

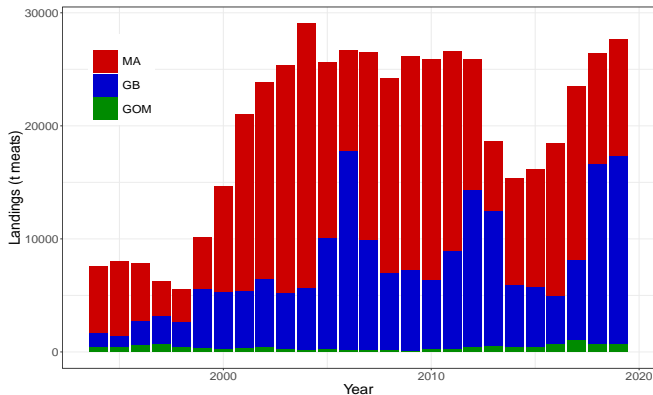
Sea Scallop Assessment Update, 2020

*Dvora Hart and Jui-Han Chang
Northeast Fisheries Science Center
Woods Hole MA 02543*

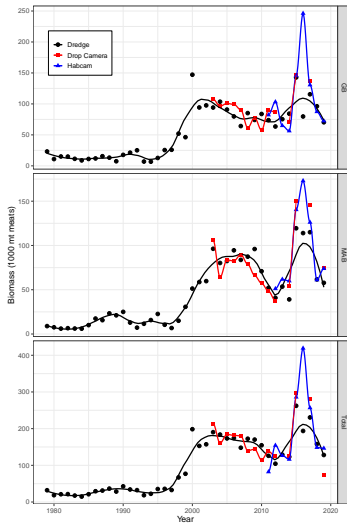
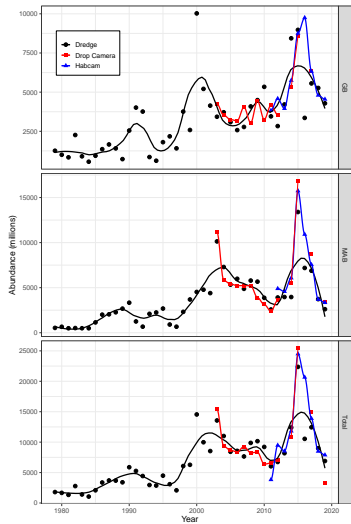
- Last benchmark in 2018 (SARC-65). Not overfished, no overfishing.
- TOR: Update catch and survey data, CASA assessment and SYM reference point models
- No projections (SAMS model) will be presented for this update; these will be done after the 2020 survey data is available
- Level 3 review to consider new variable selectivity SYM reference point model

Landings

Landings increased in 2018-2019, in large part due to harvesting of the 2012 year class in the Nantucket Lightship area and the 2013 year class in the Elephant Trunk and Hudson Canyon South rotational areas. Landings in 2019 were the second highest on record.



Sea Scallop Surveys - Plots



CASA Models

CASA is a size-based forward projecting stock assessment model that has been used to assess sea scallop populations since 2007. It provides historical estimates of abundance, biomass, and fishing mortality based on commercial data (landings and commercial shell heights from observers), surveys and biological information such as growth data.

Due to differences in life history parameters and fishing history, CASA models are developed for three regions, Mid-Atlantic, Georges Bank open and Georges Bank closed, and then combined.

The 2018 benchmark CASA models included for the first time temporal estimation of natural mortality. This was modeled for juveniles only in Mid-Atlantic and Georges Bank open, based on empirical evidence of high juvenile mortality of strong year classes. Natural mortality in the Georges Bank closed areas was modeled for all sizes, based on observations of anomalous declines in certain years.

New Survey Data Used in CASA

- Survey data from the 2018 and 2019 lined dredge, Habcam, and SMAST digital camera data we added to CASA for this assessment.
- 2019 Habcam and SMAST digital camera survey data were combined to obtain a complete survey coverage for the Georges Bank.

Survey	Georges Bank Closed	Georges Bank Open	Mid-Atlantic
Lined dredge	1979-2019	1979-2019	1979-2019
Unlined dredge	1975; 1977	1975; 1977	1975; 1977
SMAST large camera	2003-2012; 2014	2003-2012; 2014	2003-2012; 2014
Habcam	2011-2019	2011-2018	2012-2019
SMAST digital camera	2015; 2017	2015; 2017; 2019	2015; 2017; 2019
NEFSC winter bottom trawl	-	-	1992-2007

New Commercial Data and Selectivities Used in CASA

- Fishery shell height data 1975-1984 were from port samples and 1992-2019 from observers.
- Selectivities changed in 2018 and 2019 for Georges Bank Closed area due to the reopening of the Nantucket Lightship West area, which had mainly intermediate sized scallops.

Fishery Selectivity Period	Georges Bank Closed	Georges Bank Open	Mid-Atlantic
1	1975-1997 (logistic)	1975-1998 (logistic)	1975-1979 (domed)
2	1998-2017 (logistic)	1999-2004 (logistic)	1980-1997 (logistic)
3	2018 (logistic)	2005-2019 (logistic)	1998-2001 (logistic)
4	2019 (domed)	-	2002-2004 (logistic)
5	-	-	2005-2019 (logistic)

Growth modeling

Growth is modeled by growth transition matrices that are estimated using shell growth increment and a mixed-effects model to estimate von Bertalanffy parameters and their variance among individuals (Hart and Chute 2009). Evidence from the 2018 benchmark indicated that there has been substantial temporal changes in growth, with growth rates tending to increase from about 1994 to 2012. This is modeled in CASA by employing different growth transition matrices for different periods of time.

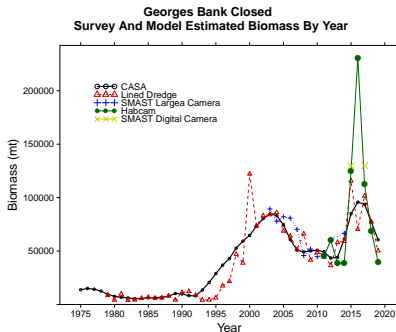
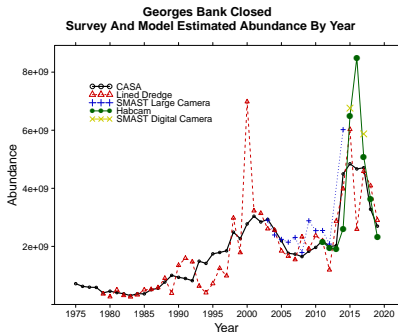
In recent years, growth appears to have slowed, so we modeled growth in the most recent period using the transition matrices for the mid-1990s slow growth era, except in GB Open, where we used new data to estimate a new growth transition matrix. Growth matrices were the same as in the benchmark for all other periods.

New Growth in CASA

Growth Period	Georges Bank Closed	Georges Bank Open	Mid-Atlantic
1	1993-1996 2011-2019	1993-1996	1975-1977; 1987-2003; 2006; 2011-2019
2	2000-2006	2000-2006	1978; 1983-1986; 2004-2005; 2007
3	1975-1992; 1997-1999	1975-1992; 1997-1999	1979-1982; 2008-2010
4	2007-2010	2007-2011	-
5	-	2012-2019	-

Georges Bank Closed Area

Observed and estimated abundance and biomass

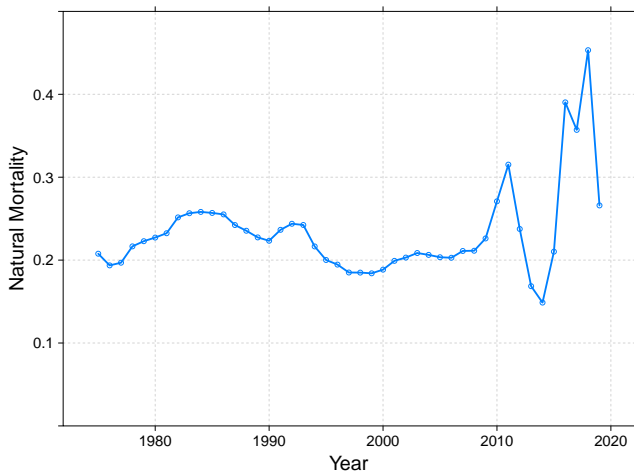


Estimated abundance (left) and biomass (right) with expanded estimates from the lined dredge (red), SMAST large camera (blue), Habcam (green), and SMAST digital camera (light green) surveys.

Georges Bank Closed Area

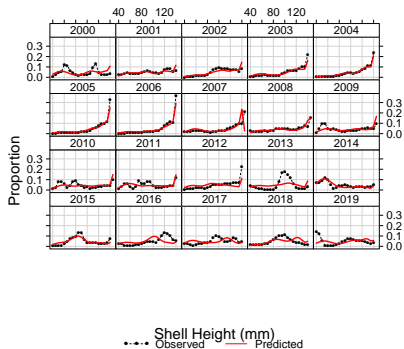
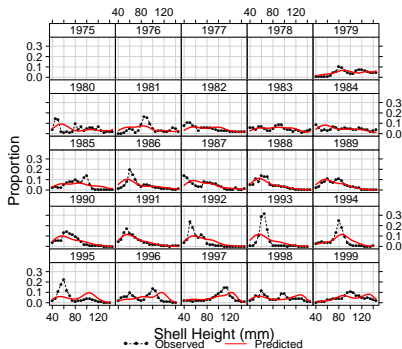
Natural mortality for all sizes by year

Georges Bank Closed



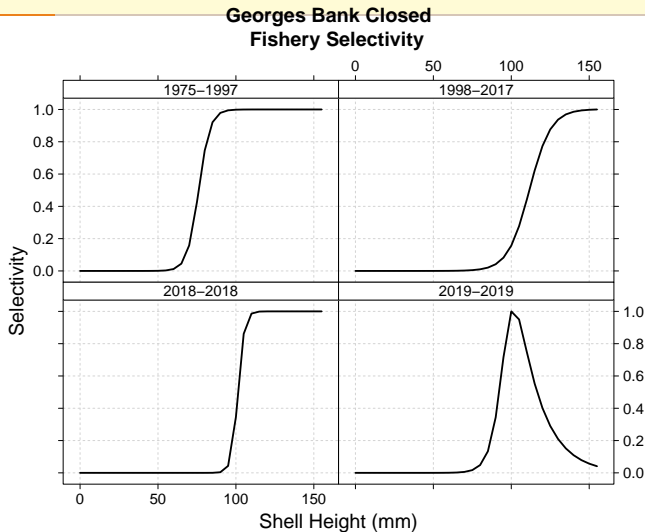
Georges Bank Closed Area

Dredge survey shell height proportions



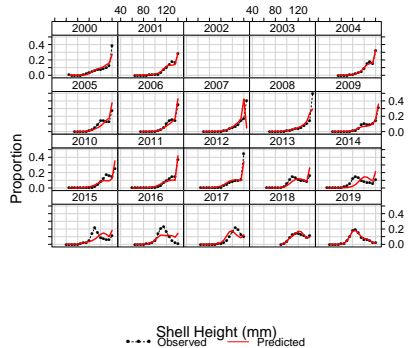
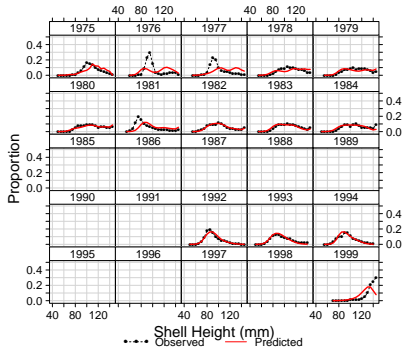
Georges Bank Closed Area

Estimated fishery selectivity curves



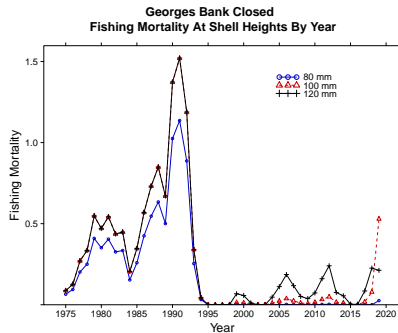
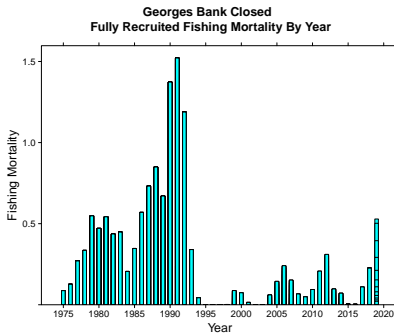
Georges Bank Closed Area

Fishery shell height proportions



Georges Bank Closed Area

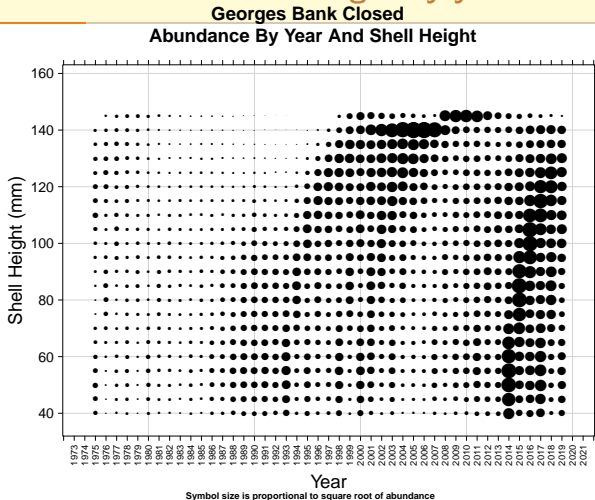
Fully recruited fishing mortality



All sizes (left) and at 80, 100, and 120 mm shell height (right).

Georges Bank Closed Area

Estimated abundances at shell height by year

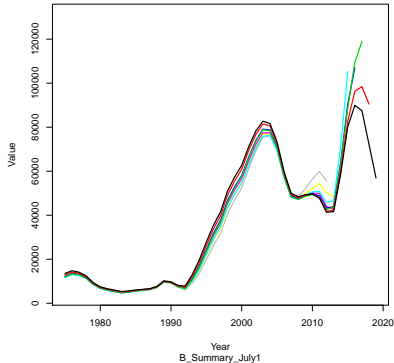


Symbol are proportional to abundance

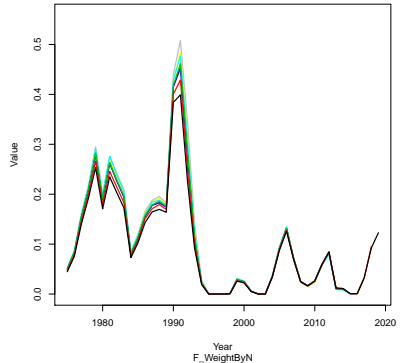
Georges Bank Closed Area

Seven peels retrospective analysis for biomass and fishing mortality

Retrospective Analysis Scallop CASA Model (peels=7, $\rho = 0.23$)

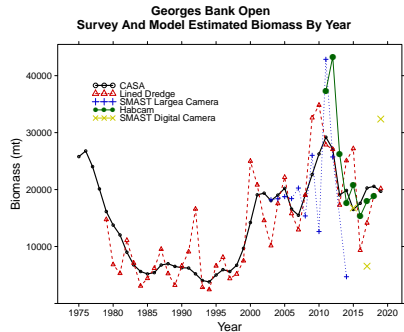
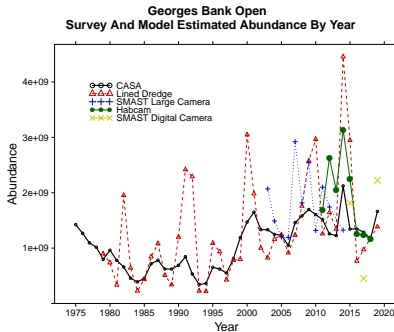


Retrospective Analysis Scallop CASA Model (peels=7, $\rho = 0.077$)



Georges Bank Open Area

Observed and estimated abundance and biomass

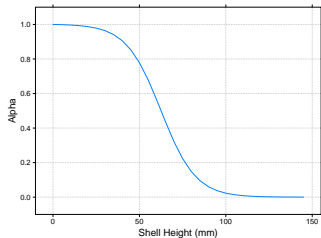


Estimated abundance (left) and biomass (right) with expanded estimates from the lined dredge (red), SMAST large camera (blue), Habcam (green), and SMAST digital camera (light green) surveys.

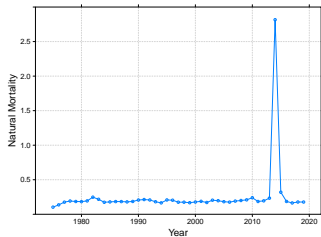
Georges Bank Open Area

Logistic curve and natural mortality by size and year

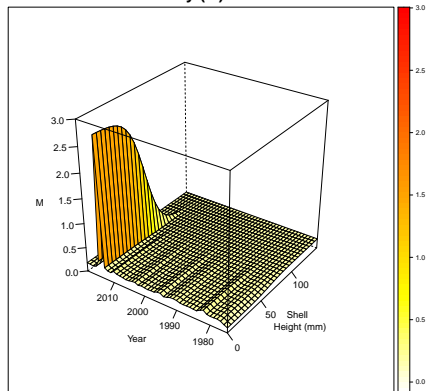
Georges Bank Open
Shape To Determine Natural Mortality By Size



Georges Bank Open
Natural Mortality At Smallest Size

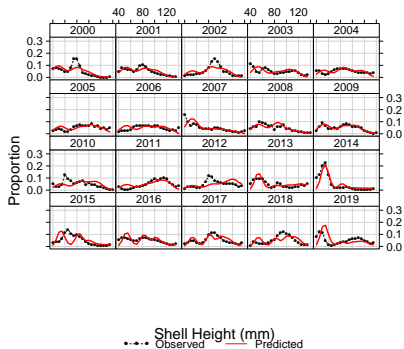
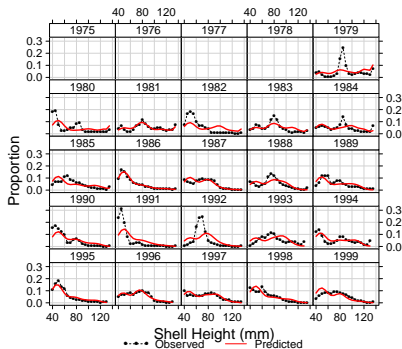


Georges Bank Open
Natural Mortality (M) From All Sources



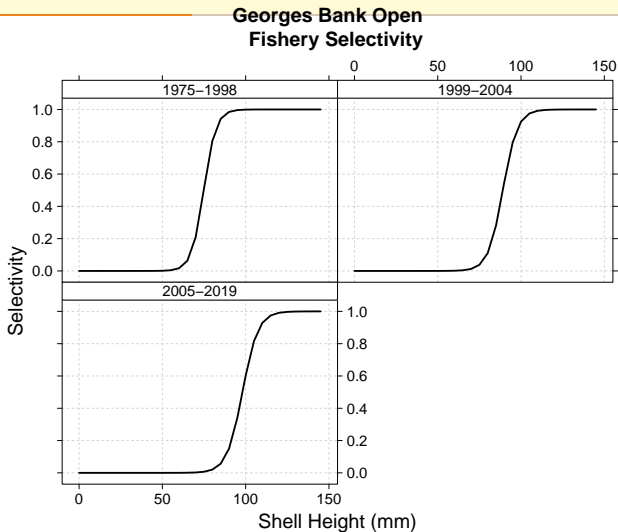
Georges Bank Open Area

Dredge survey shell height proportions



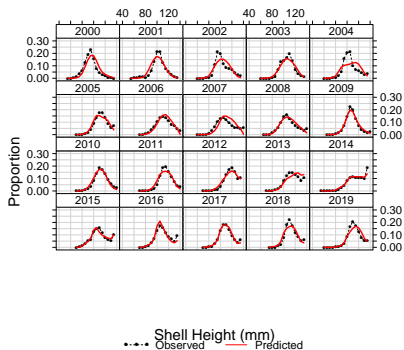
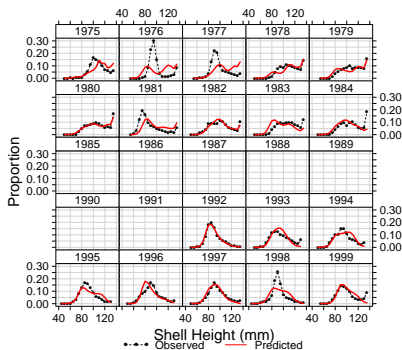
Georges Bank Open Area

Estimated fishery selectivity curves



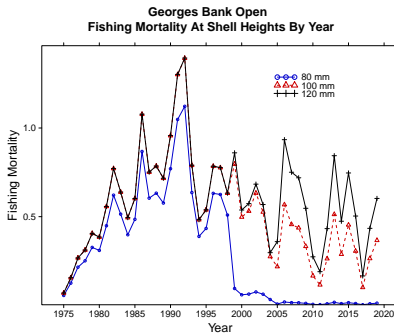
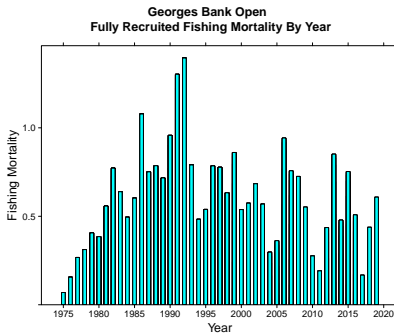
Georges Bank Open Area

Fishery shell height proportions



Georges Bank Open Area

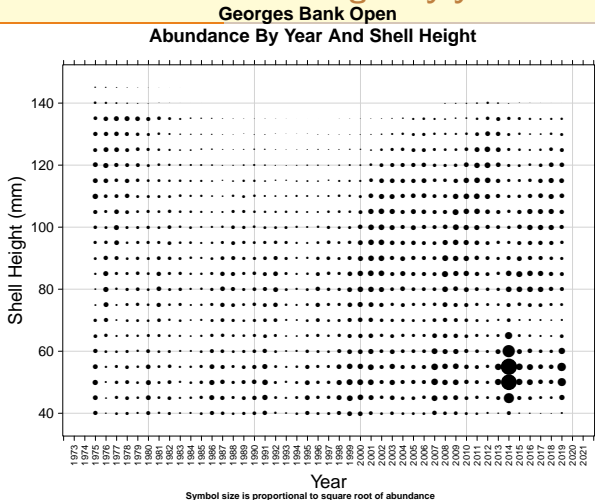
Fully recruited fishing mortality



All sizes (left) and at 80, 100, and 120 mm shell height (right).

Georges Bank Open Area

Estimated abundances at shell height by year

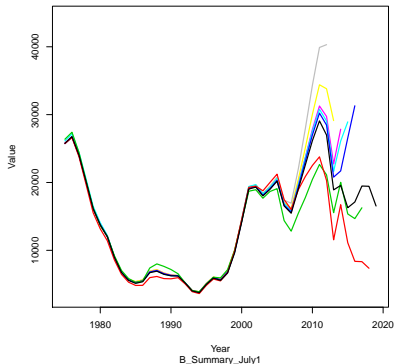


Symbol are proportional to abundance

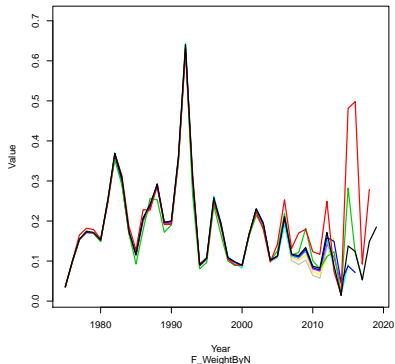
Georges Bank Open Area

Seven peels retrospective analysis for biomass and fishing mortality

Retrospective Analysis Scallop CASA Model (peels=7, $\rho = 0.33$)

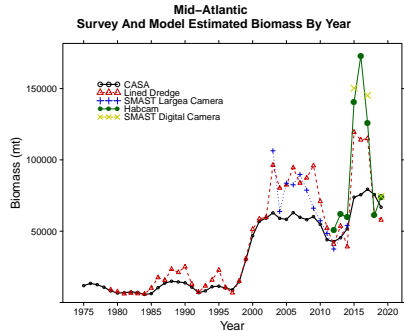
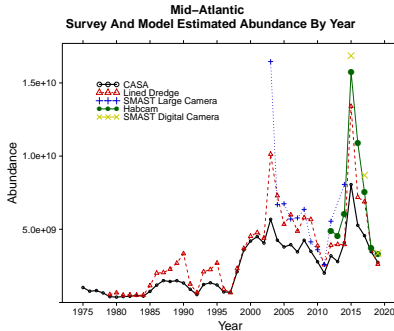


Retrospective Analysis Scallop CASA Model (peels=7, $\rho = 0.41$)



Mid-Atlantic Area

Observed and estimated abundance and biomass

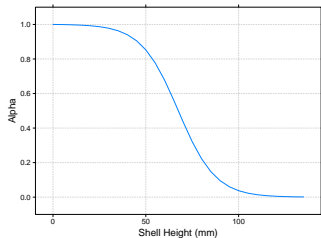


Estimated abundance (left) and biomass (right) with expanded estimates from the lined dredge (red), SMAST large camera (blue), Habcam (green), and SMAST digital camera (light green) surveys.

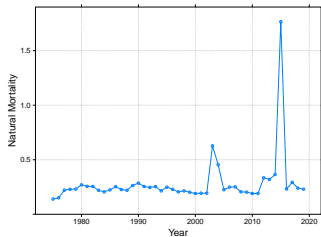
Mid-Atlantic Area

Logistic curve and natural mortality by size and year

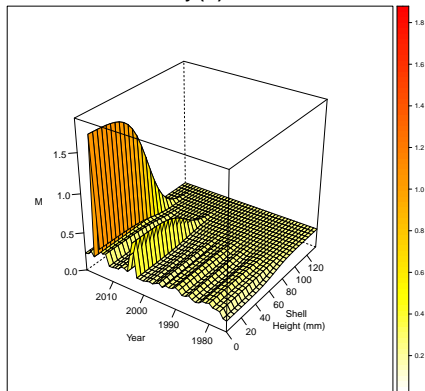
Mid-Atlantic
Shape To Determine Natural Mortality By Size



Mid-Atlantic
Natural Mortality At Smallest Size

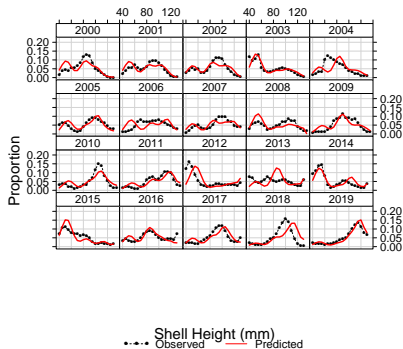
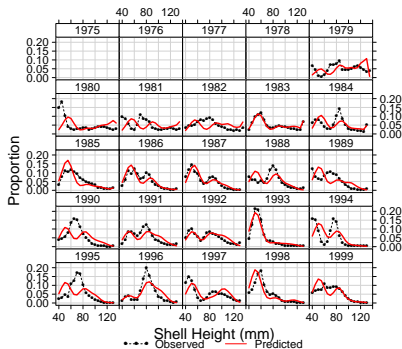


Mid-Atlantic
Natural Mortality (M) From All Sources



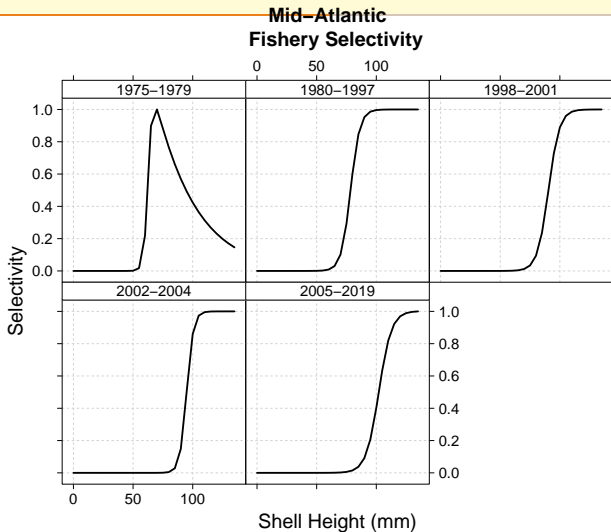
Mid-Atlantic Area

Dredge survey shell height proportions



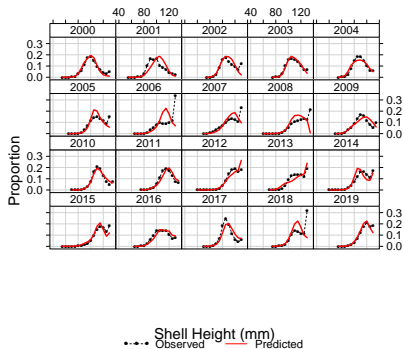
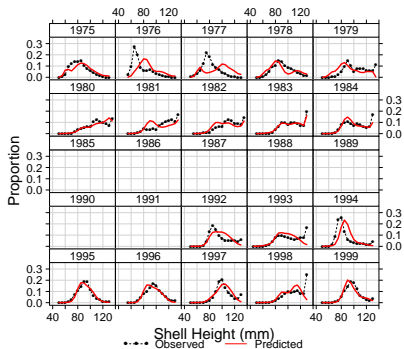
Mid-Atlantic Area

Estimated fishery selectivity curves



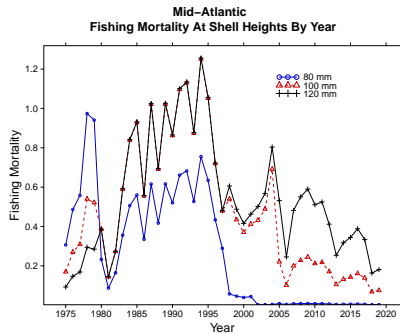
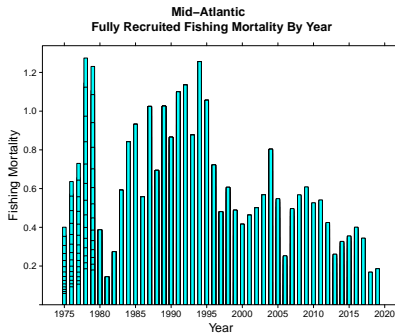
Mid-Atlantic Area

Fishery shell height proportions



Mid-Atlantic Area

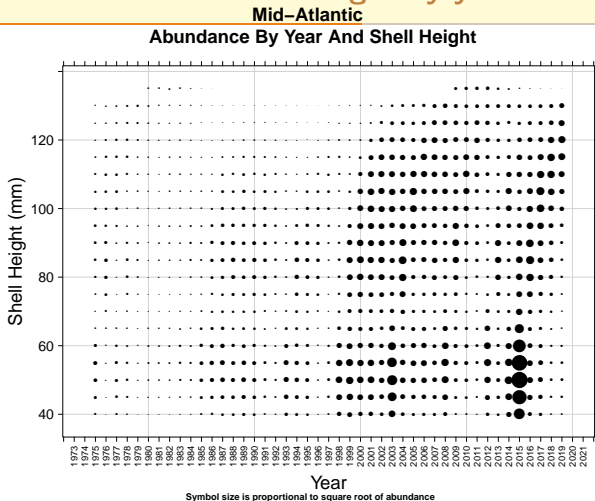
Fully recruited fishing mortality



All sizes (left) and at 80, 100, and 120 mm shell height (right).

Mid-Atlantic Area

Estimated abundances at shell height by year

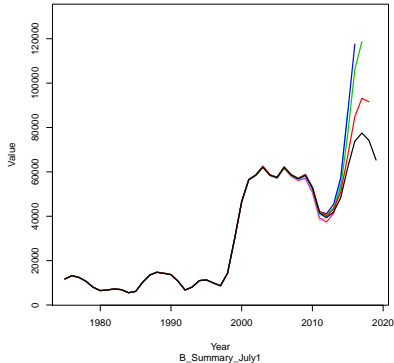


Symbol are proportional to abundance

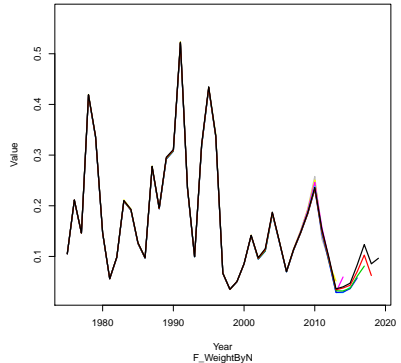
Mid-Atlantic Area

Seven peels retrospective analysis for biomass and fishing mortality

Retrospective Analysis Scallop CASA Model (peels=7, $\rho=0.28$)

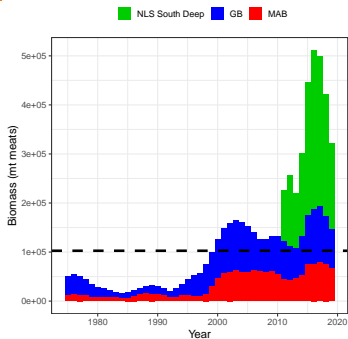
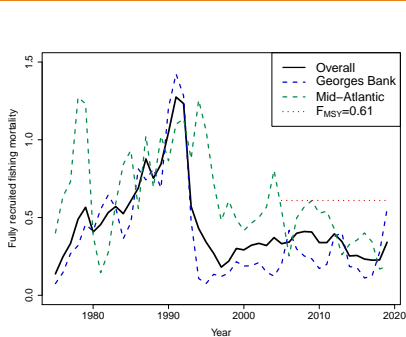


Retrospective Analysis Scallop CASA Model (peels=7, $\rho=-0.028$)



All Three Regions Combined

Fully recruited fishing mortality and biomass



Estimated fully recruited fishing mortality (left) and biomass (right) for Georges Bank (open and closed combined) and Mid-Atlantic sea scallops, including Habcam biomass estimates of scallops located in the deep water southeast portion of Nantucket Lightship Area.

All Three Regions Combined

2019 biomass and fishing mortality estimates

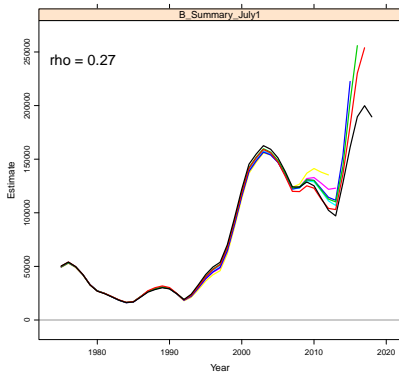
Stock	Biomass (mt meats)	CV	F	CV
Georges Bank Closed	60,587	0.09	0.53	0.35
Georges Bank Open	19,692	0.06	0.61	0.14
Mid-Atlantic	66,795	0.04	0.19	0.34
Total	147,073	0.04	0.34	0.06

Scallops located in the deep water southeast portion of Nantucket Lightship Area are excluded.

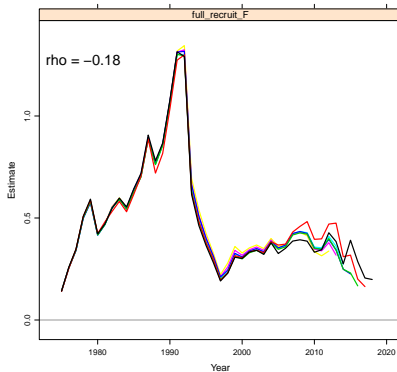
All Three Regions Combined

Seven peels retrospective analysis for biomass and fishing mortality

Retrospective analysis (CASA model, whole stock, peels=7)



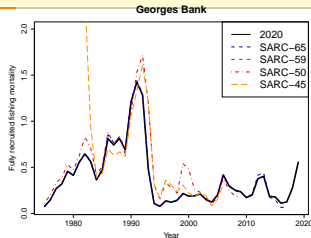
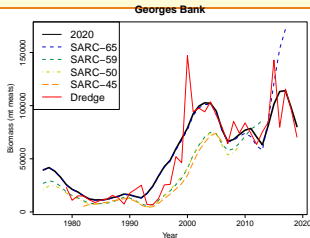
Retrospective analysis (CASA model, whole stock, peels=7)



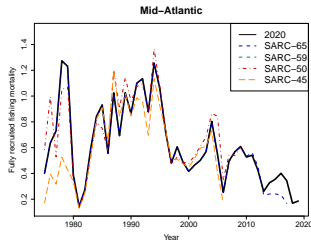
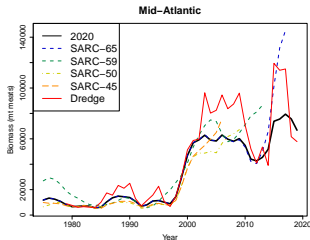
Historical Retrospective Analysis

SARC-45, 50, 59, 65, 65-2020 CASA estimates of biomass, lined dredge biomass, and fishing mortality

Georges Bank
(open and closed
combined)



Mid-Atlantic



SYM Reference Point Model

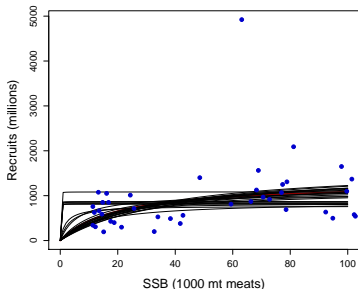
SYM combines per-recruit calculations with a stock-recruit relationship to obtain MSY-based reference point estimates (Hart 2013). It treats per-recruit and stock-recruit parameters as uncertain, and propagates this uncertainty to give probabilistic reference point estimates. Although this model is separate from CASA, it models population dynamics in a similar way, with growth transition matrices based on growth in the latest period from the CASA model, and parameter means are the same as the CASA point estimates for these parameters (e.g., natural mortality and shell height/meat weight relationships).

There are two SYM models, one for Georges Bank and the other for the Mid-Atlantic.

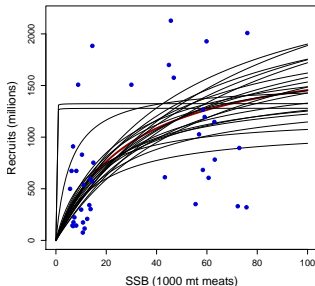
Stock-Recruit Relationships

We used three year old “recruits” in order to avoid high density-dependent natural mortality in some years. Beverton-Holt functions fairly well estimated with lowest recruitment during the lower biomass period and highest recruitment when biomass was higher. The Georges Bank relationship is fairly certain to be near saturation greater than 50000 t, but the saturation point is less clear for the Mid-Atlantic.

Georges Bank



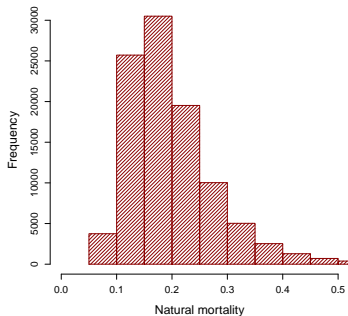
Mid-Atlantic



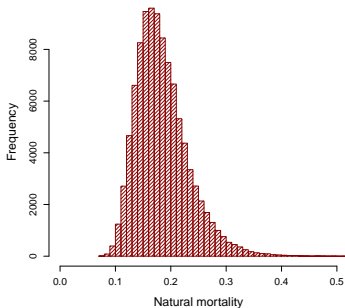
Natural Mortality

Simulated as $1/\gamma$ distribution with $\mu = 0.2$ (GB), $\mu = 0.25$ (MA), standard deviation reduced by 33% from SARC-65.

$\sigma = 0.082$ (GB, SARC-65)



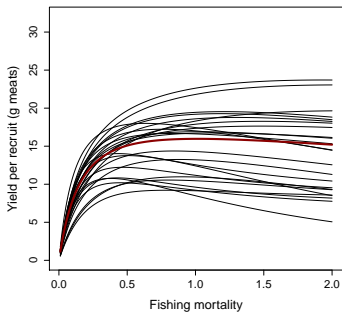
$\sigma = 0.055$ (GB, this assessment)



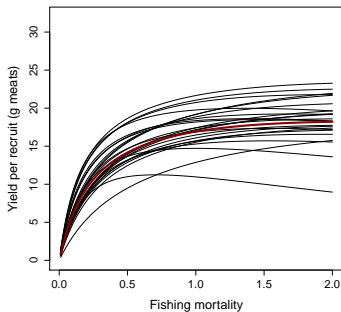
Example Yield Per Recruit Curves

Substantial variation, mainly from propagation of the uncertainty in natural mortality. The mean YPR curve is almost flat.

Georges Bank

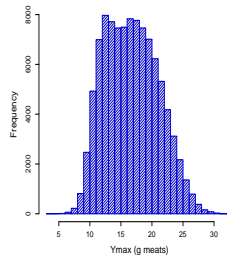
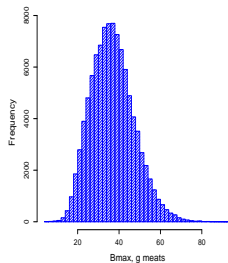
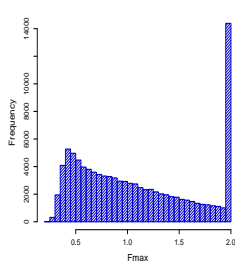


Mid-Atlantic



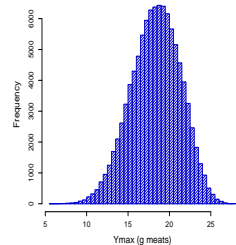
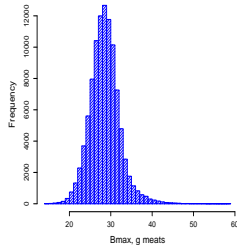
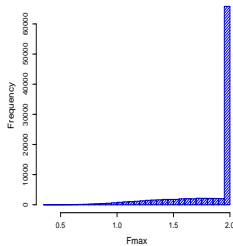
Georges Bank Per Recruit Reference Points

Yield per recruit reference point F_{MAX} not well defined, although B_{MAX} and Y_{MAX} are somewhat more certain.



Mid-Atlantic Per Recruit Reference Points

Yield per recruit reference point F_{MAX} hits the $F = 2$ bound in a majority of cases.

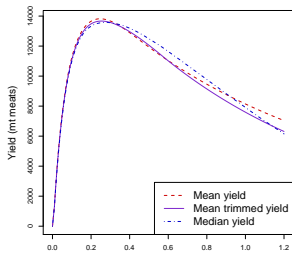


Yield Curves

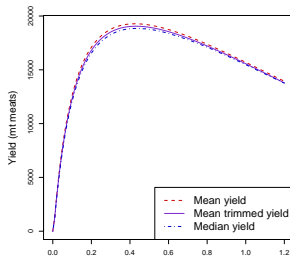
The 100,000 yield curves were aggregated pointwise using three measures of central tendency: mean, trimmed mean (mean after the highest and lowest 10% was removed), and median.

The mean yield curve is typically higher than the trimmed mean and median yield curves, due to the influence of a small percentage of the runs that give extreme yields. As in SARC-65, the median curve was used.

Georges Bank



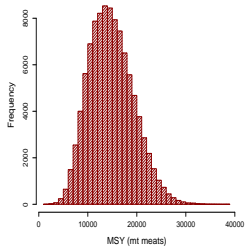
Mid-Atlantic



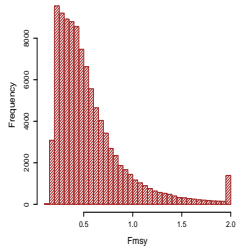
Georges Bank MSY, F_{MSY} and B_{MSY}

Uncertainty in MSY, F_{MSY} , and B_{MSY} on Georges Bank

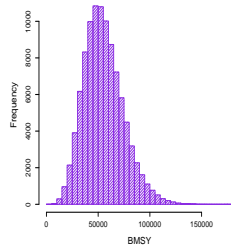
MSY



F_{MSY}



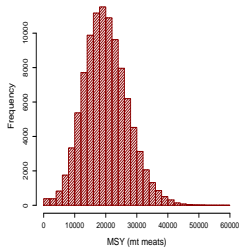
B_{MSY}



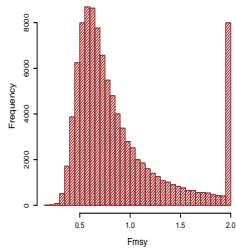
MSY, F_{MSY} and B_{MSY} - Mid-Atlantic

Uncertainty in MSY, F_{MSY} , and B_{MSY} in Mid-Atlantic

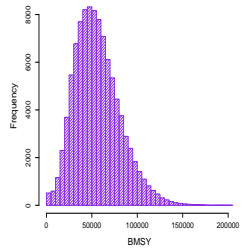
MSY



F_{MSY}



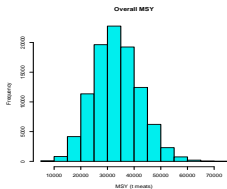
B_{MSY}



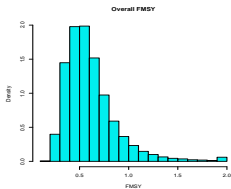
MSY, F_{MSY} and B_{MSY} - Combined

Uncertainty in MSY, F_{MSY} , and B_{MSY} for Georges Bank and Mid-Atlantic combined

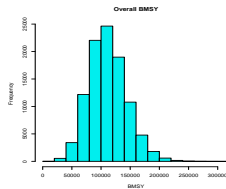
MSY



F_{MSY}



B_{MSY}



Combined Yield and Biomass Curves

2020

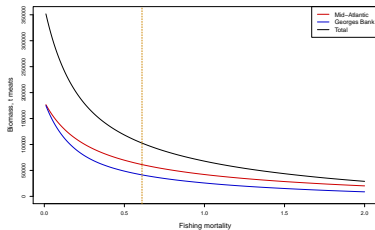
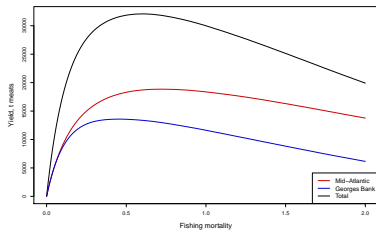
$$F_{\text{MSY}} = 0.61$$

2018

$$F_{\text{MSY}} = 0.64$$

$$B_{\text{MSY}} = 102,657 \text{ t}$$

$$B_{\text{MSY}} = 116,766 \text{ t}$$



Variable selectivity SYM model

Reference point models are typically based on an assumption that fishing mortality and fishery selectivity are separable, that is, selectivity does not change with fully recruited fishing mortality. As will be shown, this assumption is not always correct.

In the scallop fishery, there is an incentive to target larger scallops both because of their price premium and because they can be processed (shucked) faster per unit weight. Thus, larger scallops are typically targeted provided they occur at sufficiently high densities. Thus, at low fishing mortality rates, large scallops are targeted, but as fishing mortality increases, and the number of large scallops declines, smaller scallops may be targeted because they are the only sizes available in commercially viable quantities.

Recent Auction Prices

Market categories are expressed by the number of meats per pound, together with location. Larger scallops command higher prices.

Market Category	Quantity (lbs)	Low price (\$)	High price (\$)
30-40 NLCA-S Scallops	17874	7.65	8.10
U-10 NLCA-N	5848	12.70	12.95
10-20 NLCA-N	3045	10.60	11.50
U-12 Channel Scallops	5609	12.25	12.30
10-20 Channel Scallops	14292	9.50	12.95
U-10 Mid-Atlantic Scallops	3248	12.10	12.65
10-20 Mid-Atlantic Scallops	48258	9.70	10.05
10-20 MAAA Scallops	10483	9.75	9.90

Estimation of selectivity by fishing mortality

Logistic fishery selectivity S as a function of shell height h was modeled as:

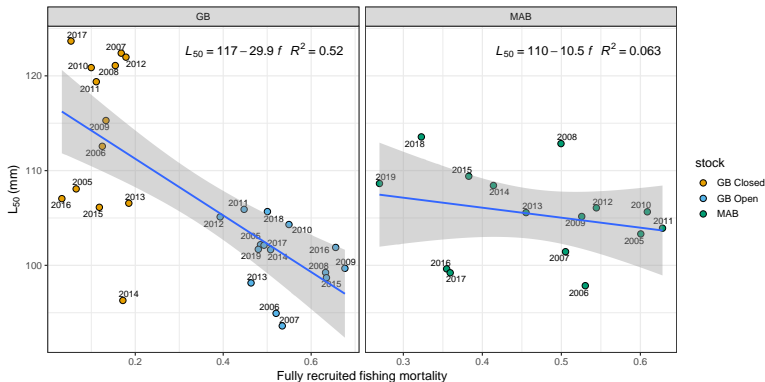
$$S(h) = \frac{1}{1 + \exp(\alpha - \beta h)}$$

For the period since implementation of the 4" ring regulation (2004 or 2005), the slope parameter β was fixed at its estimated value in the base CASA models. Then α was estimated for each year (excluding 2015-2016 and 2018-2019 in the closed areas) by the CASA model. It is more intuitive to express α in terms of L_{50} , the shell height where selectivity is 0.5. A simple calculation shows that $L_{50} = \alpha/\beta$, so that for fixed β , L_{50} is directly proportional to α .

Relationship between L_{50} and fishing mortality

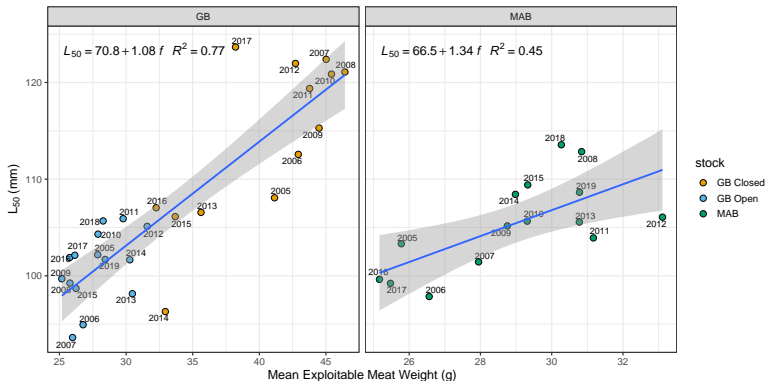
L_{50} was regressed against four year lagged (current and previous three years) moving average fishing mortality, from the CASA model.

Relationship is strong for GB but weak in MA.



Relationship between L_{50} and mean exploitable meat weight

Stronger relationships were found between L_{50} and mean exploitable meat weight (“exploitable” scallops are determined by gear selectivity). Scallopers are responding directly to meat sizes, but only indirectly to fishing mortalities. Therefore, we used the mean exploitable meat weight regressions in the SYM model.



Estimating mean exploitable meat weight in the SYM model

In the per-recruit calculations, the selectivity curve is required to calculate mean exploitable weight at a given F , but the mean exploitable weight is required to use the regression to estimate L_{50} and therefore selectivity.

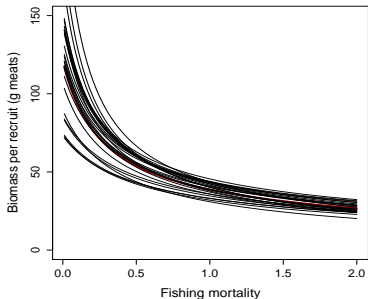
To get around this problem, for the purposes of estimating L_{50} only, the mean exploitable weight at F , $W(F)$ is estimated based on $W(F - 0.01)$ and $W(F - 0.02)$:

$$\begin{aligned} W(F) &\simeq W(F - 0.01) + [W(F - 0.01) - W(F - 0.02)] \\ &= 2W(F - 0.01) - W(F - 0.02) \end{aligned}$$

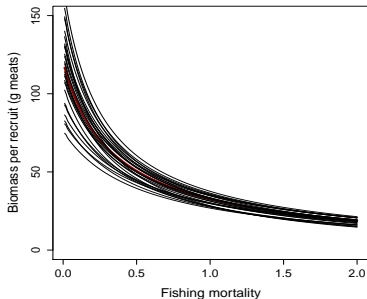
Comparison of biomass per recruit curves

BPR declines faster with the variable selectivity approach, and is about 50% lower at $F = 2$ than with fixed selectivity. This causes recruitment, and therefore yield, to be lower under the variable selectivity assumption at high fishing mortality rates.

Standard SYM model



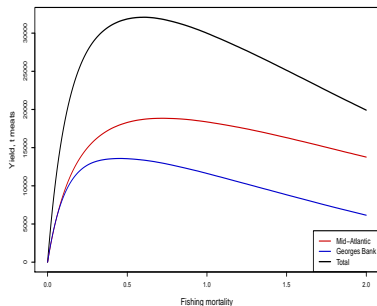
Variable Selectivity SYM Model



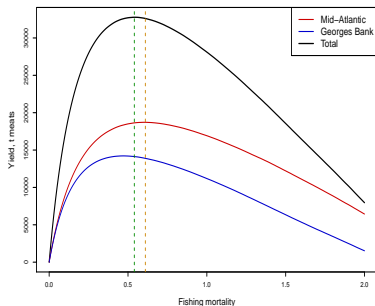
Comparison of yield curves

The variable selectivity yield curve is much steeper than that of the standard model.

Standard SYM model



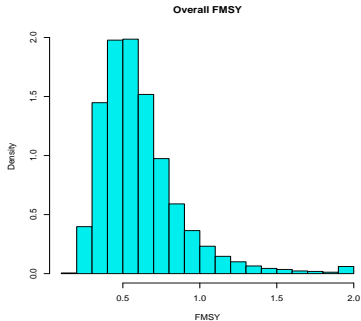
Variable Selectivity SYM Model



Comparison of F_{MSY} distributions

Estimates of F_{MSY} are more certain using the variable selectivity approach

Standard SYM model



Variable Selectivity SYM Model

