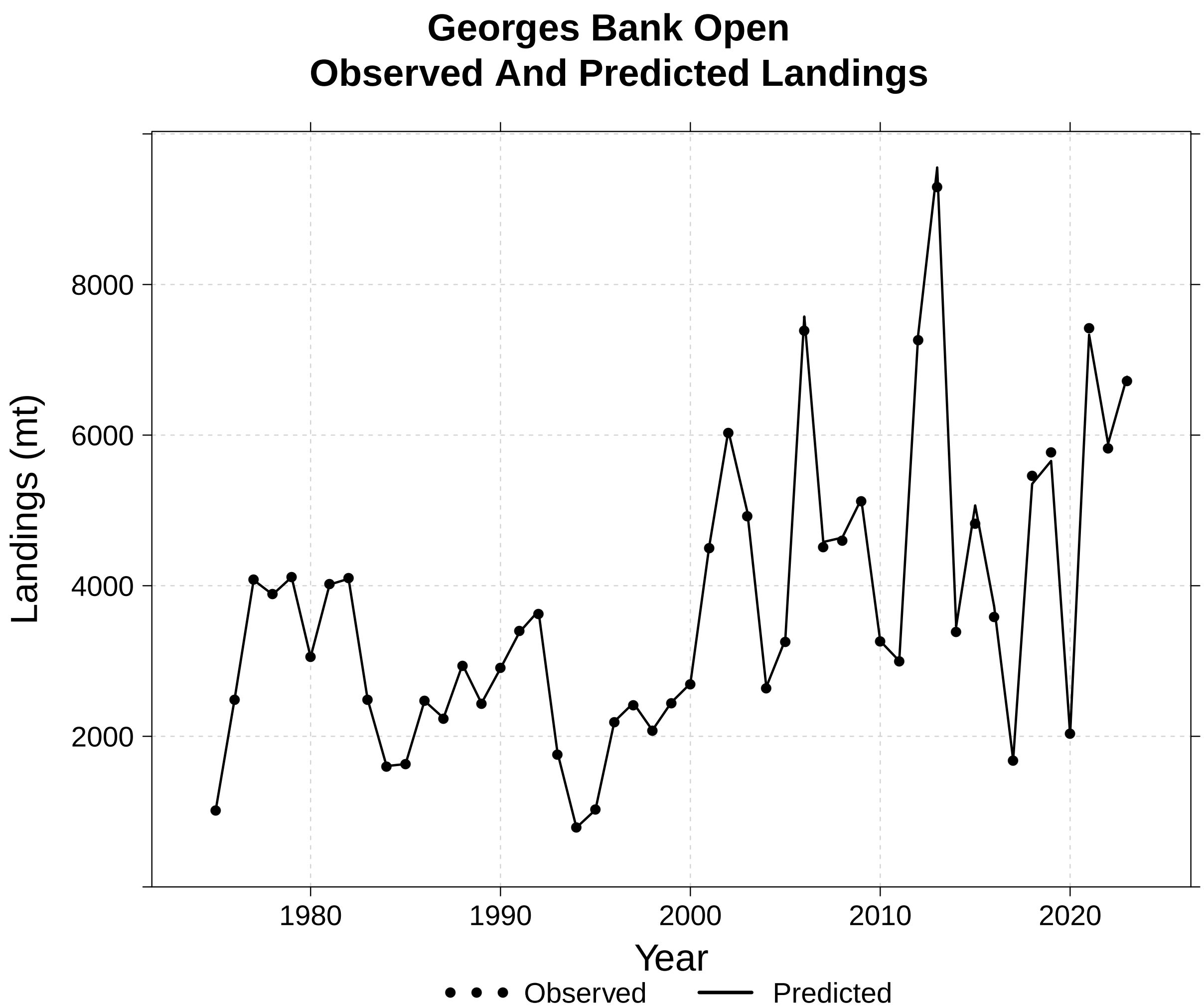


Figure 4.68: Observed catch (mt meats, solid circles) and corresponding model estimates (lines) by year in Georges Bank open areas.

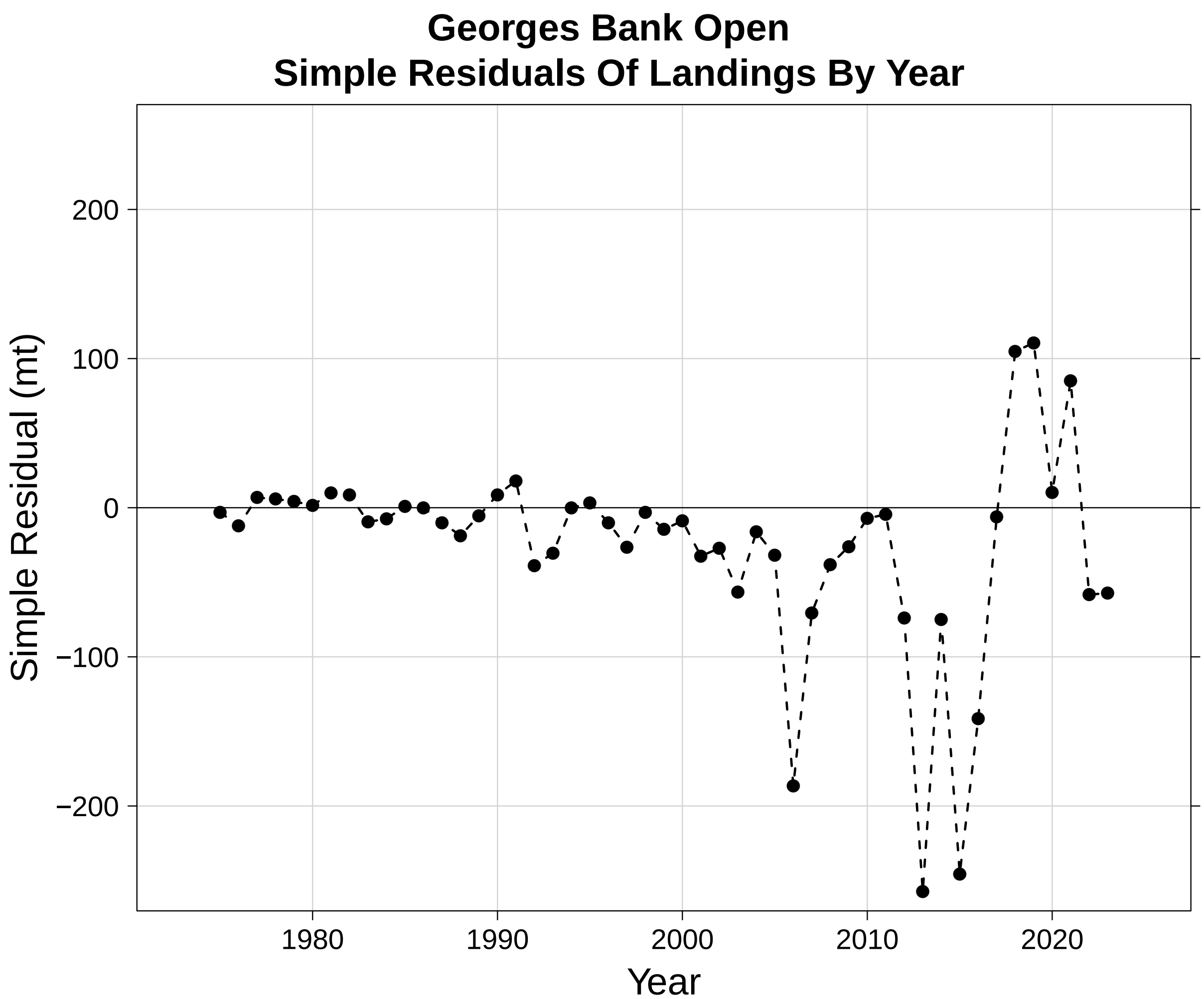


Figure 4.69: Simple residuals of catch (mt meats) by year in Georges Bank open areas.

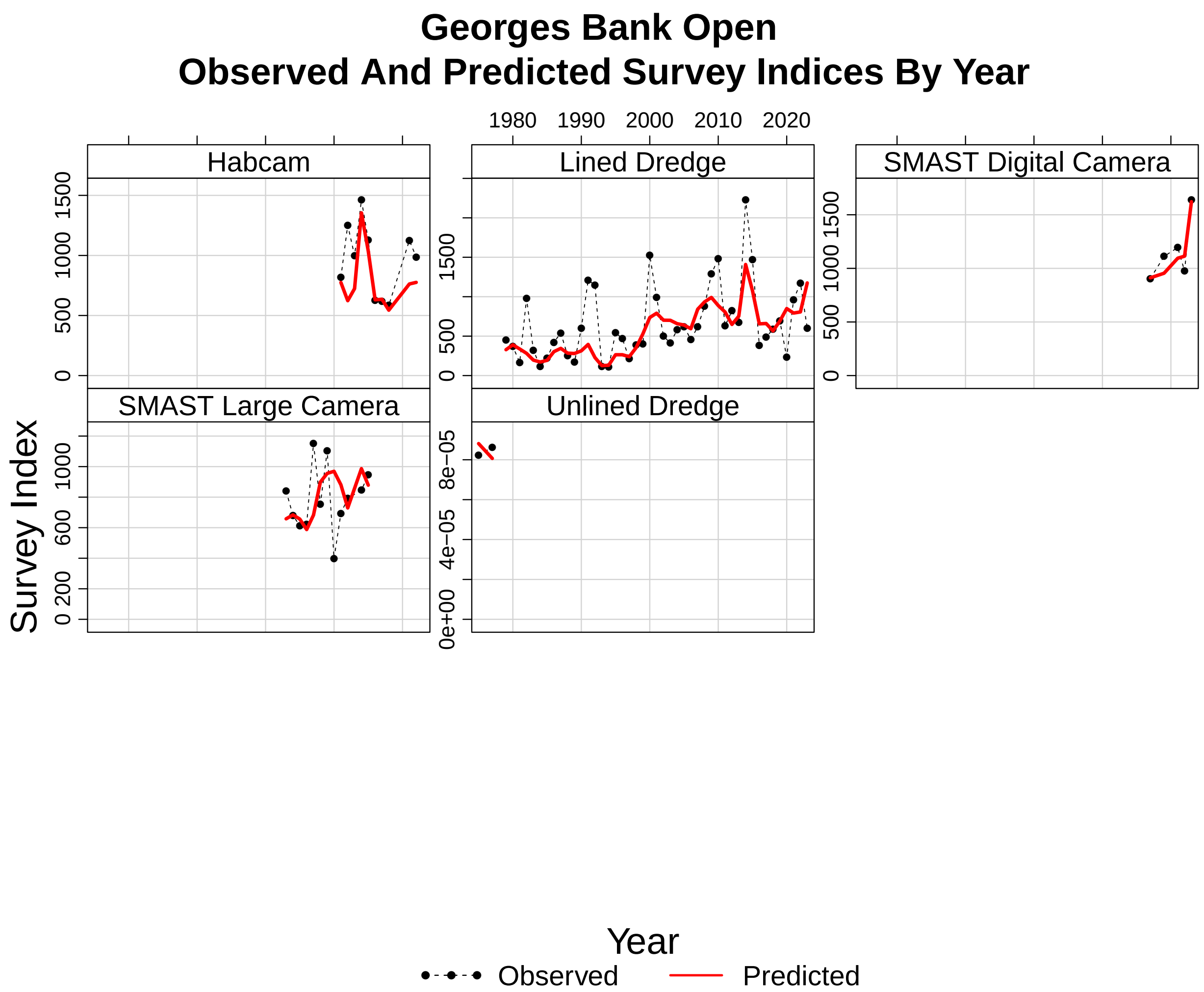


Figure 4.70: Observed survey trend (solid circles) and corresponding model estimates (lines) for the SMAST digital camera, lined dredge, Habcam, SMAST large camera, and unlined dredge surveys in Georges Bank open areas.

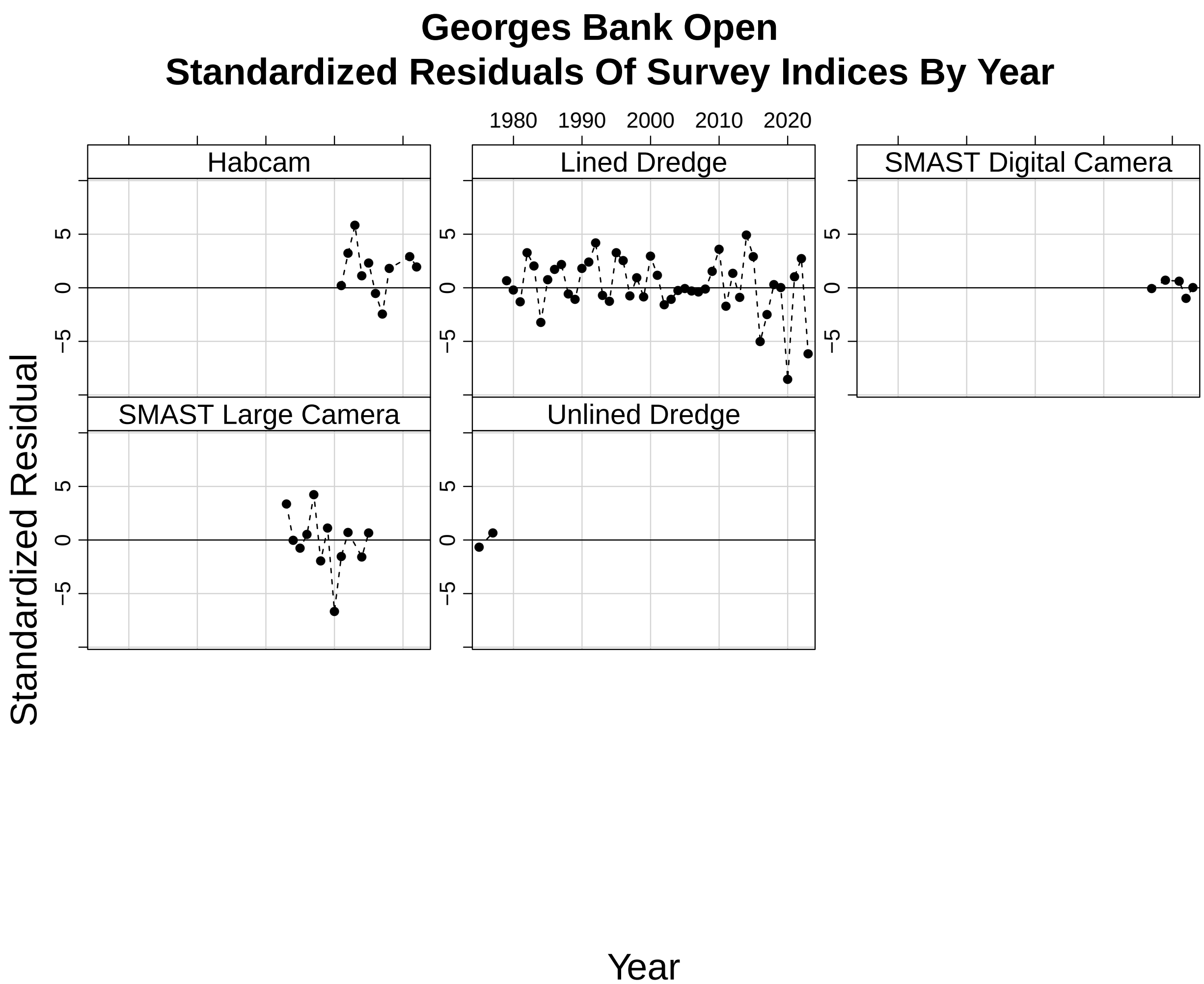


Figure 4.71: Standardized residuals of survey indices by year for the SMAST digital camera, lined dredge, Habcam, SMAST large camera, and unlined dredge surveys in Georges Bank open areas.

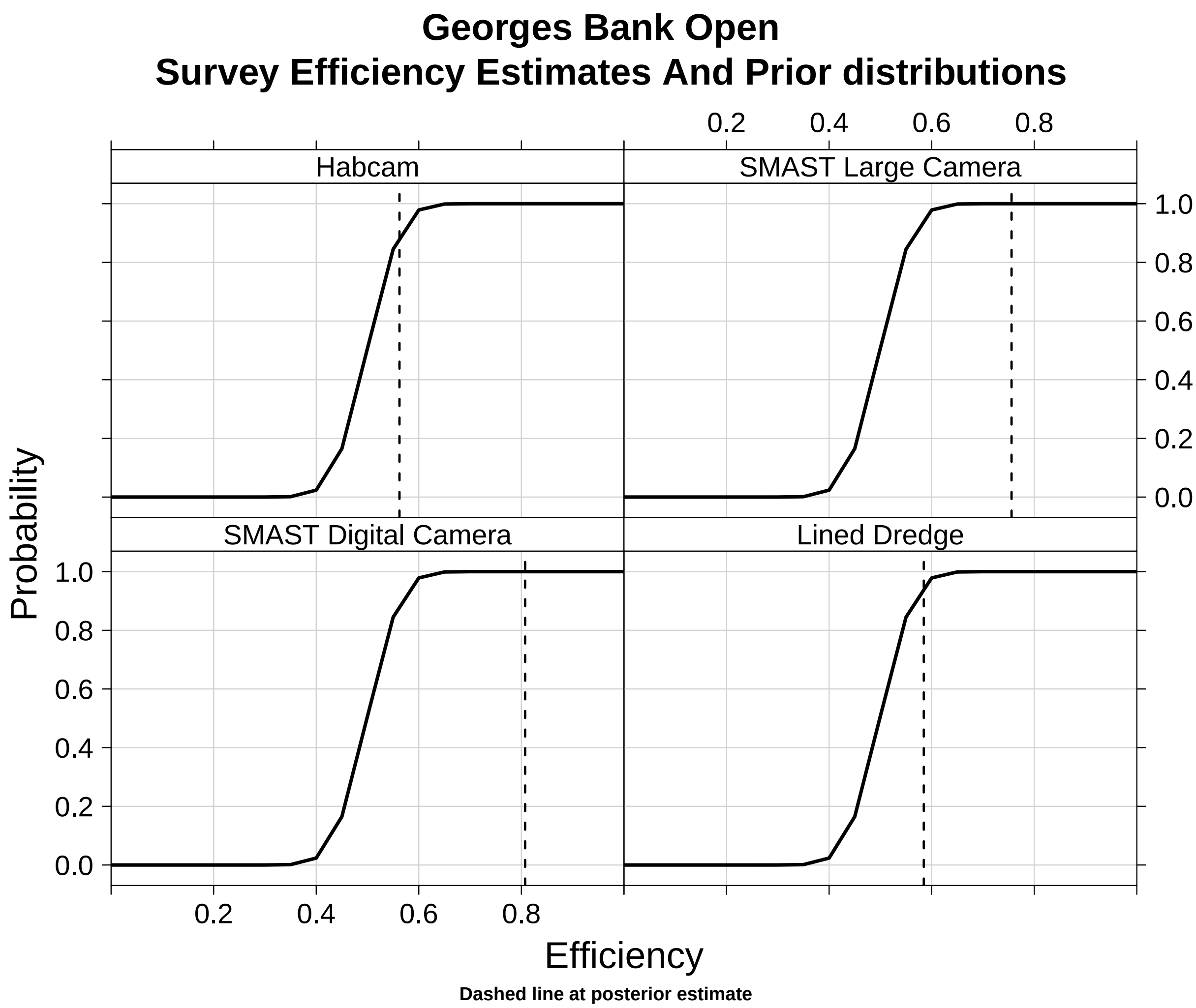
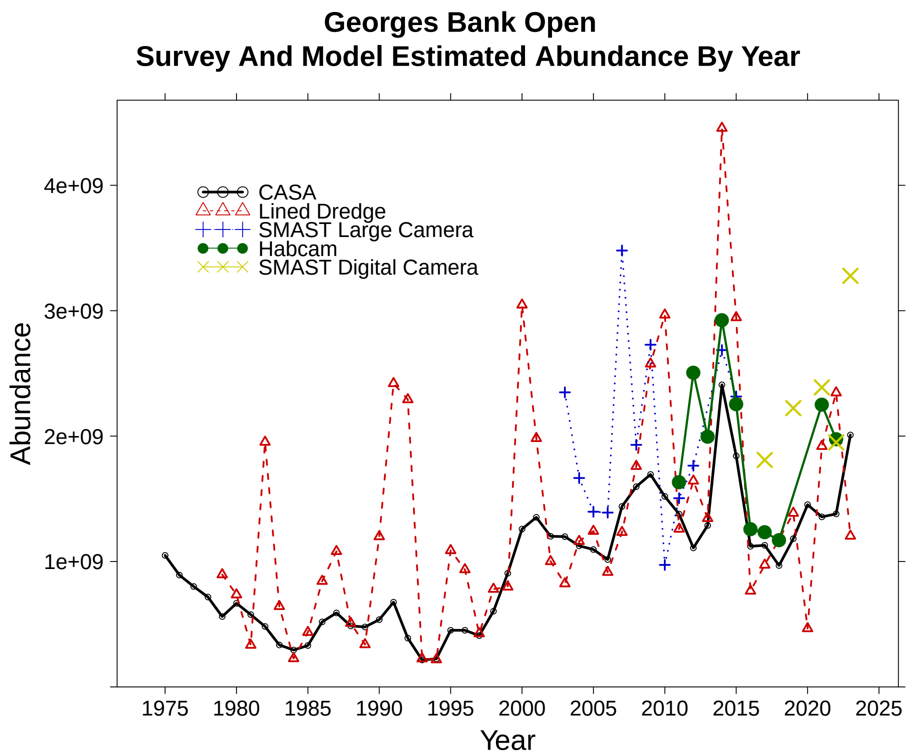


Figure 4.72: Prior cumulative distributions for catchability of Habcam, SMAST large camera, SMAST digital camera, and lined dredge surveys for Georges Bank open areas. The dashed lines are the mean posterior estimate for survey catchability. For the purposes of this plot, the surveys were adjusted to have a mean prior catchability of 0.5.



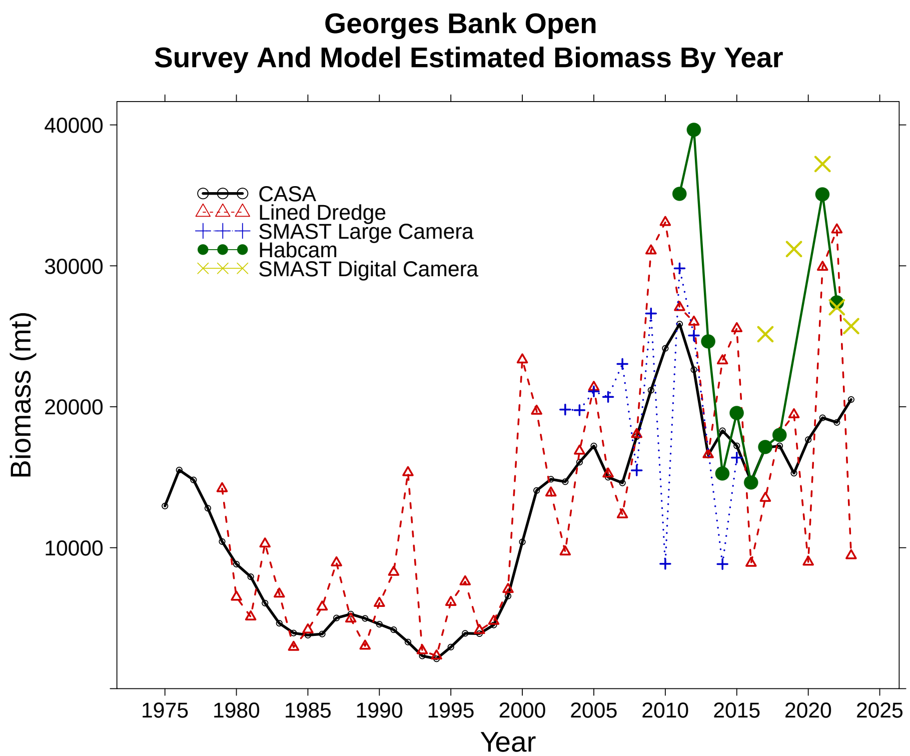


Figure 4.73: Comparison of CASA model estimated abundance (top) and biomass (bottom) with expanded estimates from the lined dredge (red triangle), SMAST large camera (blue cross), HabCam (green dots), and SMAST digital camera (light green x) for Georges Bank open areas.

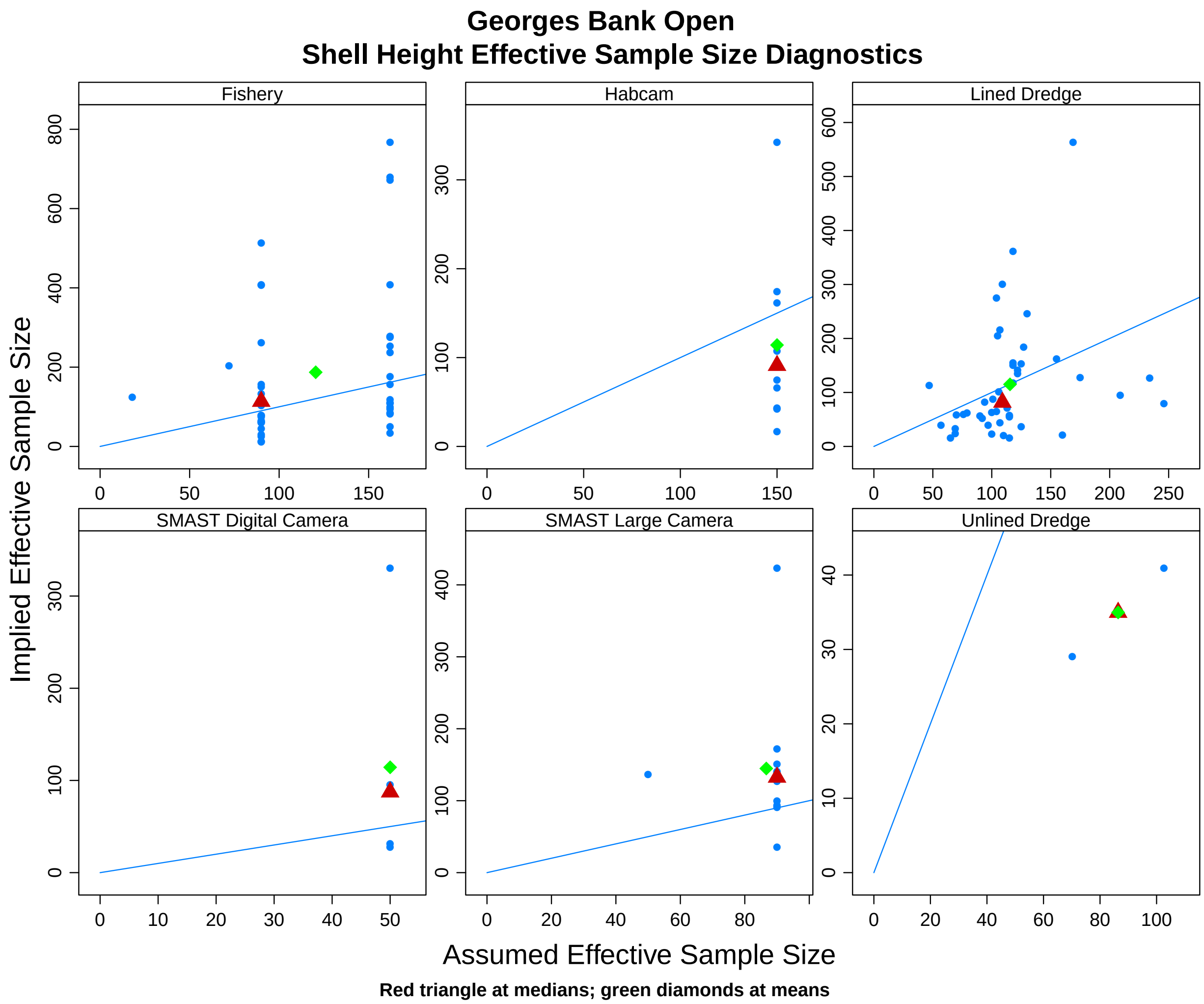
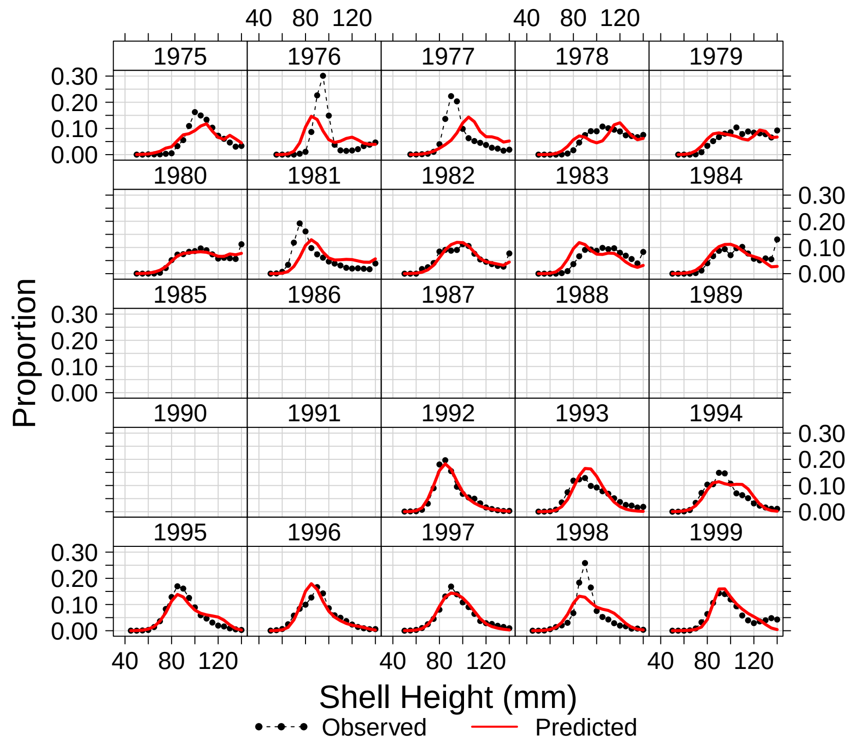


Figure 4.74: Assumed and model implied effective sample sizes for SMAST digital camera, lined dredge, Habcam, SMAST large camera, and unlined dredge surveys, and the fishery shell height compositions for Georges Bank open areas. The triangle is the median and the diamond is the mean.



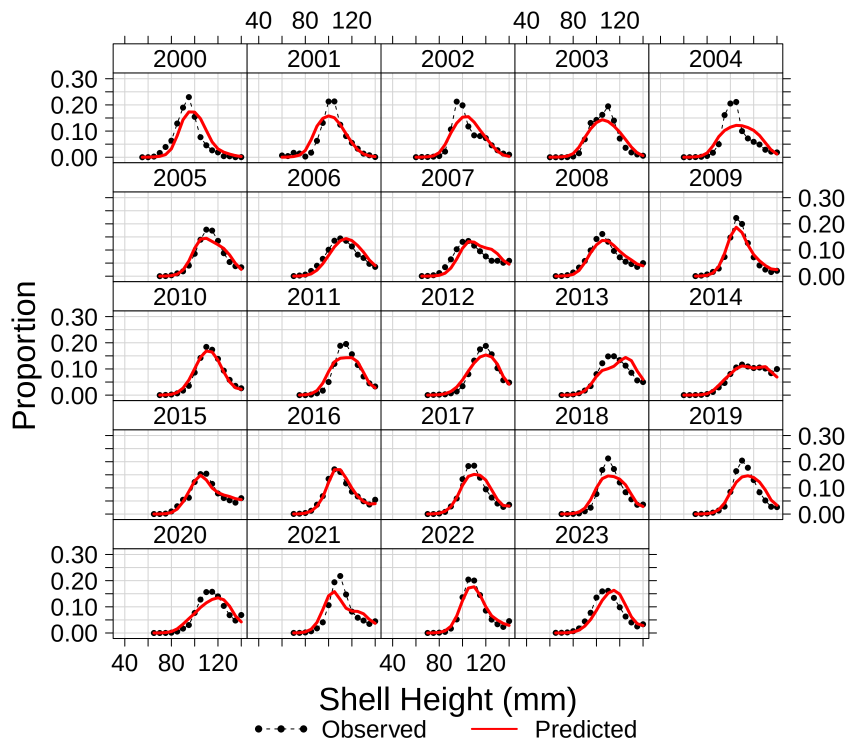
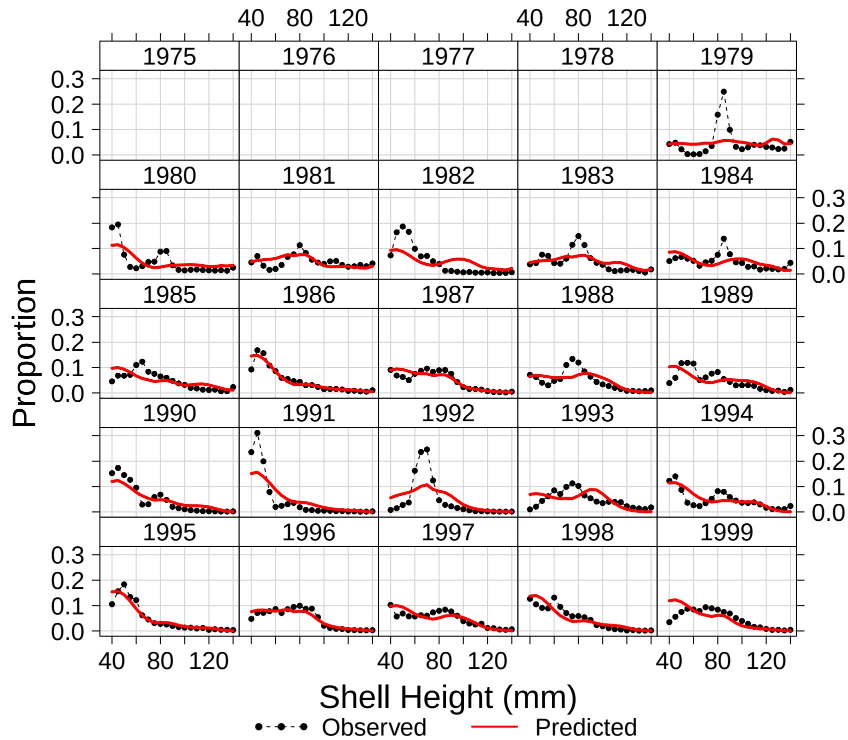


Figure 4.75: Comparison of observed fishery shell height proportions (solid circles) and model estimated fishery shell height proportions (lines) for Georges Bank open areas.



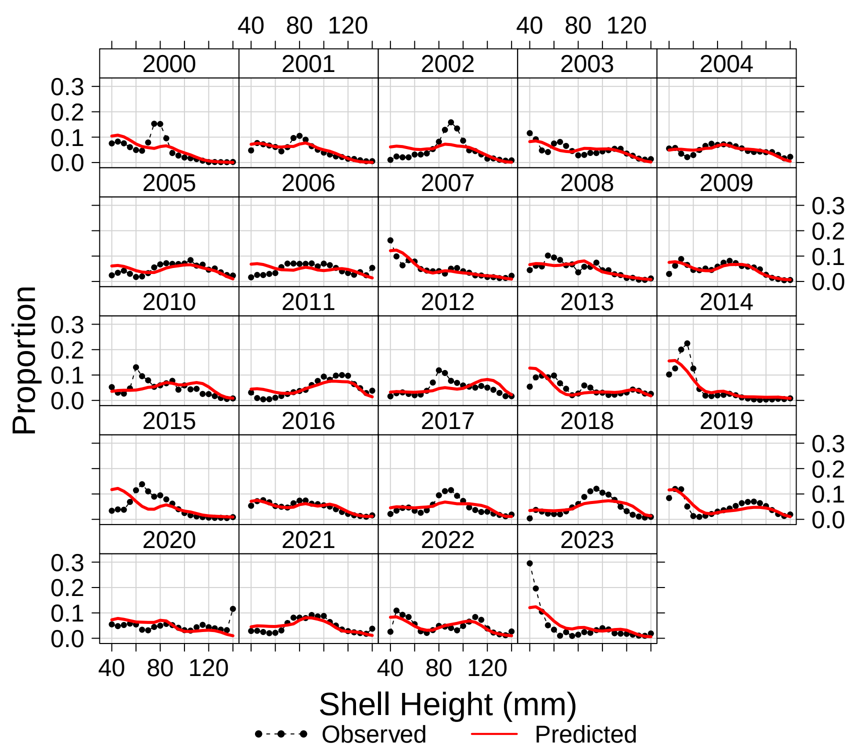


Figure 4.76: Comparison of lined dredge survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank open areas.

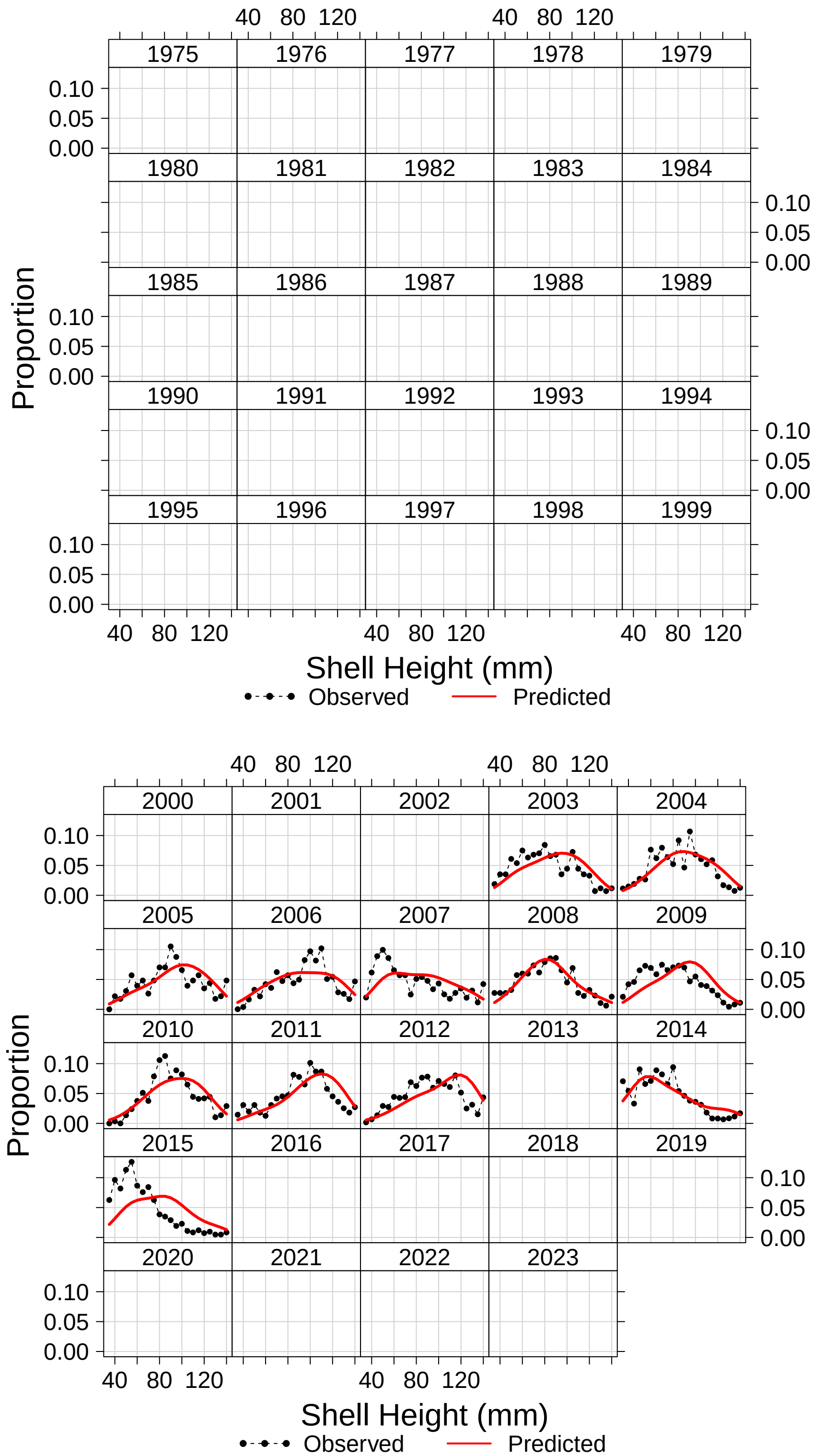


Figure 4.77: Comparison of SMAST large camera survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank open areas.

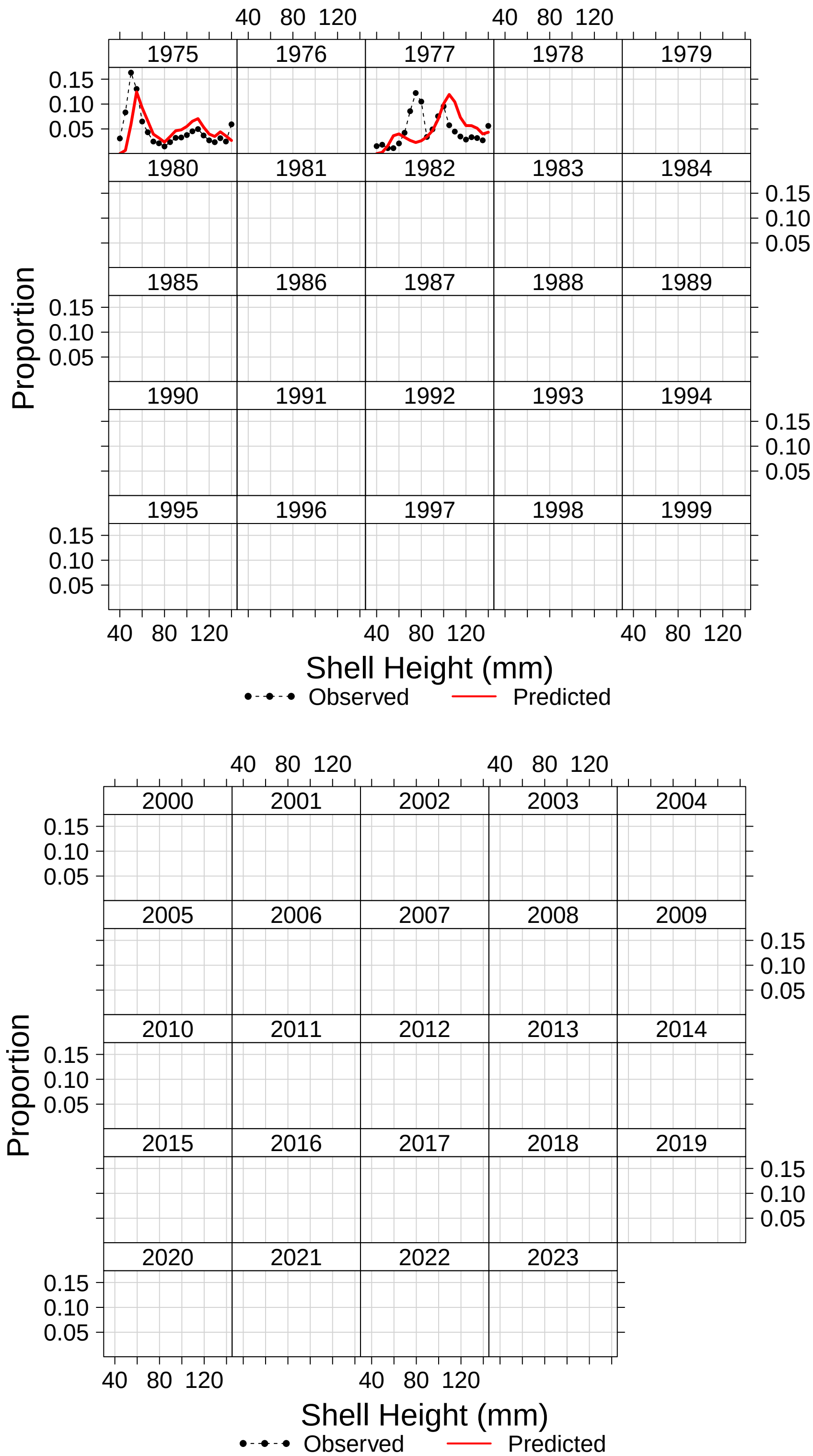


Figure 4.78: Comparison of unlined dredge survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank open areas.

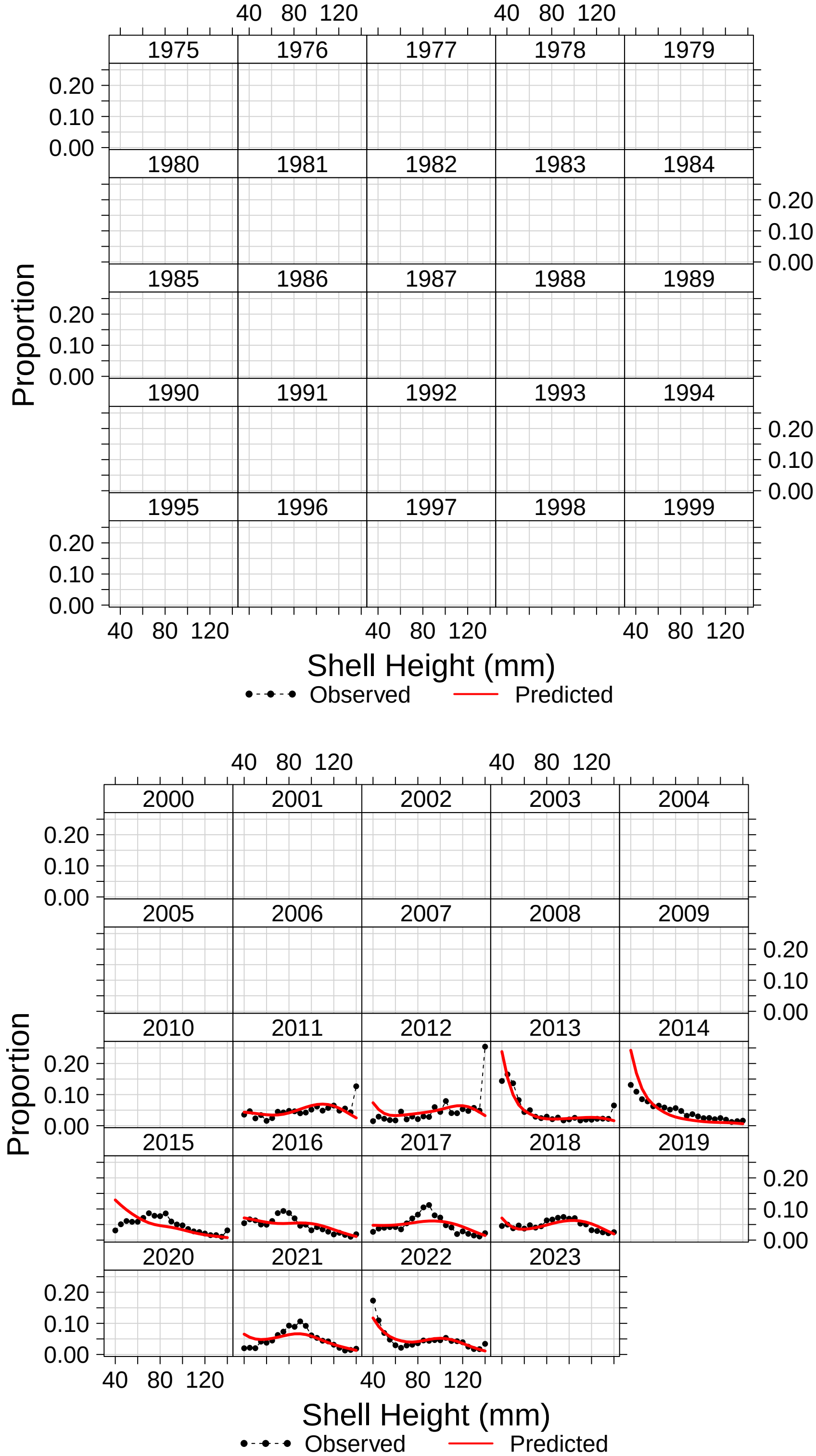


Figure 4.79: Comparison of Habcam survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank open areas.

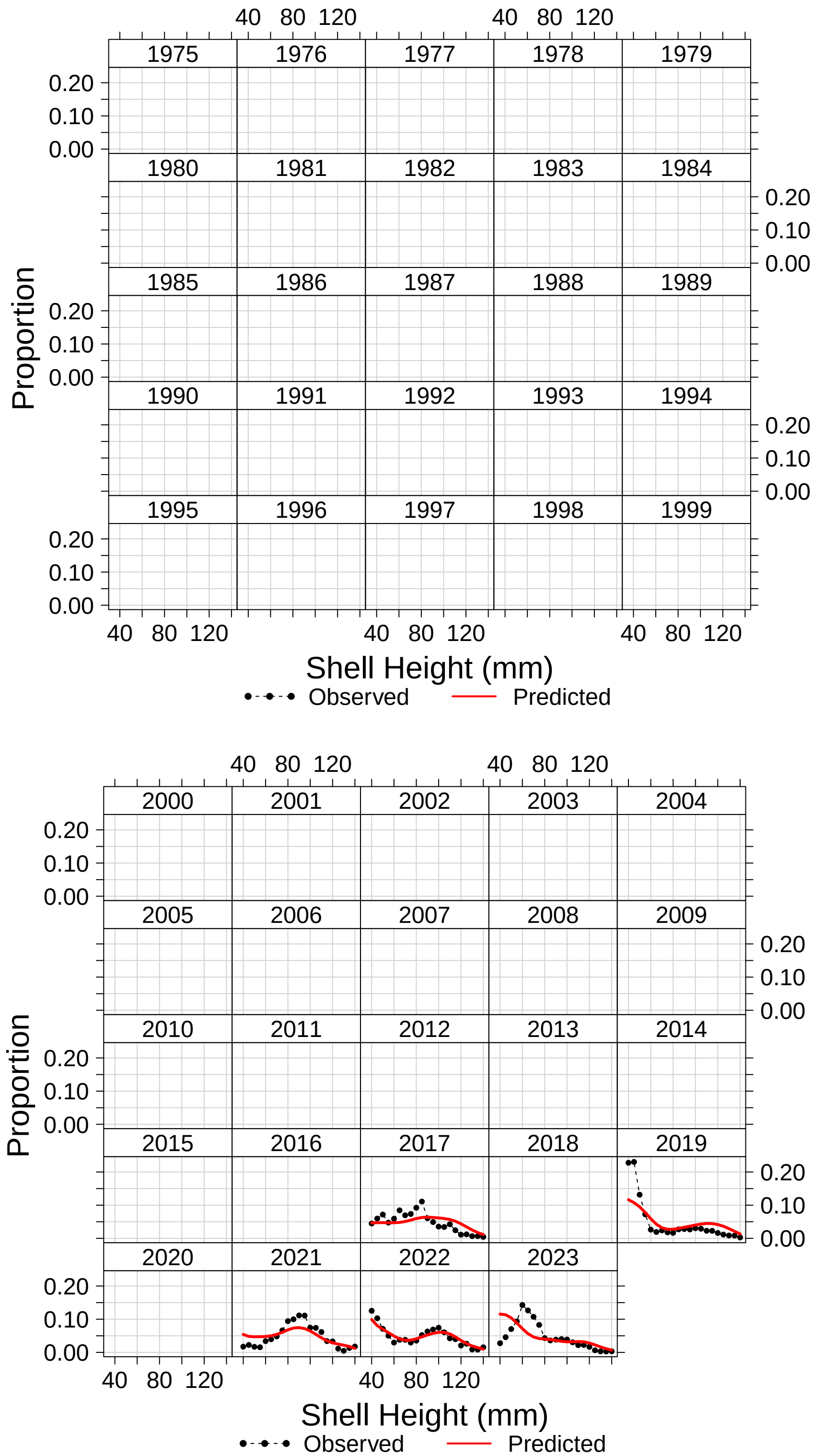


Figure 4.80: Comparison of SMAST digital camera survey shell height proportions (solid circles) and model estimated shell height proportions (lines) for Georges Bank open areas.

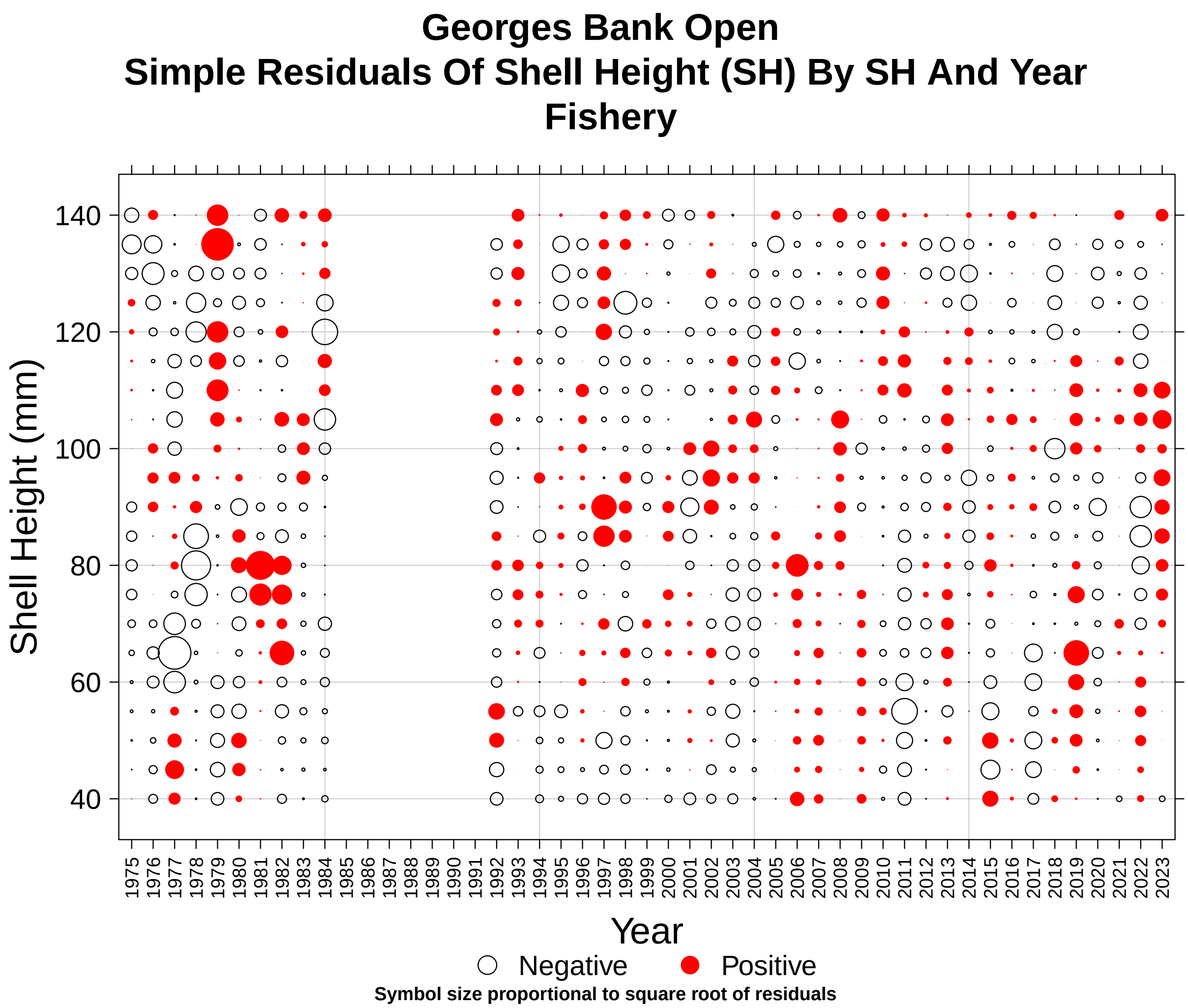


Figure 4.81: Simple residuals of fishery shell height proportions for Georges Bank open areas. Symbol areas are proportional to residual.

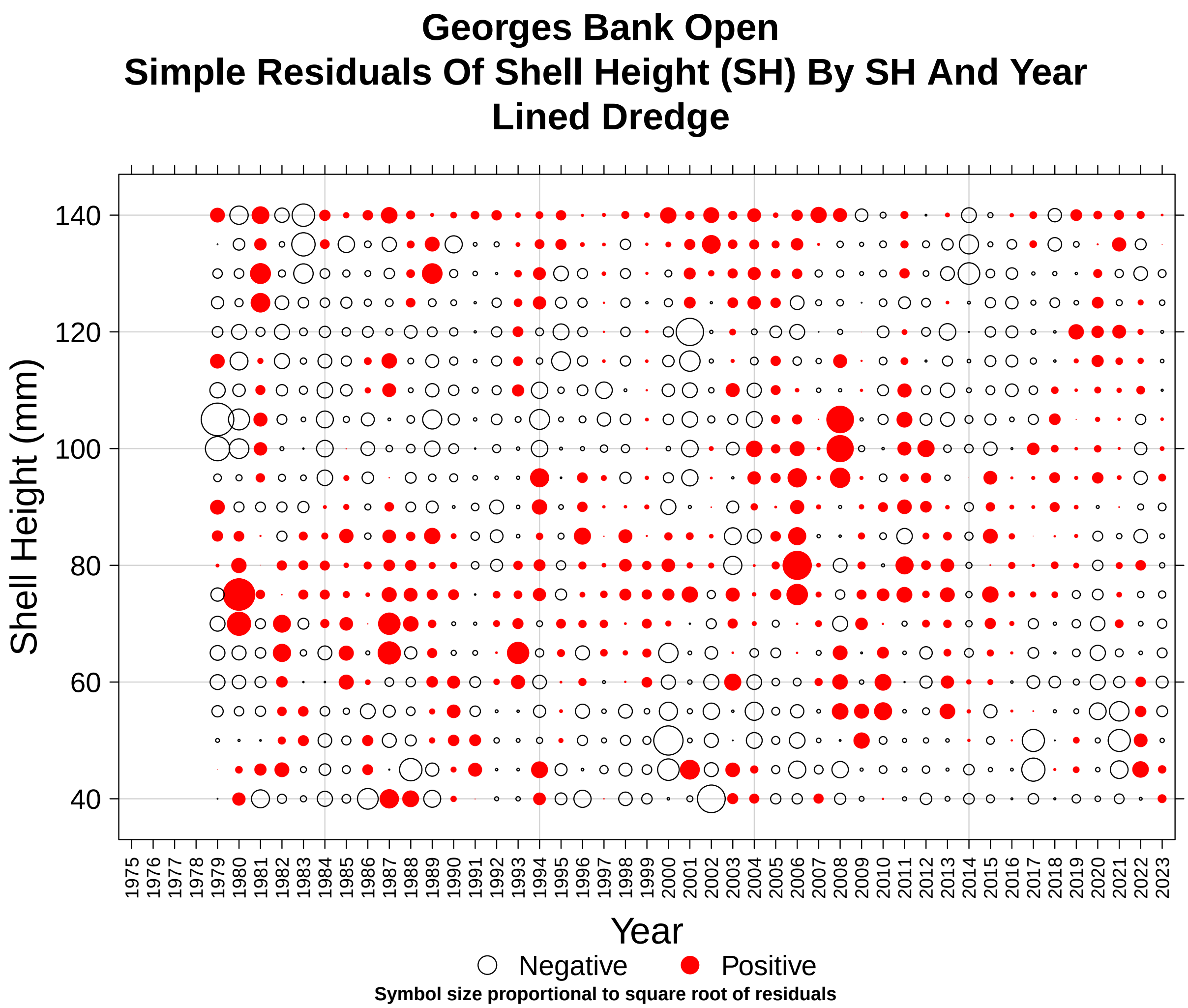


Figure 4.82: Simple residuals of lined dredge survey shell height proportions for Georges Bank open areas. Symbol areas are proportional to residual.

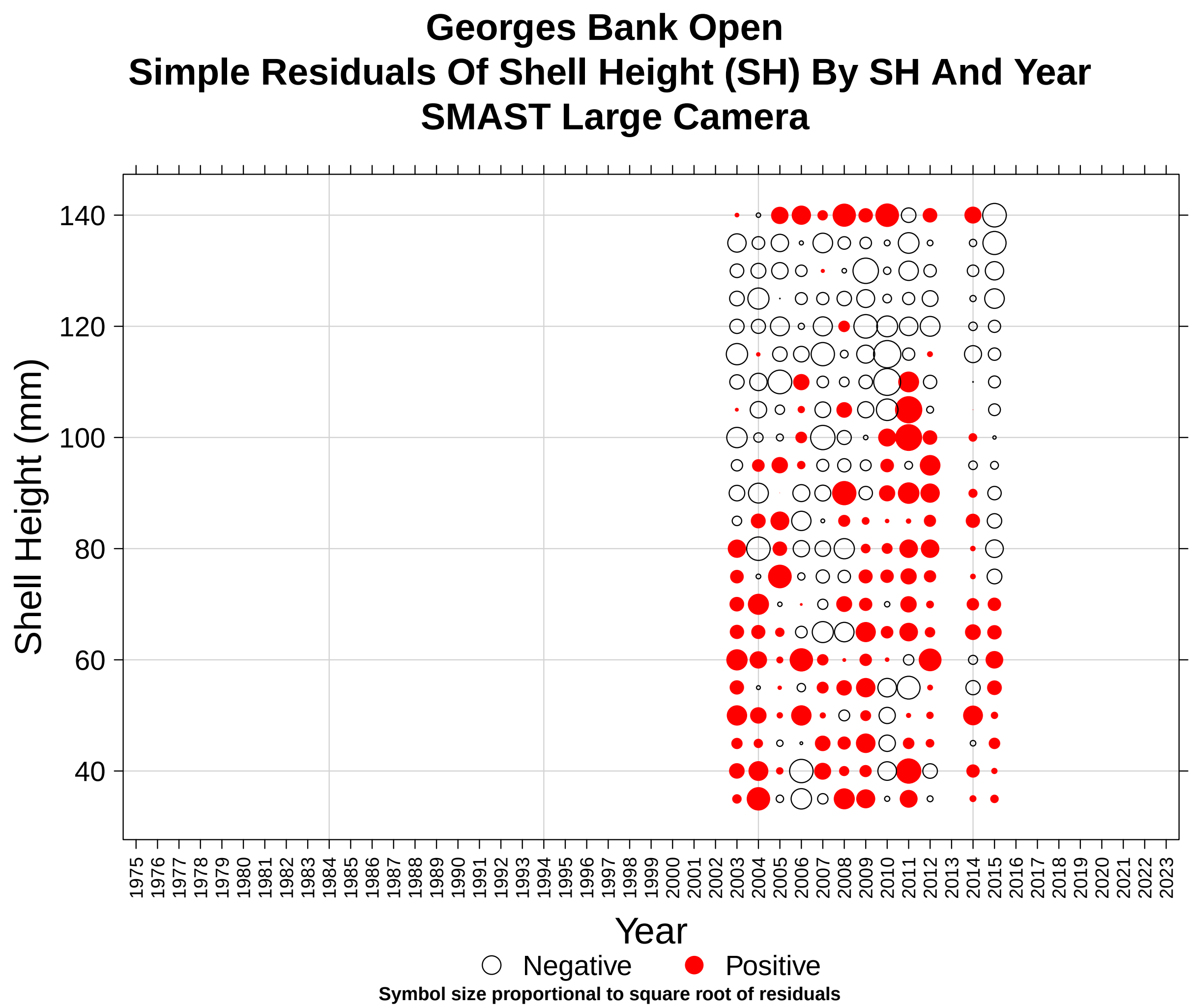


Figure 4.83: Simple residuals of SMAST large camera survey shell height proportions for Georges Bank open areas. Symbol areas are proportional to residual.

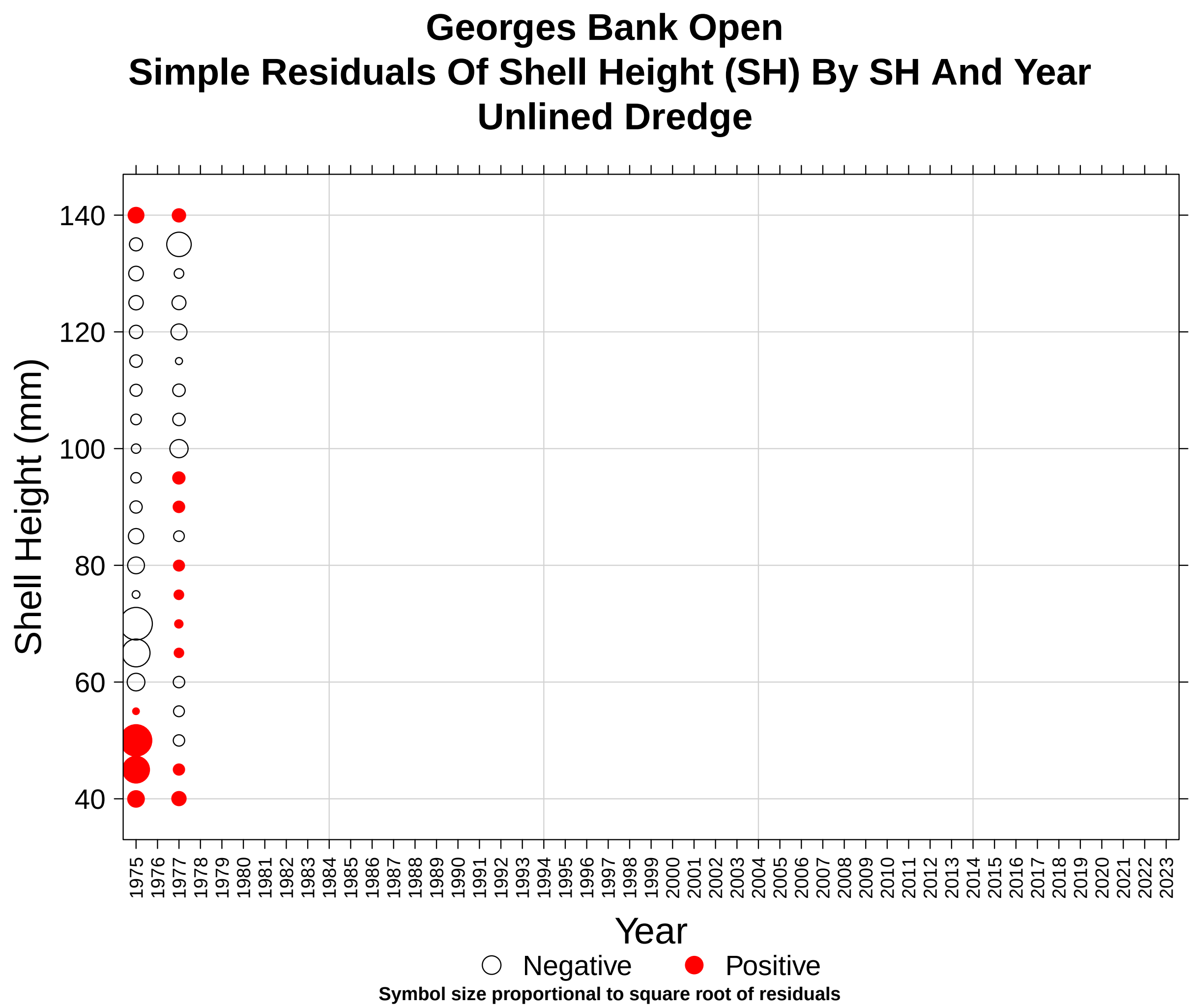


Figure 4.84: Simple residuals of unlined dredge survey shell height proportions for Georges Bank open areas. Symbol areas are proportional to residual.

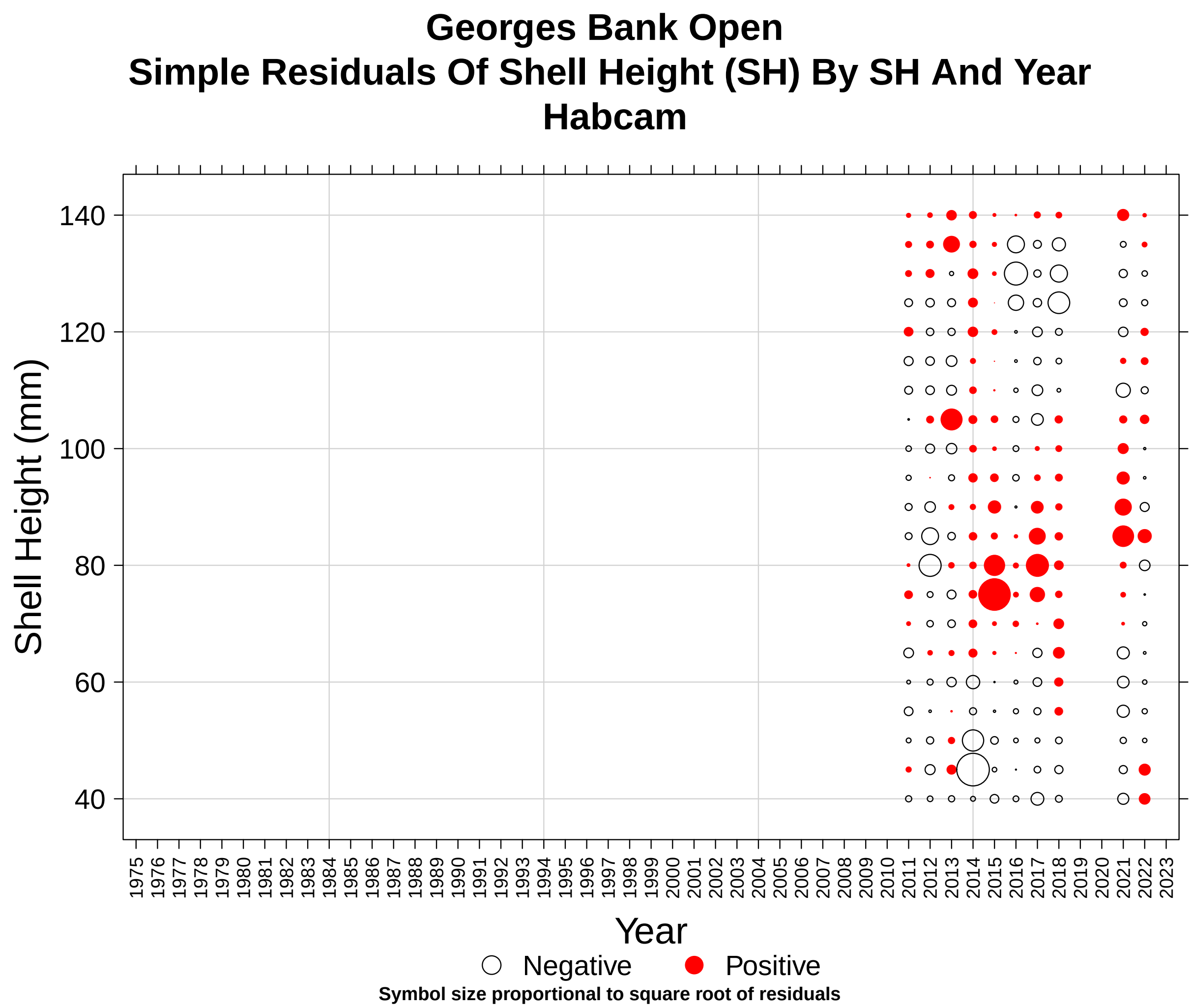


Figure 4.85: Simple residuals of Habcam survey shell height proportions for Georges Bank open areas. Symbol areas are proportional to residual.

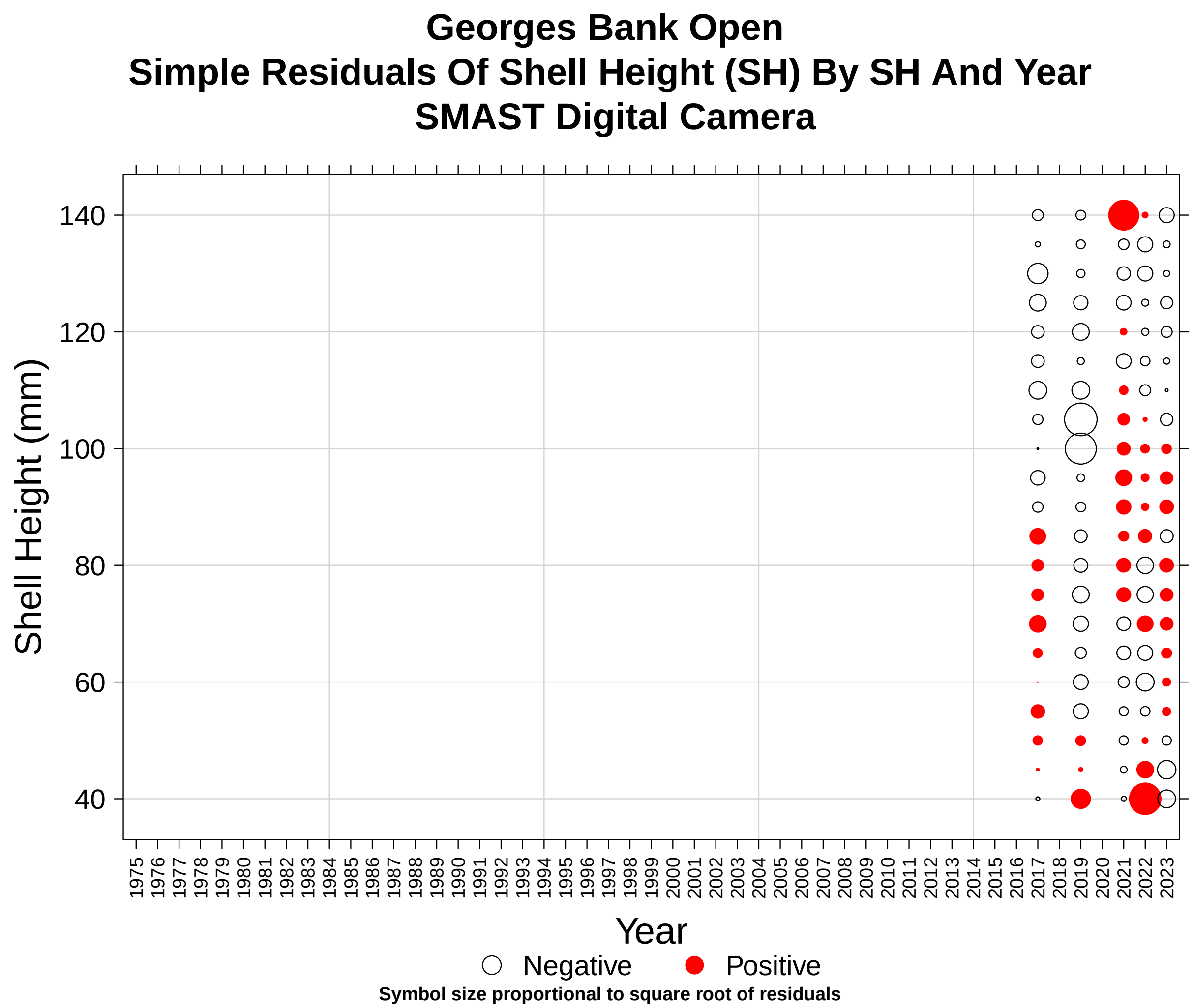


Figure 4.86: Simple residuals of SMAST digital camera survey shell height proportions for Georges Bank open areas. Symbol areas are proportional to residual.

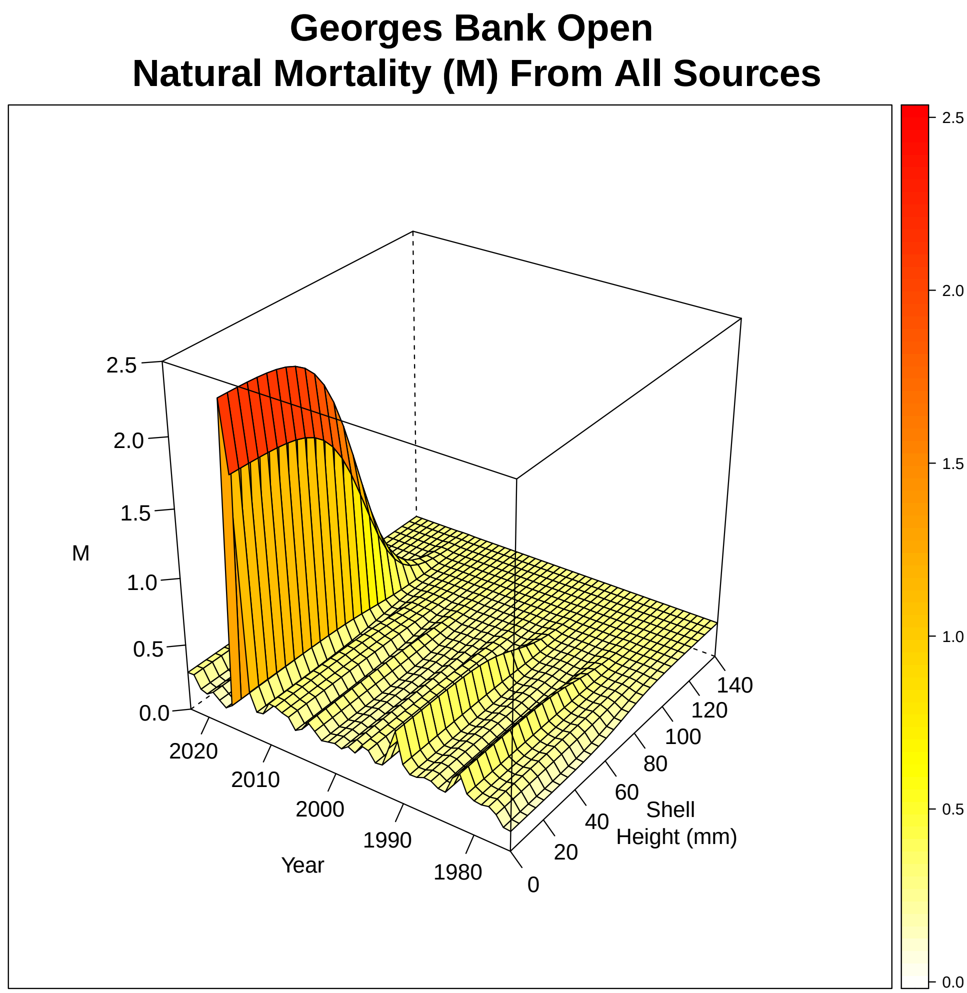


Figure 4.87: Estimated natural mortality by size from 1975 to 2023 for Georges Bank open areas.

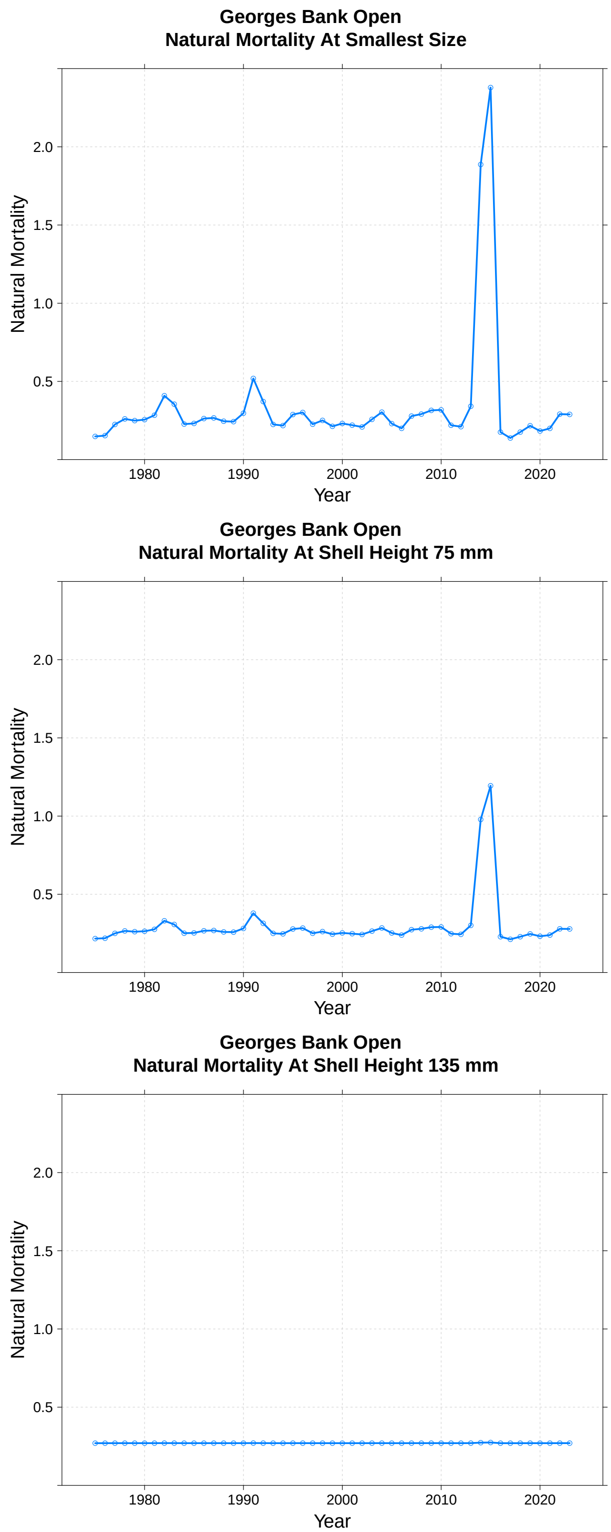


Figure 4.88: Estimated natural mortality for 0-5 mm (top), 75-80 mm (middle), and 135+ mm (bottom) scallops from 1975 to 2023 for Georges Bank open areas.

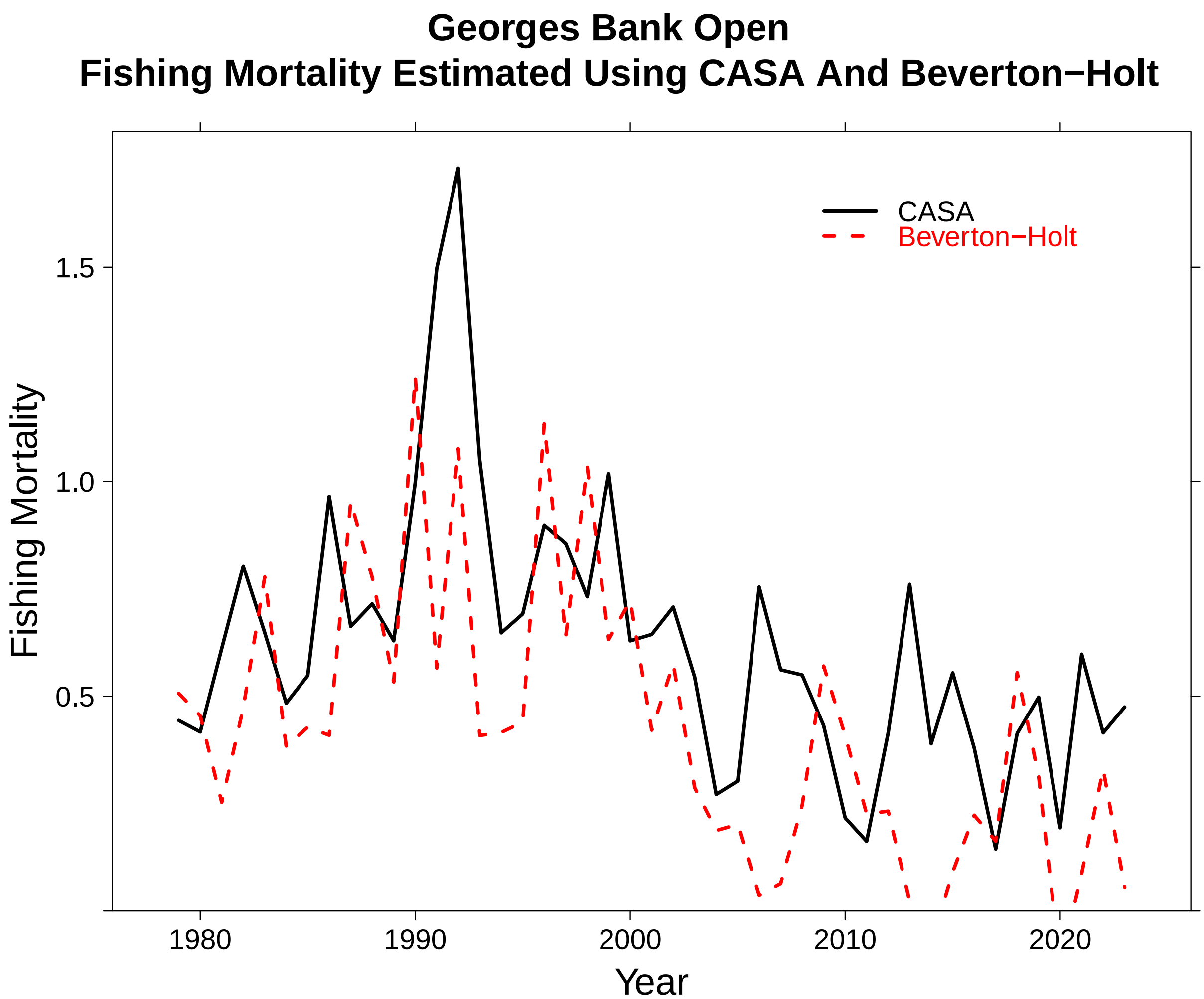


Figure 4.89: Comparison of fully recruited CASA fishing mortality with those calculated from the Beverton-Holt equilibrium length based estimator for Georges Bank open areas.

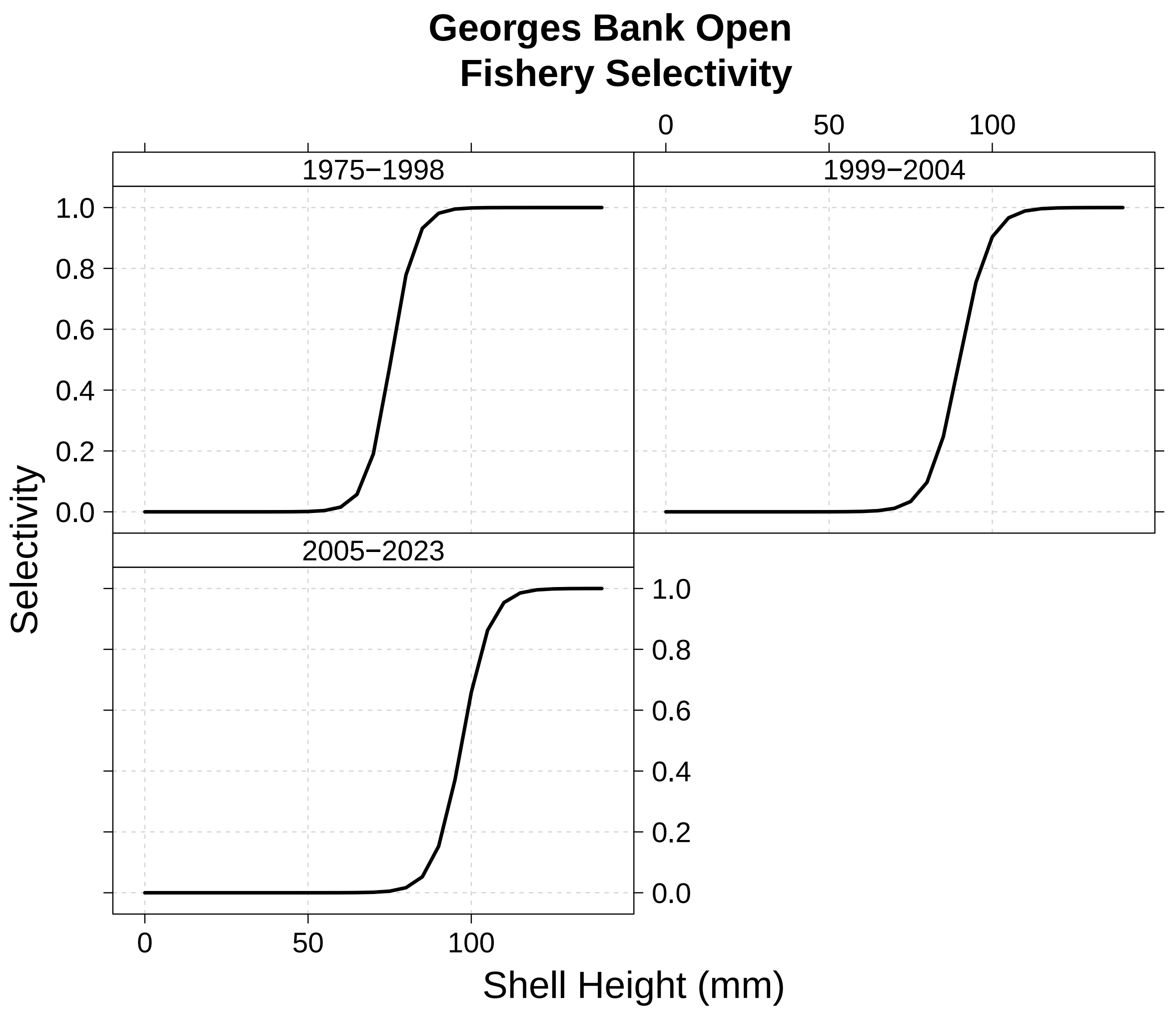


Figure 4.90: Estimated fishery selectivity curves for Georges Bank open areas.

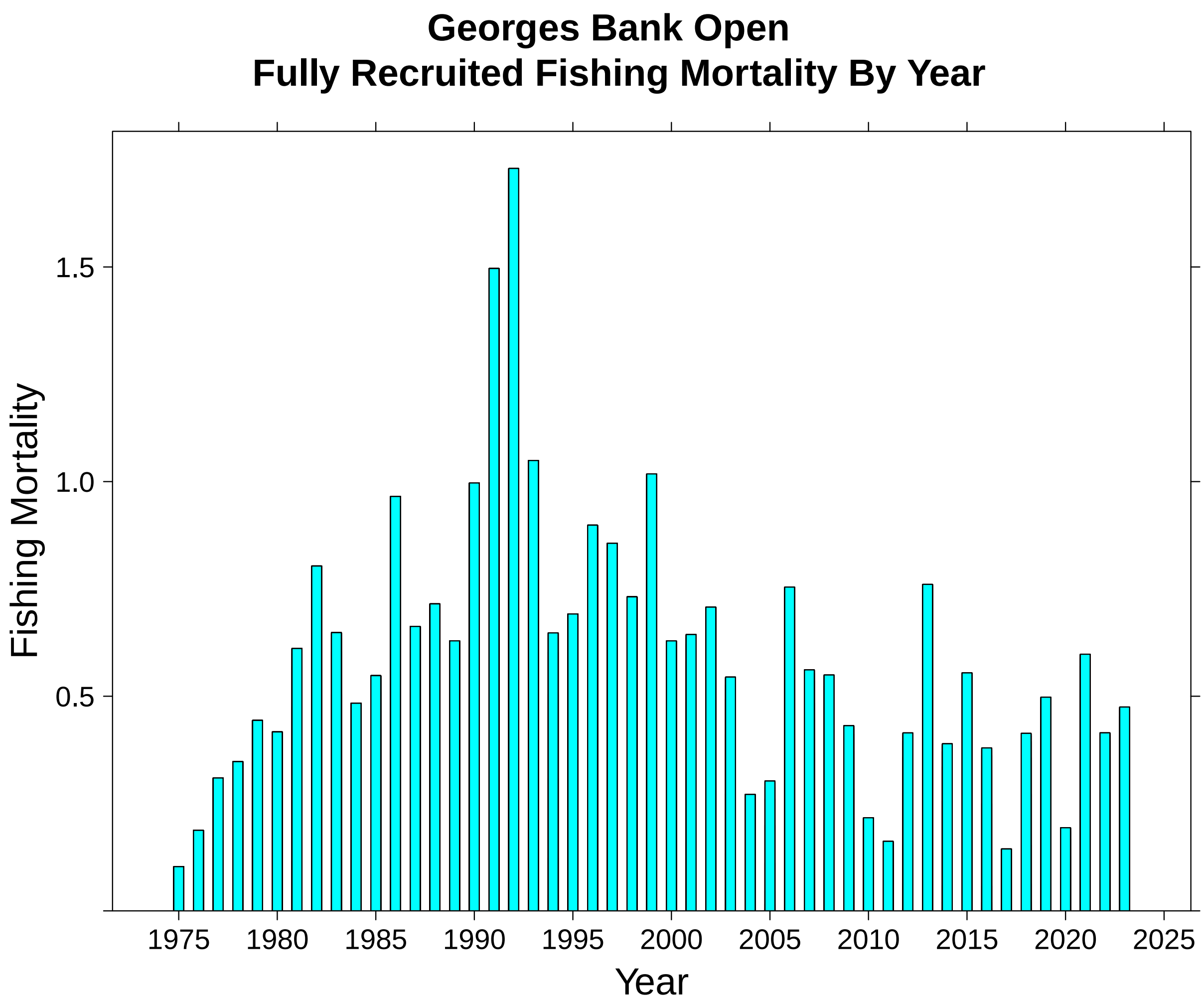


Figure 4.91: CASA model estimated fully recruited fishing mortality for Georges Bank open areas.

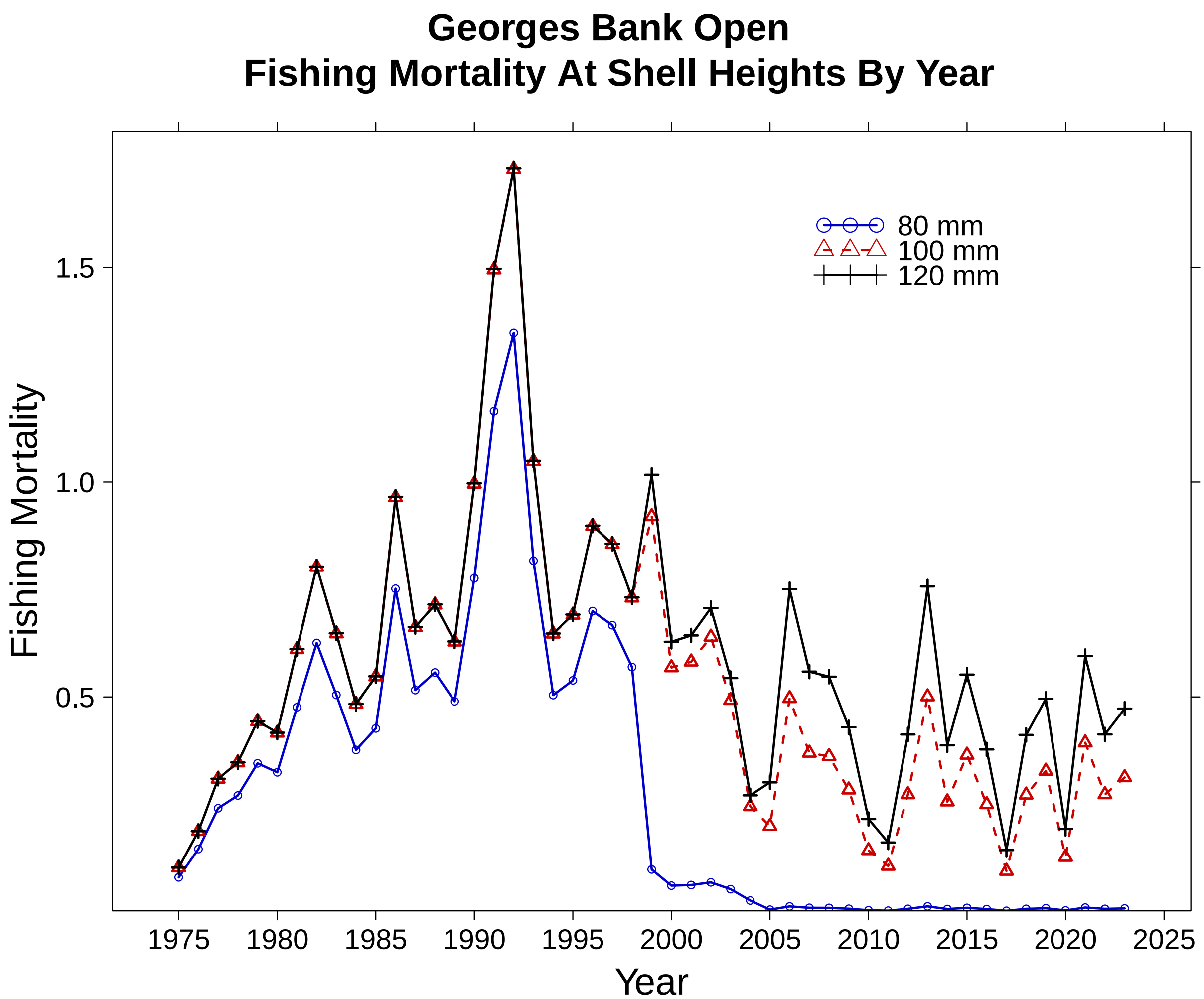


Figure 4.92: CASA model estimated fishing mortality at 80 mm (solid line with circles), 100 mm (dashed line with triangles), and 120 mm SH (dashed line with crosses) for Georges Bank open areas.

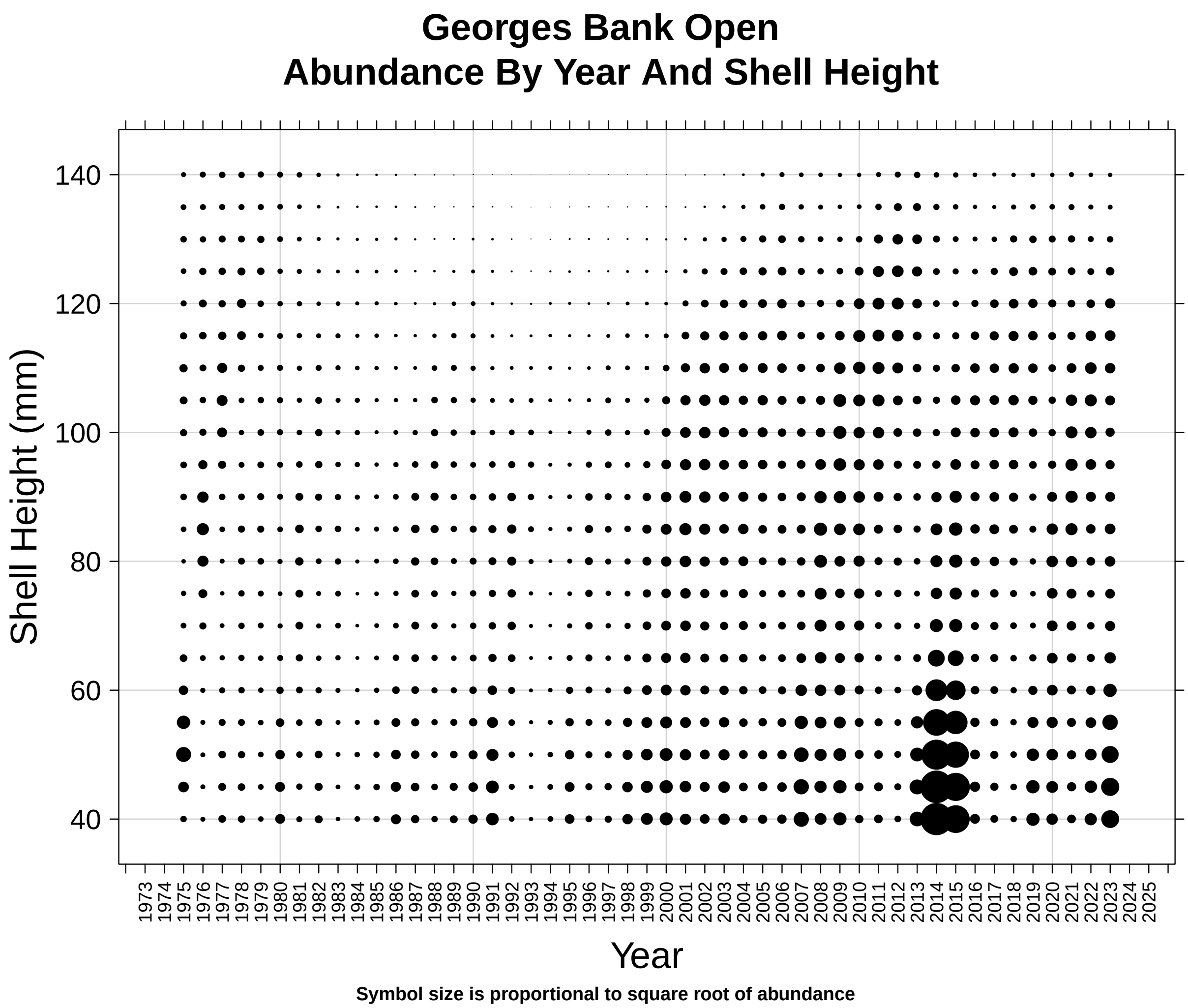


Figure 4.93: CASA model estimated abundances at shell height for Georges Bank open areas. Symbol areas are proportional to abundance.

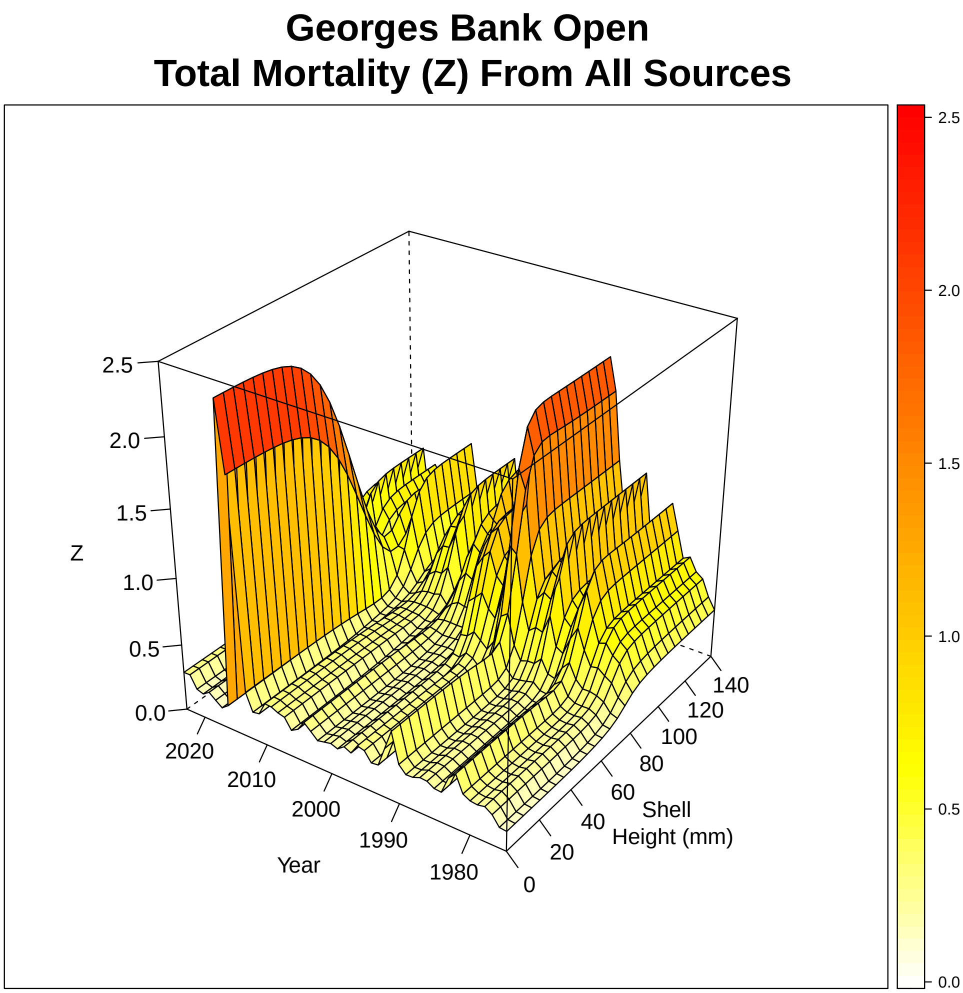


Figure 4.94: Estimated total mortality by size from 1975 to 2023 for Georges Bank areas.

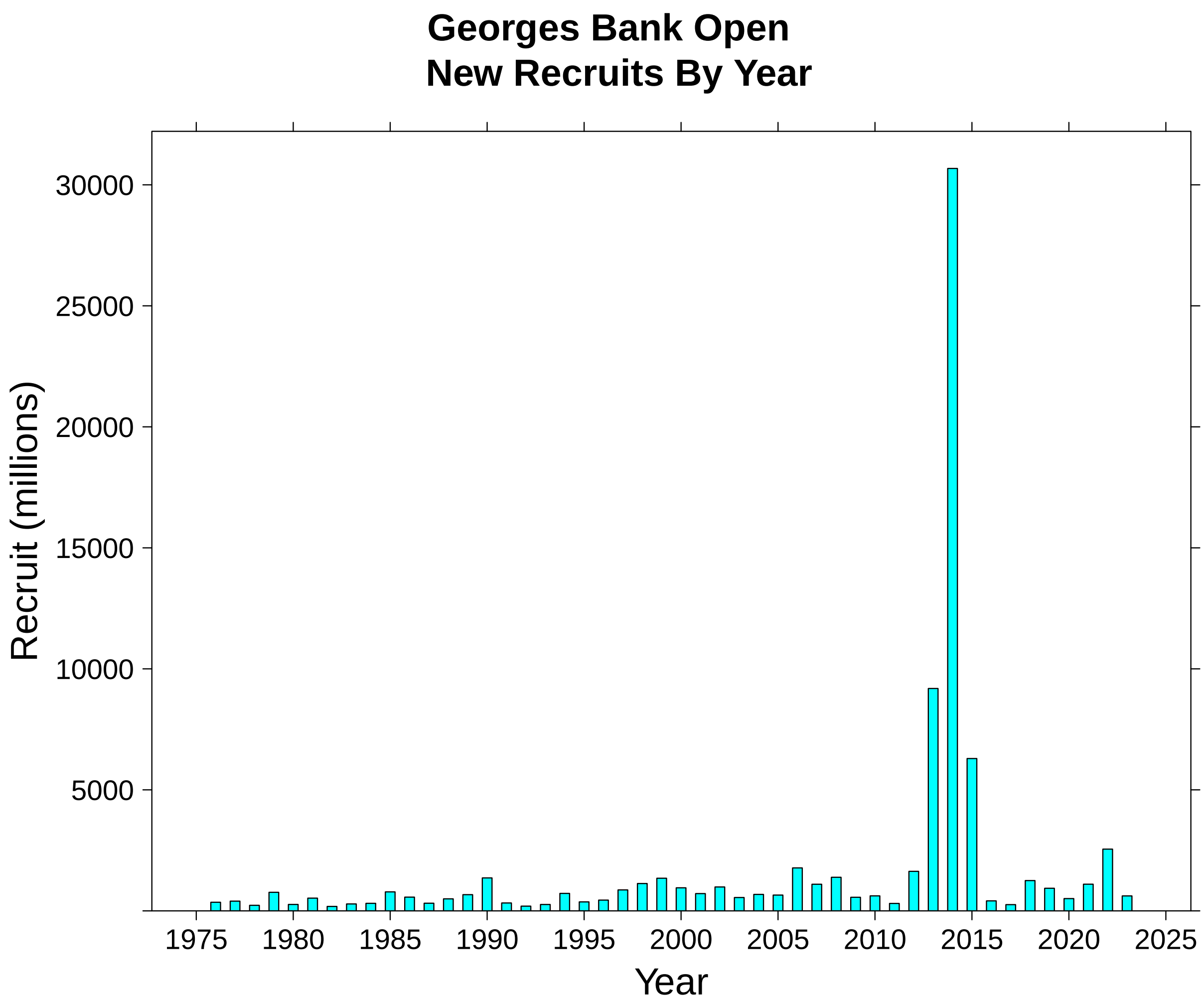


Figure 4.95: CASA model estimated recruitment for Georges Bank open areas.

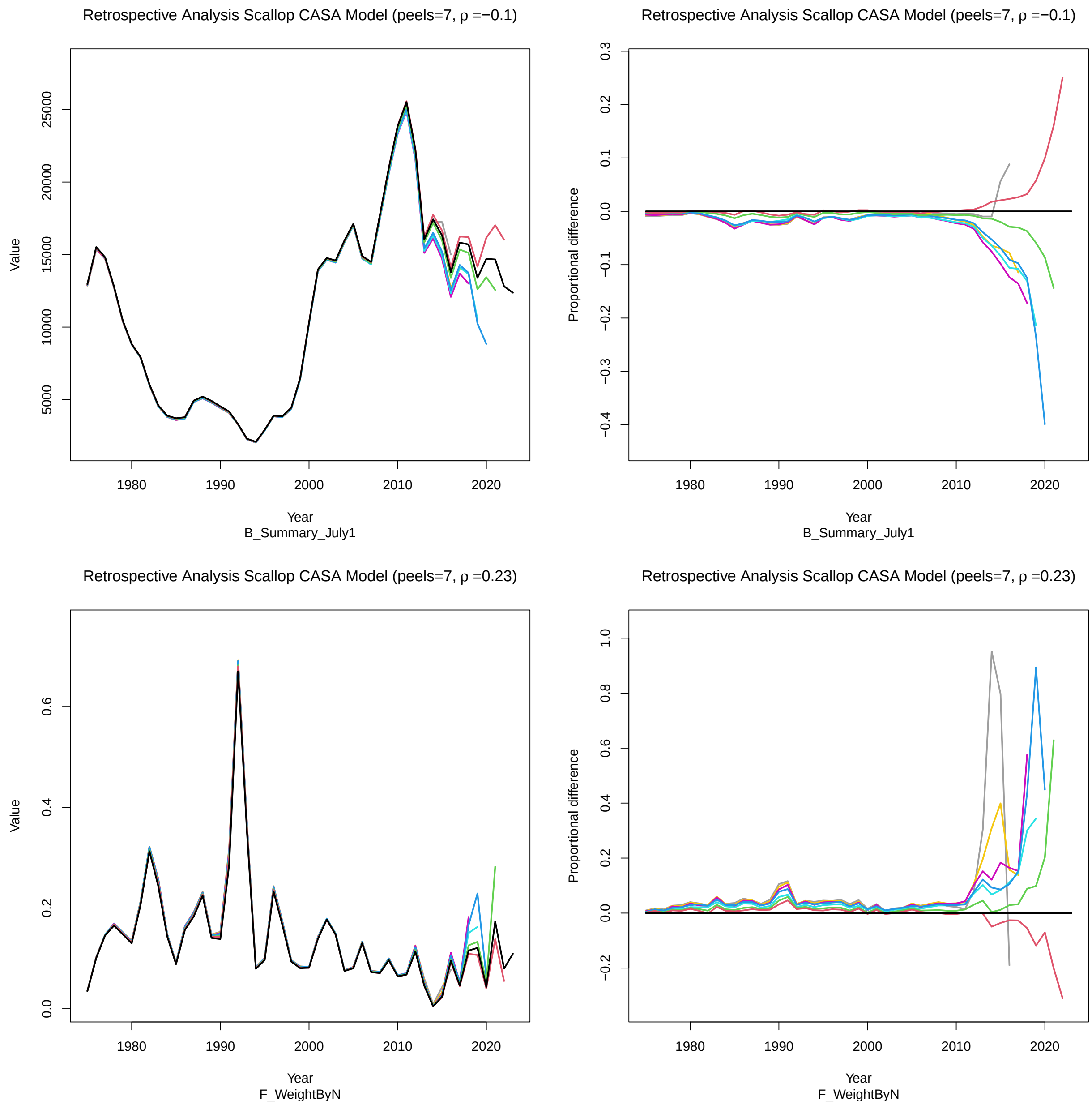


Figure 4.96: Retrospective plots for biomass and fishing mortality for Georges Bank open areas. Retrospectives are shown on both absolute and relative scales.

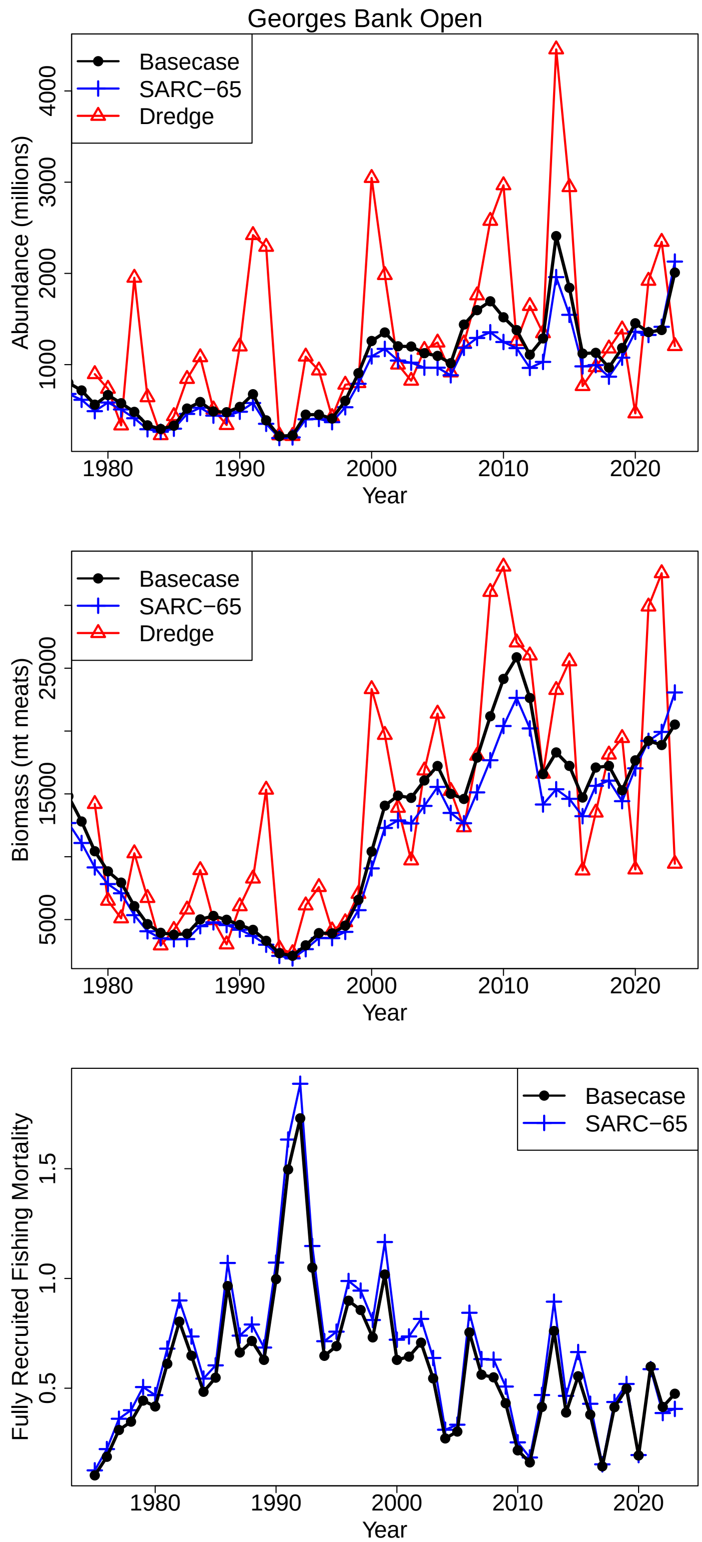


Figure 4.97: Comparison of estimated abundance (millions), biomass (mt meats), and fully recruited fishing mortality from current and SARC-65 CASA model configurations, and lined dredge survey for Georges Bank open areas.

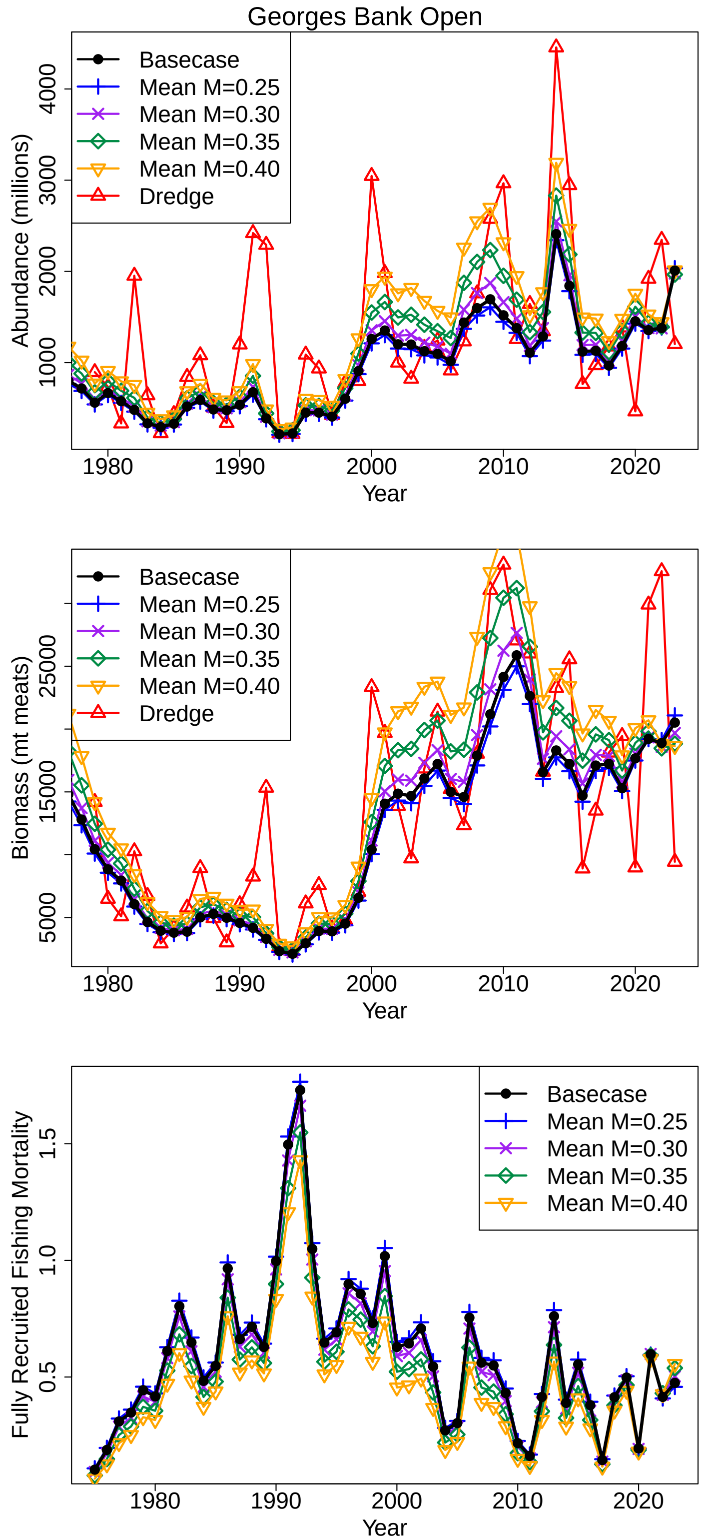


Figure 4.98: Comparison of estimated abundance (millions), biomass (mt meats), and fully recruited fishing mortality from current model, model with various mean natural mortality assumptions, and lined dredge survey for Georges Bank open areas.

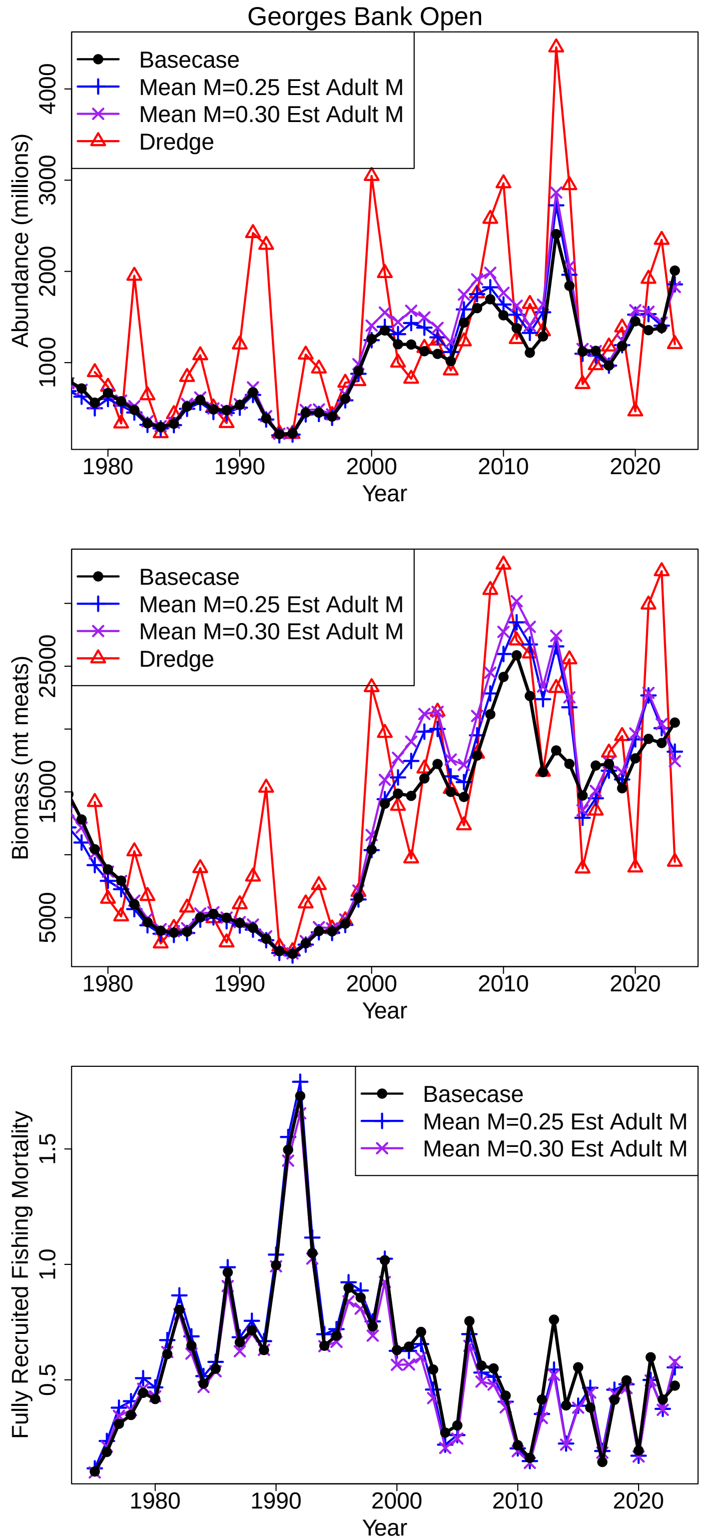


Figure 4.99: Comparison of estimated abundance (millions), biomass (mt meats), and fully recruited fishing mortality from current model, model with size-varying natural mortality, and lined dredge survey for Georges Bank open areas.

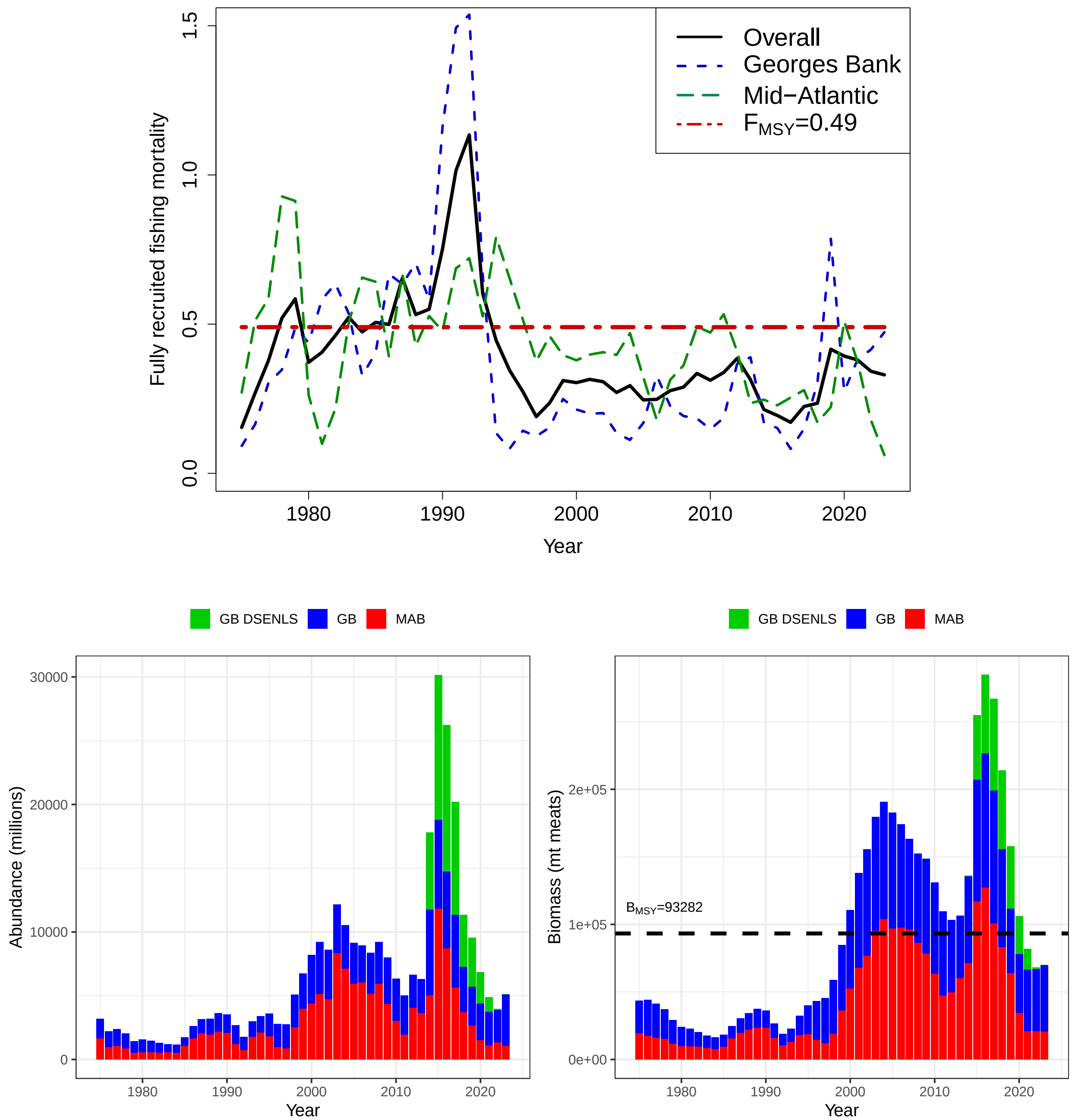


Figure 4.100: Estimated fully recruited fishing mortality (top), abundance (bottom left), and biomass (bottom right) including Habcam abundance and biomass estimates of the Deep Southeast Nantucket Lightship scallops for Georges Bank and Mid-Atlantic areas.

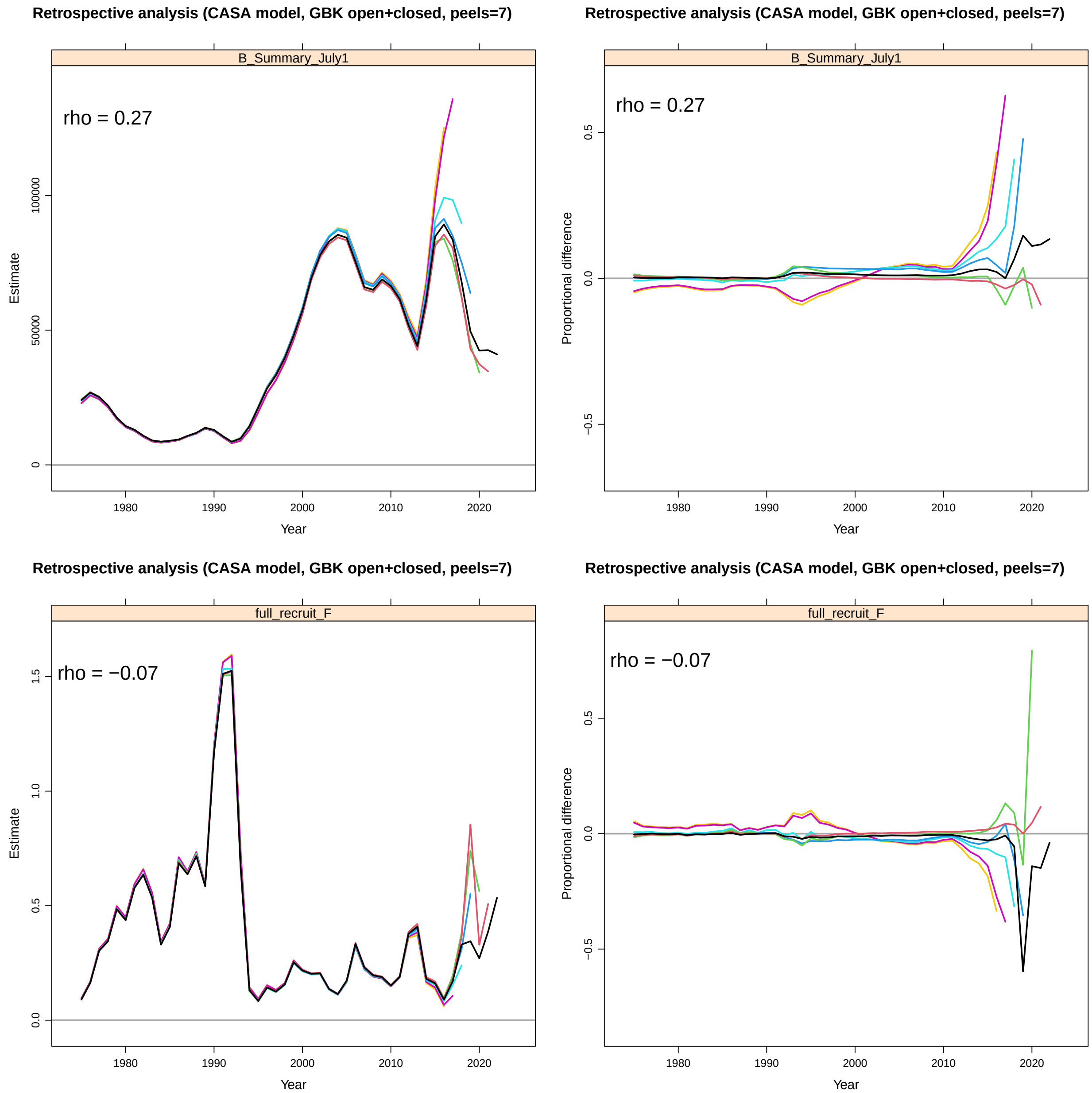


Figure 4.101: Retrospective plots for biomass and fishing mortality for the combined Georges Bank stock. Retrospectives are shown on both absolute and relative scales.

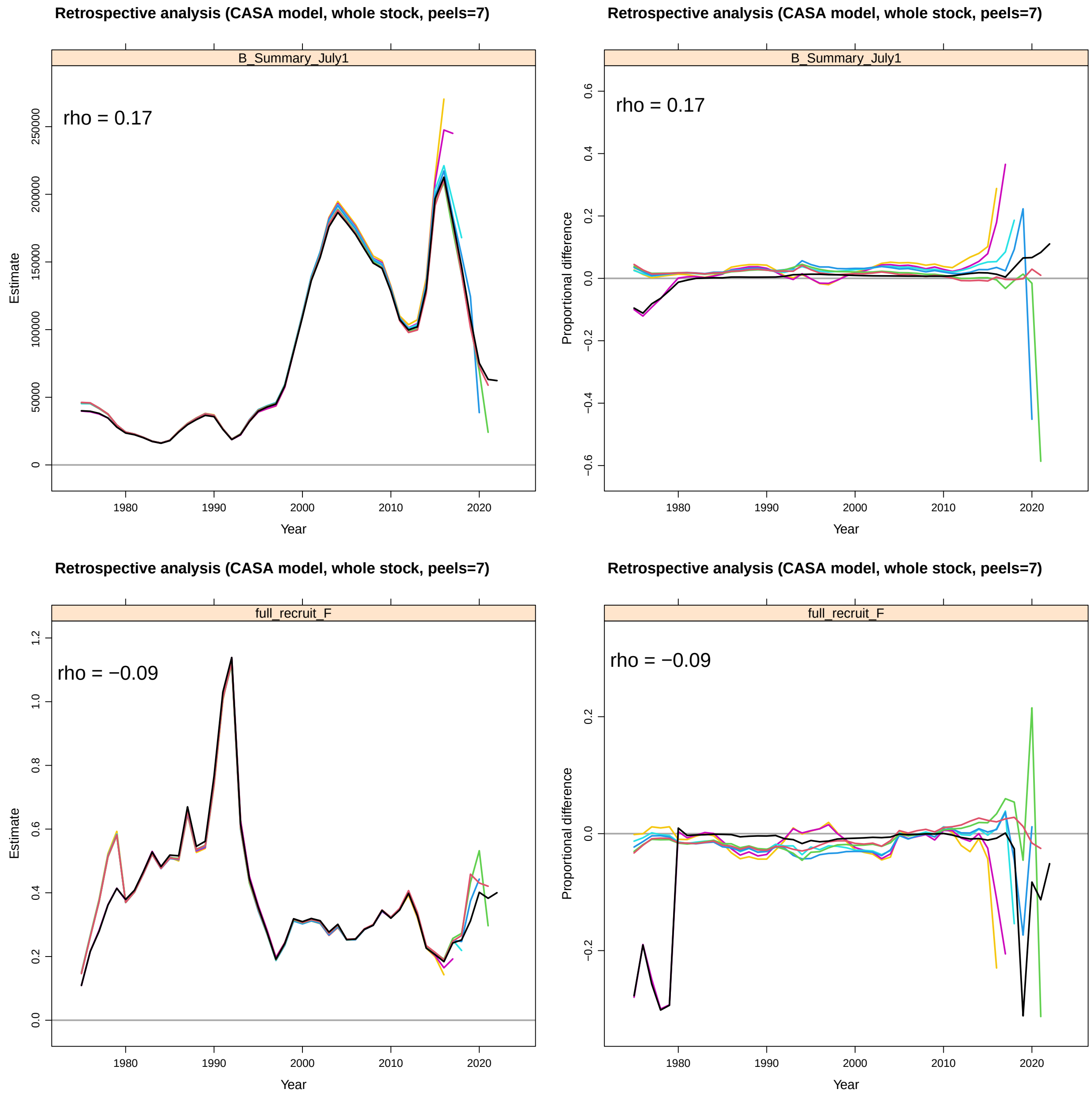


Figure 4.102: Retrospective plots for biomass and fishing mortality for all three stocks combined. Retrospectives are shown on both absolute and relative scales.

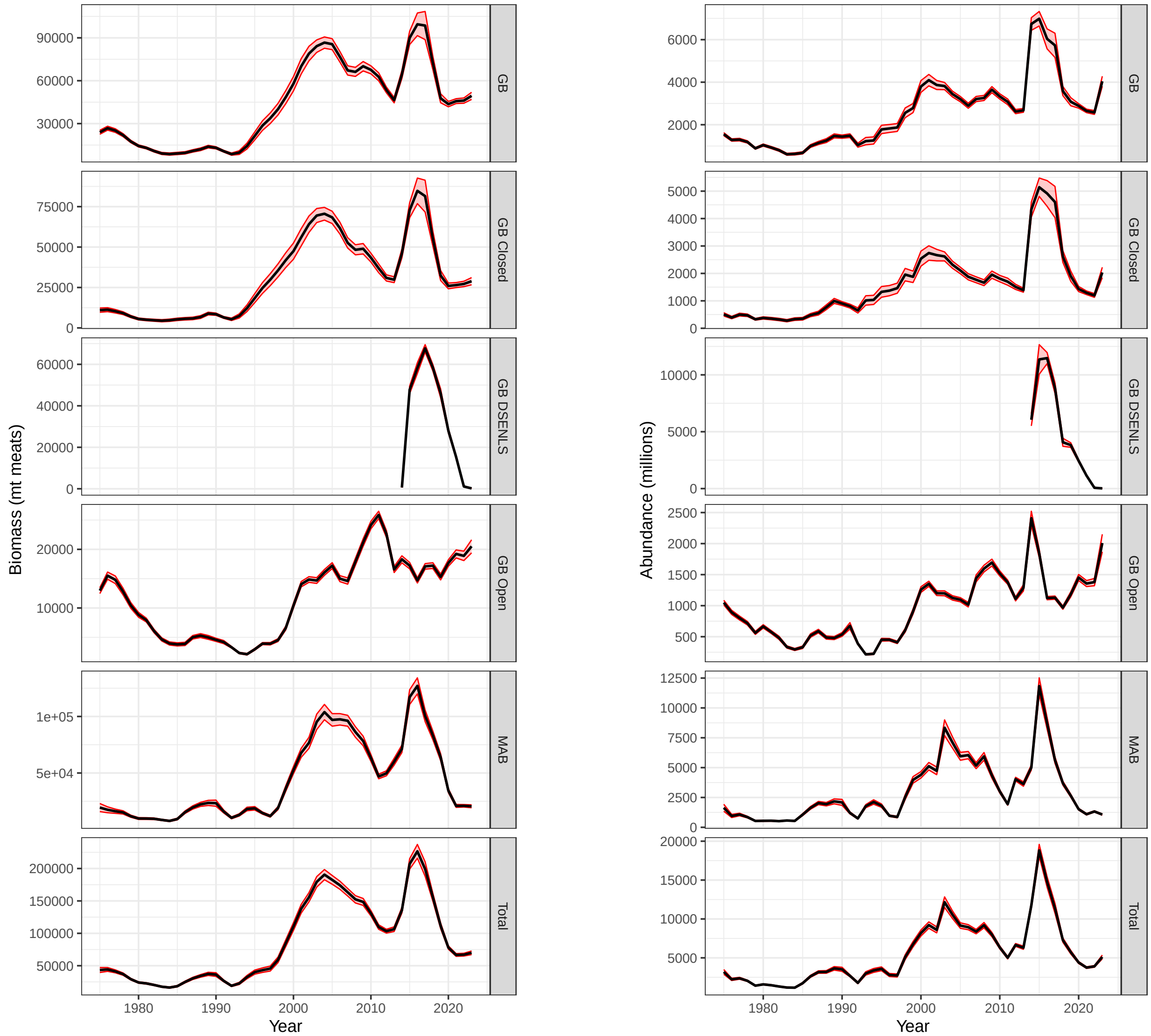


Figure 4.103: CASA estimated biomass and abundance with standard error for Georges Bank closed, Georges Bank open, Mid-Atlantic, and DSENLS stocks and all four stocks combined.

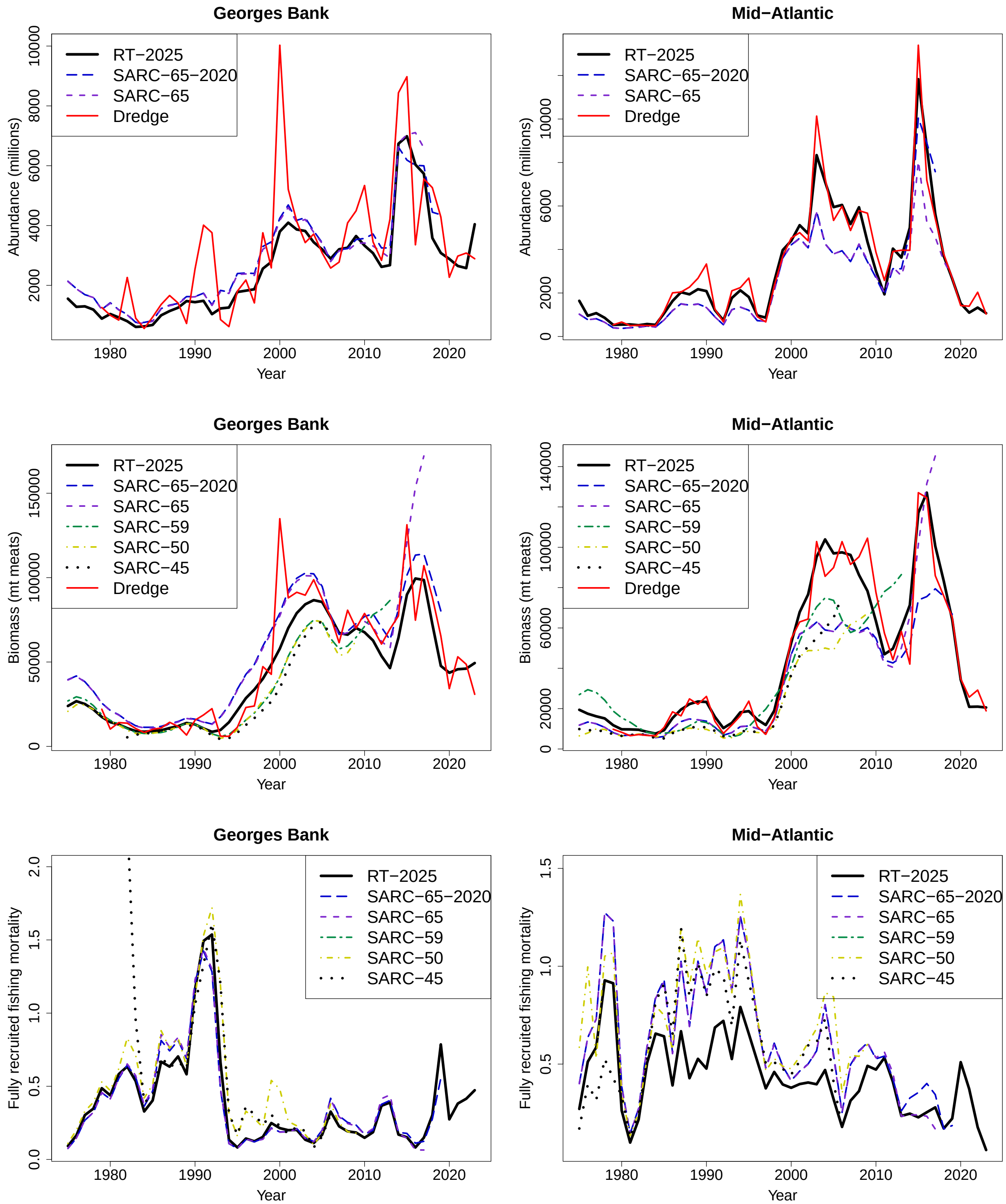


Figure 4.104: Comparison of base case CASA model estimates of abundance (top), biomass (middle), and fishing mortality (bottom) to previous CASA model estimates for Georges Bank and Mid-Atlantic sea scallops.