Appendix A2
Sea Scallop Shell Height/Meat Weight Relationships

Deborah R. Hart
Northeast Fisheries Science Center
166 Water St., Woods Hole MA 02543

Meat weight data is obtained from two sources: surveys and observers. The survey data will be analyzed first.

Shell height to meat weight relationships from survey data

Since 2001, a sample of scallops from the catch (typically 3-10 scallops on about half the stations) on the NEFSC and VIMS dredge surveys are dissected, and their shell height, whole weight, gonad weight and meat weights are measured (see Hennen and Hart 2012). Meat weight is estimated from a generalized linear mixed-effects model, with a random effect for station, a log link, and a gamma distribution:

$$W = \exp(a + b\ln(H)) \qquad \text{(App A2-1)}$$

where W is meat weight and H is shell height. Hennen and Hart (2012) and previous assessments used the lme4 package in R for this analysis, but for the analysis in this assessment, models using this package were often unstable and/or did not converge. Thus, the r2glmm package was used instead which proved much more stable. In cases where using both models converged, they gave similar answers.

Meat weights vary seasonally, and the survey timing has varied. Prior to 2009, the Mid-Atlantic survey was conducted in late June and/or July, but since then, the survey has been conducted in May and/or early June (Figure App A2-1). The Georges Bank component was conducted in July to early August, but now is conducted in June. Examination of the effects of this timing difference showed no significant effect on Georges Bank, but substantial effects in the Mid-Atlantic. Sea scallops typically lose up to 20% of their meat weight around the time that they spawn, and Mid-Atlantic scallops often have a strong spring spawn in April to early May. Thus, these scallops are recovering from their spawn during the time of the survey, and it is to be expected that meat weights at size will be less in May than June or July. To model this, the covariate "mday", the number of days after April 30, was included in the Mid-Atlantic model, together with a non-linear mday^2 term and an interaction of mday with shell height:

$$W = \exp(a_0 + a_1\text{mday} + a_2\text{mday}^2 + (b_0 + b_1\text{mday})\ln(H)). \qquad \text{(App A2-2)}$$

As expected, meat weights at size in the Mid-Atlantic are increasing with mday at least through mid-June (Figure App A2-2). The stock assessment models employ a single (regional) shell height to meat weight relationship, although, as discussed below, it is modified by annual anomalies. For the purposes of this assessment, the Working Group chose to use the Mid-Atlantic relationship with mday= 21, i.e., the predicted sh/mw relatioship on May 21. As discussed above, there was no significant seasonality for Georges Bank during the surveyed time of June-August, so the basic relationship was simply estimated using Equation (App A2-1); see Table App A2-1 and Figure App A2-3. Estimates based on limited samples of Peter Pan scallops are also presented.

Covariates such as depth, latitude, and whether a sample is in a open or closed area ("clop") can substantially affect predicted meat weights at shell height (Hennen and Hart 2012). This information is used to estimate biomass from a survey. Additionally, it is used to compute shell height to meat weight anomalies discussed in the next section.

Commercial shell height/meat weight data

Shell height to meat weight relationships on commercial vessels can vary from the survey relationship for two primary reasons. First, as discussed above, meat weights vary seasonally, and the fishery is conducted year-round, not just when the survey occurs. Secondly, scientist on the survey carefully shuck the scallops, taking all the meat. Scallopers shuck for speed, often leaving a small portion of the meat in the shell.

For these reasons, commercial meat weights are monitored by fishery observers. Once a watch, the observers take about 100 scallops retained for landing, and measure their shell heights. The scallops are then given to a fisherman to shuck, and the scallop meats are put into a graduated cylinder to get a volumetric measure. The volume is converted to a weight using a specific weight of 1.05 (Caddy and Radley-Walters 1972, Smolowitz et al. 1989). Only samples with between 50 and 200 meats were used. Additionally, a few outliers, where the meat weight anomalies (see below) were less than -0.67 or greater than 0.67 were removed. All together, about 3% of the data were removed for one of these reasons; the analysis below is based on the cleaned data set, which comprises about 97% of the original data.

The shell height measurements are used to compute the predicted meat weight, using the estimates from survey data with covariates (Table App A2-2). The data are then aggregated by month and region and "clop" (Georges Bank and Mid-Atlantic, open or rotational access area), to compute an empirical monthly meat weight anomaly A_m (Hennen and Hart 2012):

$$A = \frac{\text{predicted} - \text{observed}}{\text{predicted}}. \qquad \text{(App A2-3)}$$

Computed empirical meat weight anomalies show both a strong seasonal cycle and a long-term trend towards larger meat weights at size since 1994, when this sampling began (Figure App A2-4). These trends is similar to the trends found in growth (see Appendix

A1), and likely have been caused by similar factors. Besides potential environmental signals (such as warming temperatures, Cooley et al. 2015), fishing effects have likely contributed to these trends. Scallopers tend to target scallops with larger meats at size, which correlates to faster growth as well, leaving a disproportionately high percentage of scallops with smaller meats at size in the population. Such effects would be expected to increase at higher fishing mortality rates, which at least in part, explains the increasing trends, as fishing effort and mortality has generally declined since early 1990s.

To further explore the cycles and trends in these data, a generalized additive model (GAM) was developed for predicting the meat weight anomaly:

$$\text{MWanomaly} \sim s(\text{Year,Month}) + \text{nscallops} + \text{Clop}, \qquad \text{(App A2-4)}$$

where s is a two dimensional smoother on Year and Month, nscallops in the number of meats in the observer's sample, and Clop is 1 if the sample was taken in a rotational access area, and 0 if it was taken in an open area. The term "nscallops" was used since there is a slight tendency for the anomalies to decline with the number of scallops in the sample. This might occur if the probability that some of the measured scallops didn't get into the graduated cylinder increases with number of scallops measured. For the purposes of the predictions given below, I used nscallops = 100, which is both what is specified in the protocol, and also the most common number measured. Using the two dimensional smoother rather than separate smoothers on Year and Month substantially improved the fit and reduced AIC. This indicates that there was a significant Year/Month interaction, i.e., the annual meat weight cycle significantly varied by year (Figure App A2-5).

The predicted GAM anomalies (Figure App A2-6) also show strong seasonality and trends towards larger meats with time. Weighted (by landings) averages over each year from these anomalies were calculated and then used to adjust the CASA survey shell height to meat weight relationships by year. Yearly meat weight anomalies prior to 1994 were calculated as the weighted (by landings) average monthly anomaly from 1994-98.

Mean monthly anomalies from the GAM show the strong seasonal cycle, with meats varying by 20% or more in both regions (Figure App A2-7) over an average year. Year effects show strong trends, as discussed previously (Figure App A2-8).

Table App A2-1: Basic shell height to meat weight estimates.

Region	Estimate	Std. Error
Georges Bank All*		
a (intercept)	-9.67	0.09
b (Slope)	2.732	0.019
Georges Bank Open		
a (intercept)	-10.39	0.13
b (Slope)	2.87	0.03
Georges Bank Closed*		
a (intercept)	-10.3	0.13
b (Slope)	2.86	0.05
Peter Pans only		
a (intercept)	-11.84	0.69
b (Slope)	3.167	0.15
Mid-Atlantic		
a (intercept)	-8.396	0.13
b (Slope)	2.435	0.022
mday	-0.0235	0.0027
$mday^2$	-9.20e-05	7.2e-06
Slope:mday	0.0068	0.0006

*Without Peter Pan scallops

Table App A2-2: Shell height to meat weight relationships with covariates. "Clop" is 1 if a sample is in a closed or rotational area, and 0 otherwise. Only covariates that reduced AIC are included.

Georges Bank

Variable	Estimate	Std. Error
Intercept	-6.69	0.38
ln sh	2.878	0.027
Depth	-0.0073	0.0003
Lat	-0.073	0.009
Clop	1.28	0.17
ln sh:Clop	-0.25	0.04

Mid-Atlantic

Variable	Estimate	Std. Error
Intercept	-9.48	0.24
ln sh	2.51	0.026
mday	-0.0083	0.0086
$mday^2$	-0.000134	0.000005
Depth	-0.0033	0.00045
Lat	0.021	0.005
Clop	-0.031	0.008
ln sh:mday	0.00525	0.0005
mday:Depth	-6.5e-5	9.6e-6

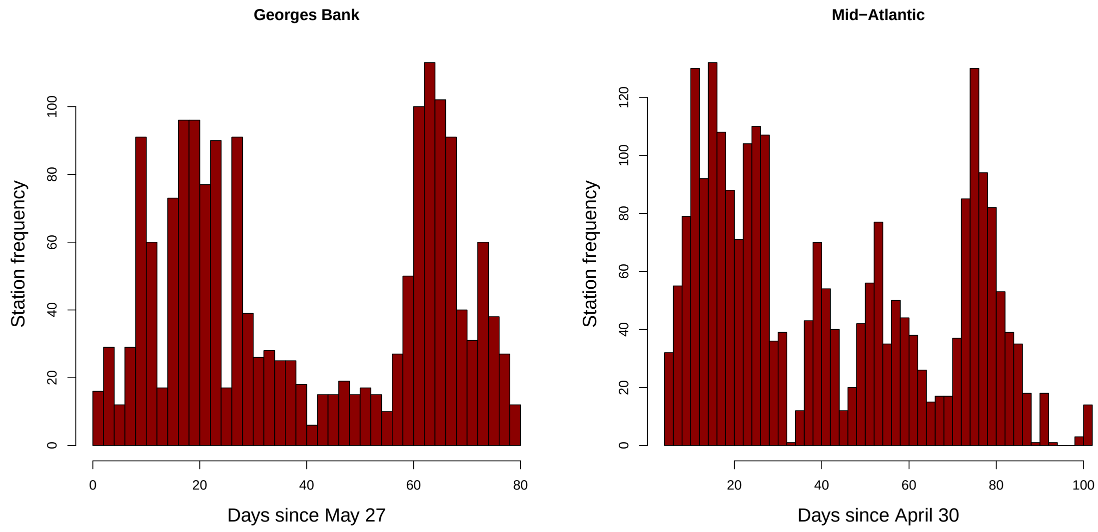


Figure App A2-1: Histograms of the timing of meat weight samples in Georges Bank (left) and the Mid-Atlantic (right).

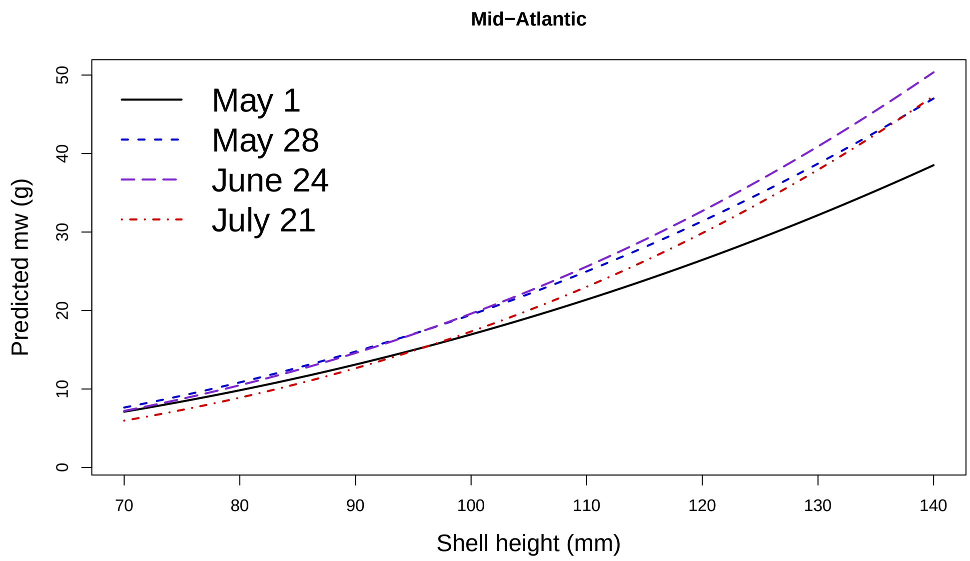
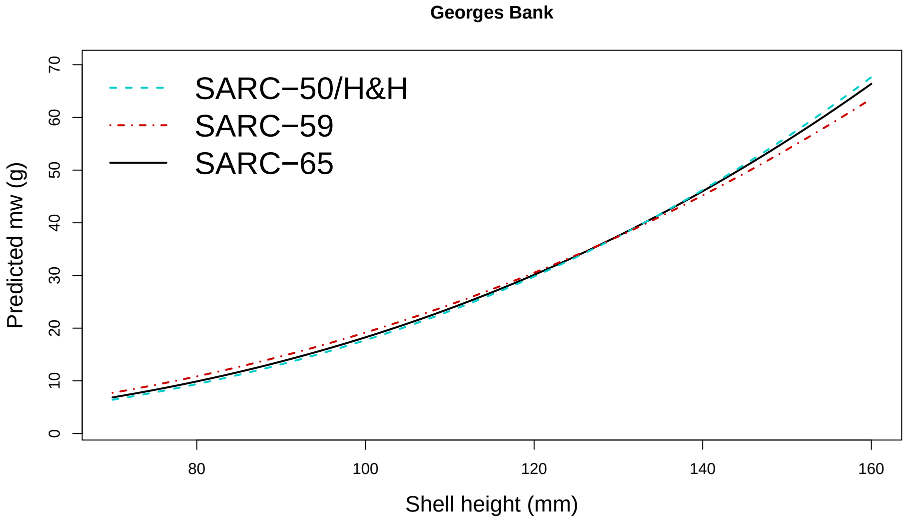


Figure App A2-2: Mid-Atlantic shell height meat weight relationships on various dates as estimated by survey data.



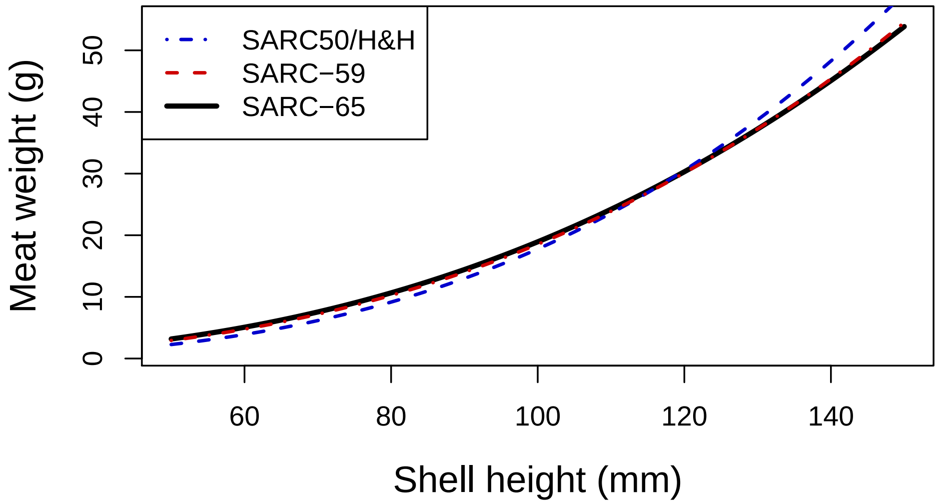


Figure App A2-3: Basic Georges Bank (above) and Mid-Atlantic (below) shell height to meat weight relationships, compared to those from the last two benchmark assessments.

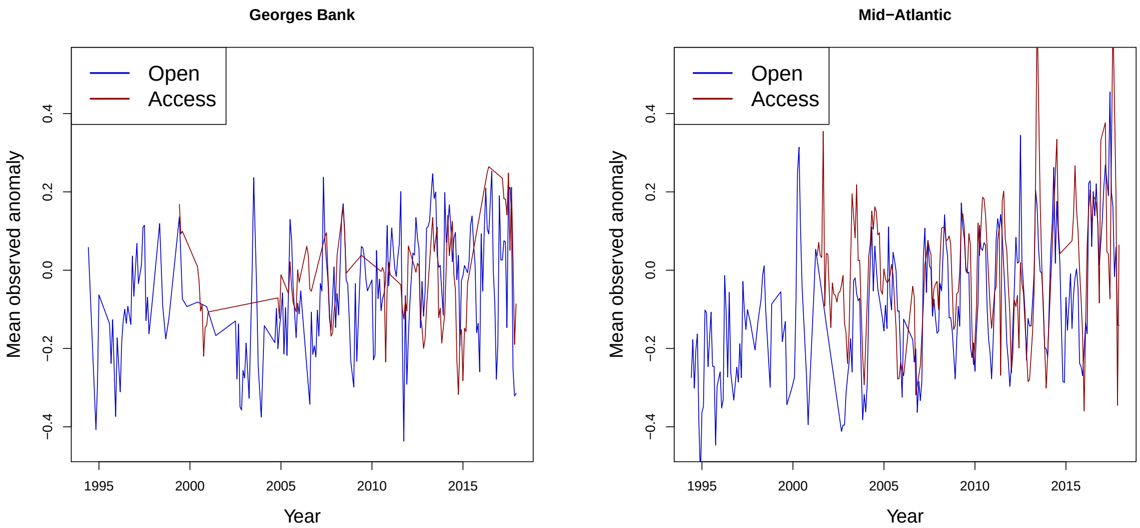


Figure App A2-4: Empirical meat weight anomalies, computed for each month and year, using equation (App A2-3) for Georges Bank (left) and Mid-Atlantic (right) open (blue) and access areas (black).

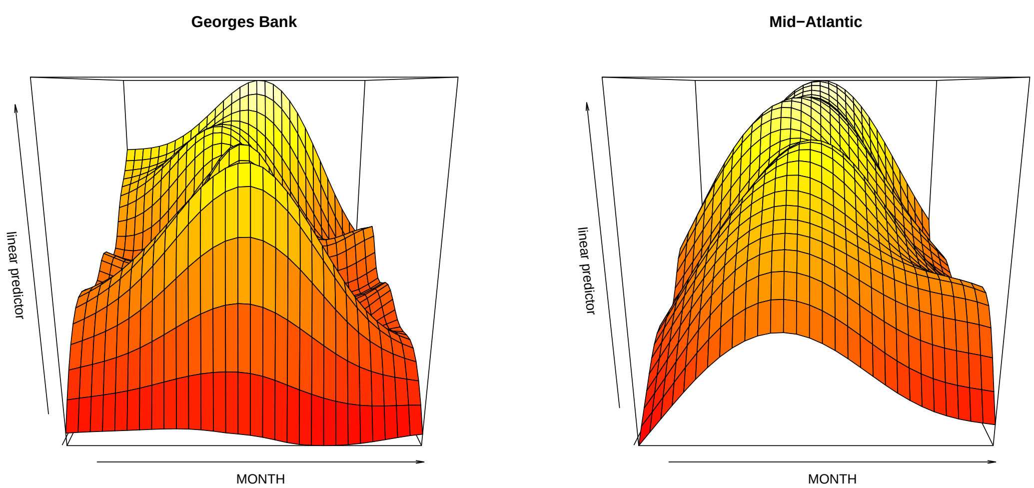


Figure App A2-5: GAM predictions as a function of month and year.

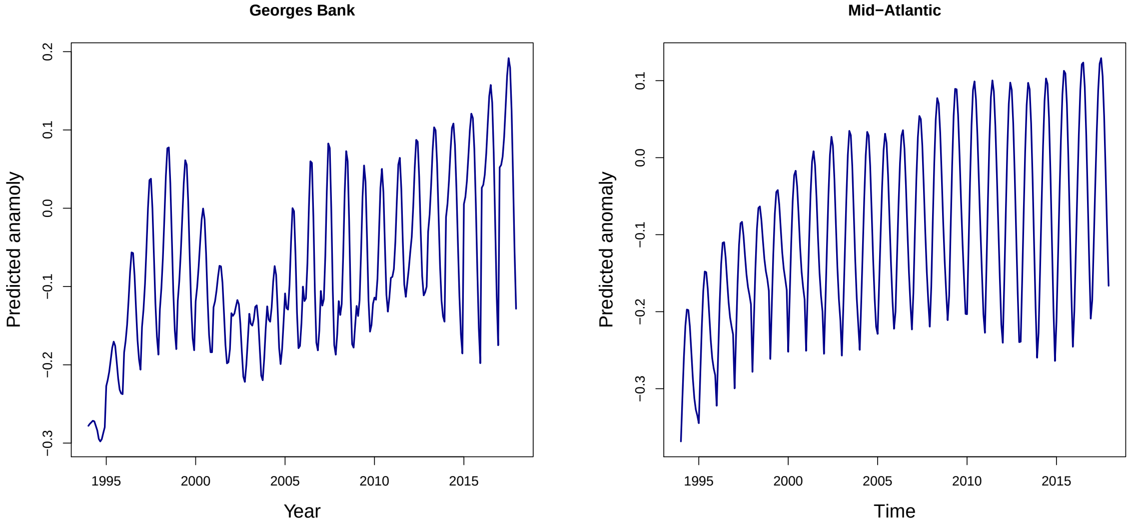


Figure App A2-6: Predicted meat weight anomalies from the GAM for Georgers Bank (left) and Mid-Atlantic (right) open areas

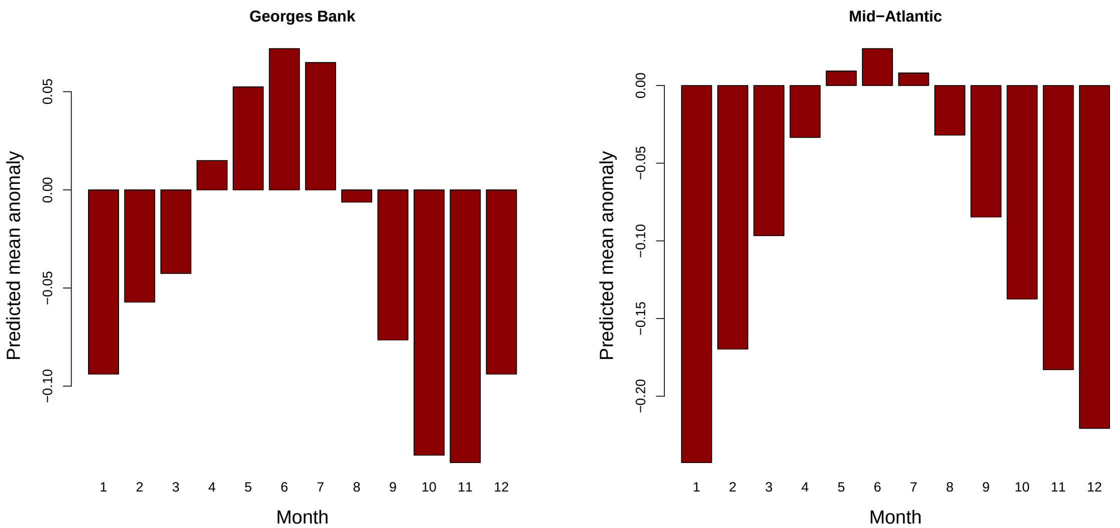


Figure App A2-7: Mean monthly meat weight anomalies on Georges Bank (left) and Mid-Atlantic (right) open areas from GAM predictions.

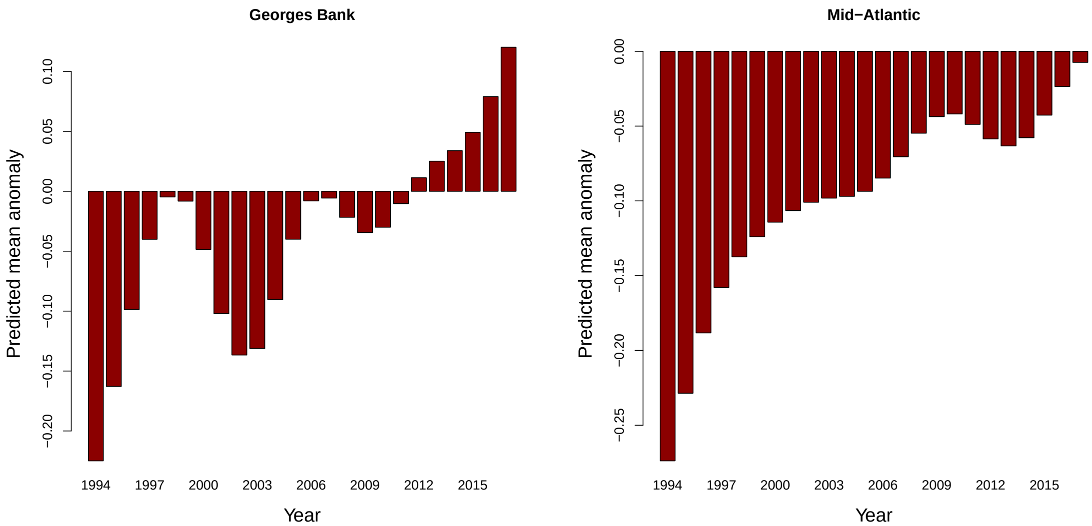


Figure App A2-8: Mean annual meat weight anomalies on Georges Bank (left) and Mid-Atlantic (right) open areas, from GAM predictions.

References

Caddy, JF, Radley-Walters, C. (1972) Estimating count per pound of scallop meats by volumetric measurement. Fisheries Research Board of Canada Manuscript Report Series, Biological Station, St. Andrews, N.B. 11 p.

Hennen DR, Hart DR (2012) Shell height-to-weight relationships for Atlantic sea scallops (*Placopecten magellanicus*) in offshore US waters. J Shellfish Res 31(4):1133-1144

Smolowitz, R. J., F. M. Serchuk, R. J. Redman. 1989. The use of a volumetric measure for determining sea scallop meat count. J. Shellfish Res. 8:151172.