Appendix A1 - Sea Scallop Growth

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This is an update on the growth estimates of Hart and Chute (2009b), and follows the methods there except as specifically noted. In brief, the data consist of the shell heights of successive growth rings on the upper valve of sea scallop shells. Because early growth rings may be obscure or missing, these data are used here as a measure of annual growth increments, rather than an estimate of absolute age.

A linear mixed-effects model (using lme4 in R) that predicts the shell height of the larger ring of an increment r_2 from the starting ring shell height r_1 is used to estimate the von Bertalanffy coefficients L_∞ and K. Random effects on both the slope and intercept, on the level of individual scallop, take into account individual variability in both K and L_∞, which otherwise would cause bias and artificially inflate sample size. Estimates of individual variation from the random effects are used, together with the estimates of the means of these parameters, to construct stochastic growth matrices for the CASA, SAMS and SYM models. The parameter t_0 is not estimatable by these methods, but it is not needed for a size-structured assessment. A station-level random effect on the intercept only was included for the first time here, so that there are now nested station and individual scallop random effects. The term was included to take into account that scallops within a station are more likely to have similar growth. Including the station-level effect mainly affected the estimated variability in L_∞; not including it, as was done in the past, biases this variability slightly low. In addition, not including the station effect biases the standard errors low since sample size is somewhat inflated. However, the station-level random effect did not measurably affect the estimates of the mean L_∞ and K parameters.

The Hart and Chute (2009b) analysis was based on shells collected in 2001-2007. There were shells collected previous to 2001, but they were archived and not analyzed. NEFSC (2014) updated the Hart and Chute (2009b) analysis with shells collected from 2008-2012 and also archived shells from 1988 and 1993. Growth from these archived shells was slower than that observed in the more recent years. It is probable that this is at least in part a fishery effect. Scallopers tend to target faster growing scallops, leaving a fished population with a disproportionately high level of slower growers. This effect would be expected to become more pronounced with higher fishing mortality; estimates of F for 1988 and 1993 are much higher than in most recent years.

For this assessment, many more archived shells were analyzed; these were collected between 1982 and 2000. In order to discern temporal changes in growth, we define the increment year (iyear) as the year when the second (larger) ring defining that increment was laid down. For example, the iyear of the last increment on a shell collected in 2017 is 2016, since shells are collected on surveys prior to the formation of the annual ring (shell rings in US waters are laid down near the temperature maximum, in fall or late summer, Chute et al. 2012). For Georges Bank (excluding shells collected from Canadian waters and from the "Peter Pan" area), there were 7298 shells analyzed from 1502 stations, which contained a total of 31480 growth increments, with samples spread out across the region (Figure App A1-1). For the Mid-Atlantic, 6486 scallops from 1469 stations were analyzed, comprising 16231 increments, which also covered a wide geographic range. However, no shells were collected during 2014-2017.

As an initial exploratory exercise, we fit the following linear model, with, as discussed above, random effects on the individual and station level, to the Georges Bank and Mid-Atlantic growth ring data:

$$r_2 = a_0 + a_1 r_1 + a_2 D + a_{12} r_1 D + a_3 I_{\mathrm{cl}} + a_y \mathrm{as.factor\ (iyear)} \qquad \text{(App A1-1)}$$

where D is depth, I_{cl} is 1 if the scallop was collected from one of the closed or rotational areas, and 0 if not, and the increment year effects were plotted (FigureApp A1-2). The covariates were included to isolate the year effect from potential confounding effects such as depth. As can be seen from Figure App A1-2, growth varied by year, and there is a negative correlation between fishing mortality (see main document) and growth.

Based on these plots, we split Georges Bank growth into 5 periods, from slowest to fastest: (1) 1993-1996, (2) 1975-1992 and 1997-1999, (3) 2000-2006, (4) 2007-2011, and (5) 2012-2017. Similarly, for the Mid-Atlantic, growth was split into three periods: (Slow) 1975-1977, 1987-2003, and 2006, (Medium) 1978, 1983-1986, 2004-2005, and 2007, and (Fast) 2008-2012. The shell increments were split into these periods, and separate growth curves and matrices were computed for each period. These periods were used to model time-varying growth in the CASA models.

For each region, period was included as a factor in the basic mixed-effects regression:

$$r_2 = a_0 + b_0 r_1 + a_p \mathrm{as.factor(period)} + b_p \mathrm{as.factor(period)} r_1 \qquad \text{(App A1-2)}$$

The slope terms for each period (b_p) were tested using AIC to determine whether the slope (which determines K) was different in that period, and only those b_p that reduced AIC were retained in the final model. Results are shown in Table App A1-1 and Figure App A1-3.

Subarea specific growth estimates are desirable for the SAMS model. Because SAMS is a foward projection model, data were taken only from the latest growth period in each region (i.e., Mid-Atlantic or Georges Bank). For each region, area-specific covariates were added to the basic mixed-effects regression model:

$$r_2 = a_0 + b_0 r_1 + a_s \mathrm{as.factor(period)} + b_s \mathrm{as.factor(period)} r_1 \qquad \text{(App A1-3)}$$

Similar to that done with periods, only the b_s coefficients on the slope that reduced AIC were included in the final model. Additionally, a total of 75 shells from Peter Pan scallops were also analyzed. Because their growth is so different than other areas, its growth parameters were estimated seperately, with no station level random effect (due to the paucity of data). Results are given in and Table App A1-2 and Figure App A1-4.

Tables

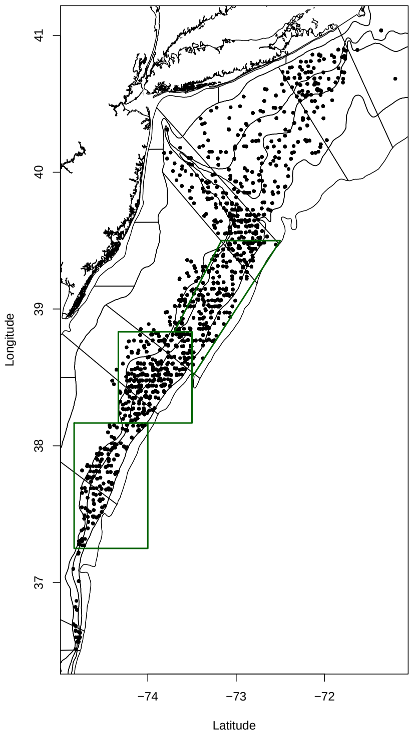
Table App A1-1. Estimated regional von Bertalanffy parameters, by temporal periods.

Years	L_∞	SDL_∞	K	SDK	SEL_∞	SEK
GB All						
75-93; 97-99	141.5	9.9	0.429	0.109	0.5	0.003
93-96	136.6	9.3	0.429	0.109	0.5	0.003
00-06	140.2	9.0	0.478	0.114	0.4	0.003
07-11	144.6	9.8	0.464	0.113	0.4	0.003
12-16	151.5	11.4	0.429	0.109	0.5	0.003
GB Open						
go 75-93; 97-99	136.8	9.1	0.442	0.110	0.6	0.003
93-96	132.1	8.5	0.442	0.110	0.6	0.003
00-06	135.8	8.2	0.494	0.116	0.6	0.004
07-11	140.1	8.9	0.479	0.114	0.6	0.004
12-16	146.7	10.4	0.442	0.110	0.7	0.003
GB Closed						
75-93; 97-99	145.7	10.7	0.420	0.108	0.7	0.003
93-96	140.8	10.0	0.420	0.108	0.7	0.003
00-06	143.8	9.5	0.470	0.113	0.6	0.004
07-11	148.5	10.4	0.455	0.111	0.7	0.004
12-16	156.0	12.3	0.420	0.108	0.7	0.003
Mid-Atlantic						
75-77; 87-03; 06	131.4	8.2	0.534	0.117	0.4	0.003
78; 83-86; 04-05; 07	133.4	8.1	0.564	0.121	0.4	0.003
79-82; 08-12	137.4	8.6	0.564	0.121	0.4	0.003

Table App A1-2. Estimated subarea specific von Bertalanffy parameters in the most recent growth period. Georges Bank areas are: South Channel (Sch), Northern Edge (NE), Southern Flank (SF), Closed Area I (CA-I), Closed Area II (CA-II), Nantucket Lightship Closed Area (NLS), and the "Peter Pan" area (PP). Mid-Atlantic areas are Delmarva (DMV),Elephant Trunk (ET), Hudson Canyon South (HCS), New York Bight (NYB), Long Island (LI), and Inshore.

Region	Year	L_∞	K	SDL_∞	SDK	SEL_∞	SEK
Georges Bank							
Sch	12-16	150.3	0.3966	9.58	0.1173	4.4	0.0055
NE	12-16	148.77	0.3966	9.62	0.1173	4.4	0.0055
SF	12-16	137.29	0.4641	6.74	0.1254	3.9	0.0058
CA-I	12-16	149.36	0.3966	9.73	0.1173	4.4	0.0055
CA-II	12-16	146.89	0.3966	9.27	0.1173	4.4	0.0055
NLS	12-16	151.15	0.3966	10.08	0.1173	4.4	0.0055
PP	12-16	110.3	0.423	18.11	0.101	2.7	0.023
Mid-Atlantic							
DMV	08-12	136.41	0.5467	8.08	0.1362	1.3	0.0057
ET	08-12	137.92	0.5467	8.28	0.1362	1.3	0.0057
HCS	08-12	129.54	0.5467	7.21	0.1362	1.3	0.0057
NYB	08-12	140.79	0.5467	8.69	0.1362	1.3	0.0057
LI	08-12	139.6	0.5467	8.52	0.1362	1.3	0.0057
Inshore	08-12	147.28	0.5467	9.64	0.1362	1.34	0.0057

Figures



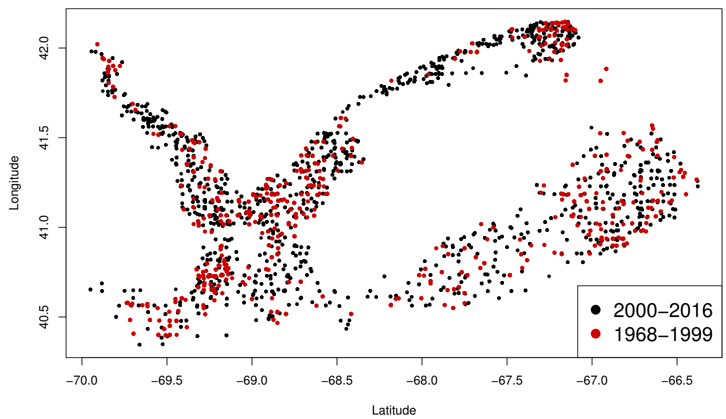
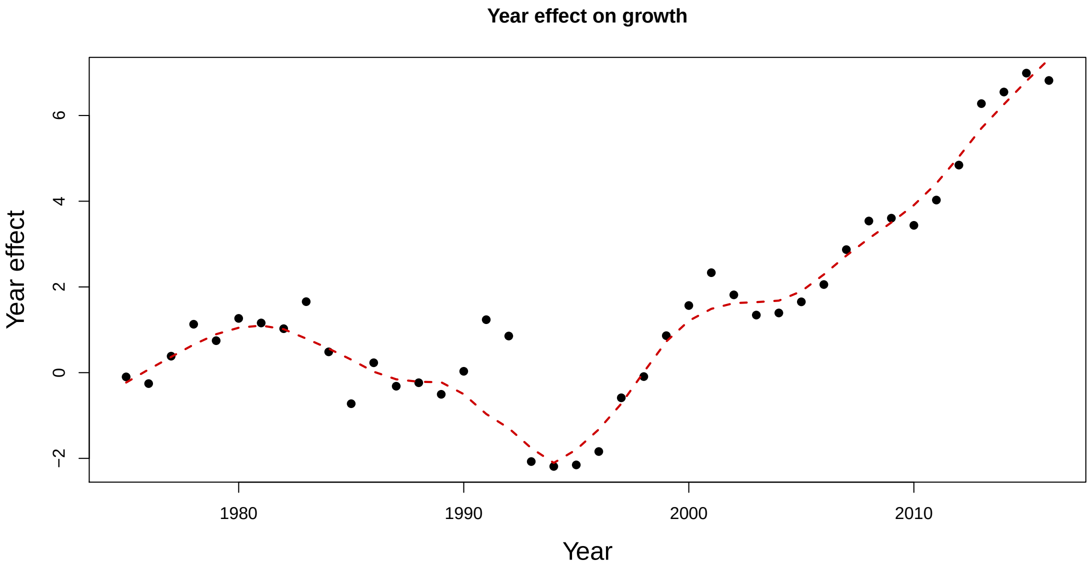


Figure App A1-1. Locations where shells samples were taken in the Mid-Atlantic (left) and Georges Bank (right)



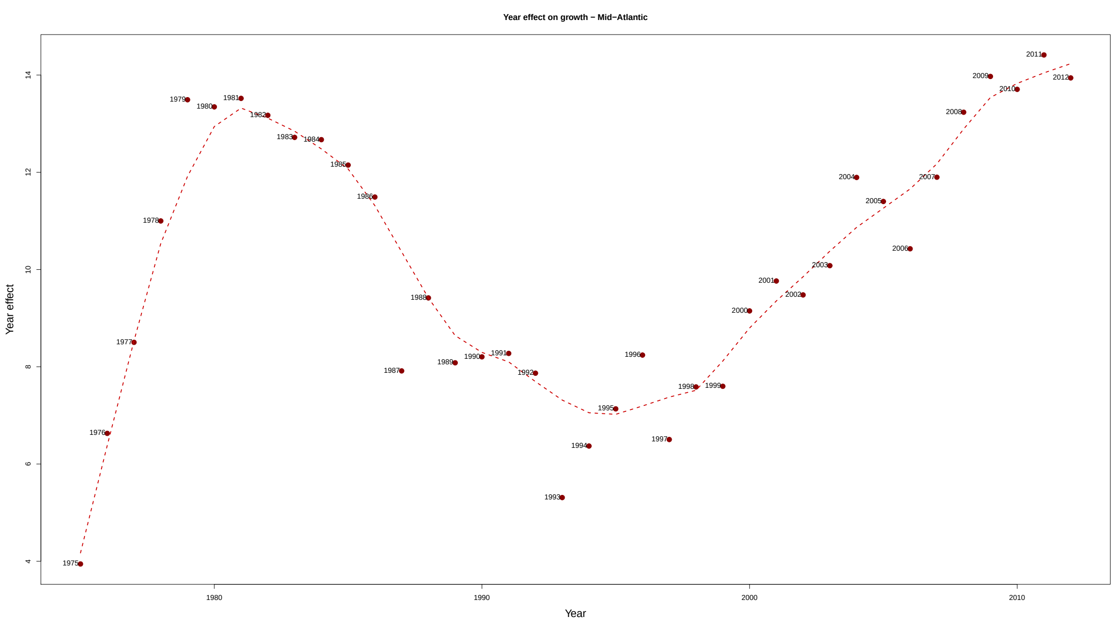


Figure App A1-2. Increment year effects, on Georges Bank (above) and Mid-Atlantic (below)

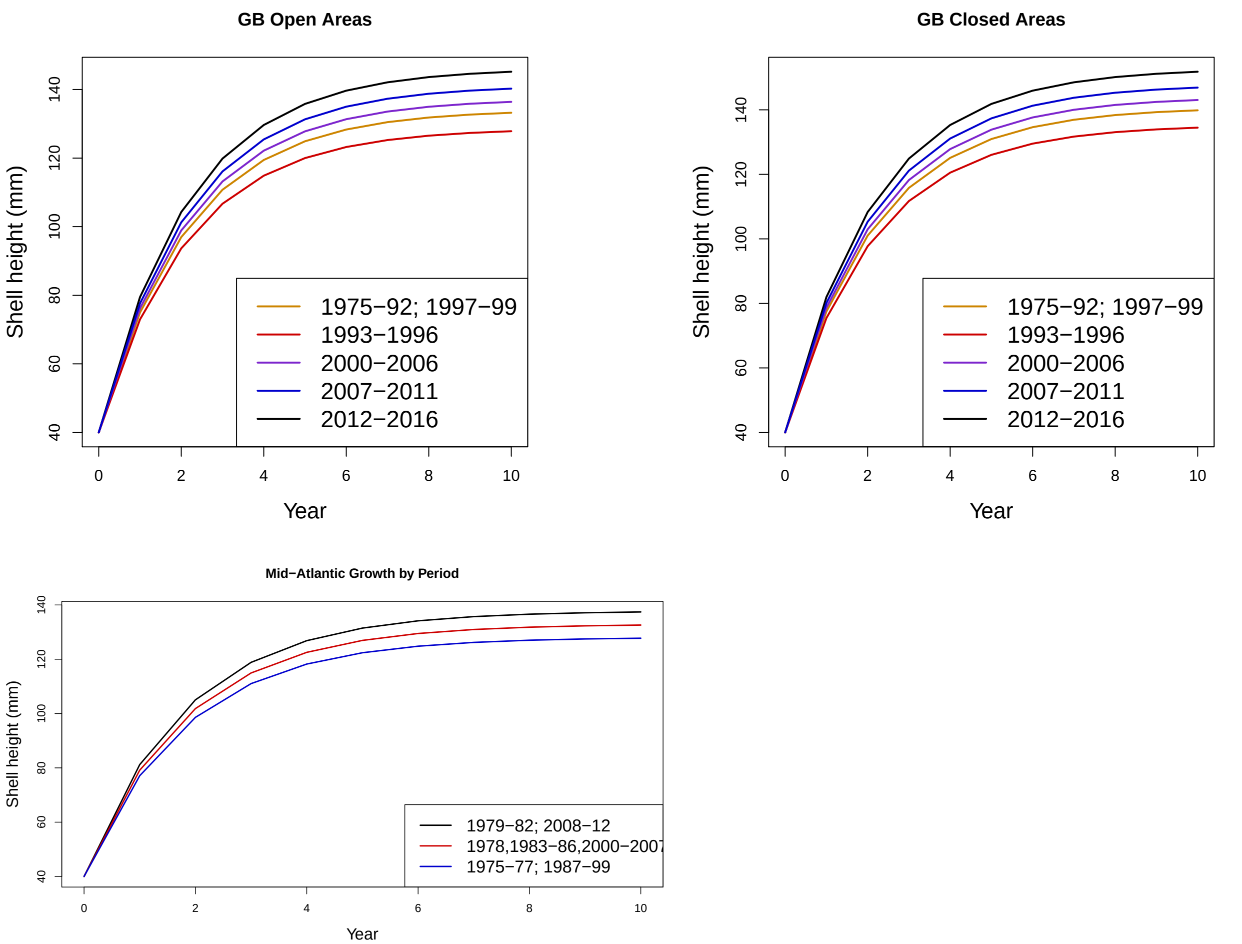


Figure App A1-3. Estimated growth of a 40 mm scallop in each of the growth periods for Georges Bank Open (left), Georges Bank Closed (right), and Mid-Atlantic, below.

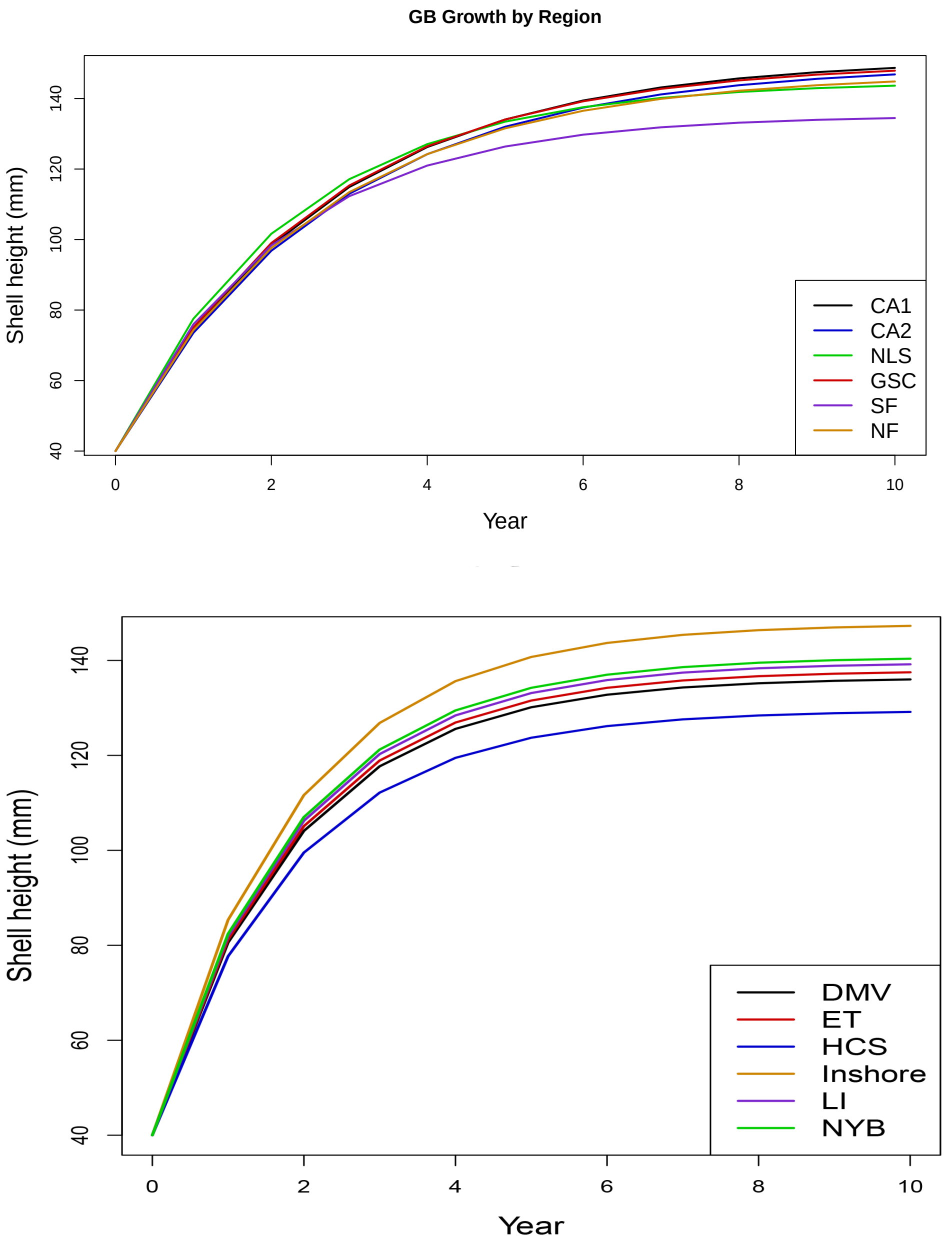


Figure App A1-4. Area-specific growth for the most recent growth period for Georges Bank and the Mid-Atlantic. Georges Bank areas are: South Channel (Sch), Northern Edge (NE), Southern Flank (SF), Closed Area I (CA-I), Closed Area II (CA-II), and Nantucket Lightship Closed Area (NLS). Mid-Atlantic areas are Delmarva (DMV),Elephant Trunk (ET), Hudson Canyon South (HCS), New York Bight (NYB), Long Island (LI), and Inshore.