APPENDIX B11: Forecasting methodology (SAMS model)

The model presented here is a modified version of the SAMS (Scallop Area Management Simulator) model used to project abundances and landings as an aid to managers since 1999. Subareas were chosen to coincide with current management. Thus, Georges Bank was divided into three open areas (South Channel, Northern Edge and Peak, and Southeast Part), the three access portions of the groundfish closures, and the three no access portions of these areas. The Mid-Atlantic was subdivided into six areas: Virginia Beach, Delmarva, the Elephant Trunk Closed Area, the Hudson Canyon South Access Area, New York Bight, and Long Island.

Methods

The model follows, for each area i and time t, population vectors $\mathbf{p}(i,t) = (p_1, p_2,..., p_n)$, where p_j represents the density of scallops in the jth size class in area i at time t. The model uses a difference equation approach, where time is partitioned into discrete time steps $t_1, t_2,...,$ with a time step of length $\Delta t = t_{k+1} - t_k$. The landings vector $\mathbf{h}(i,t_k)$ represents the catch at each size class in the ith region and kth time step. It is calculated as:

$$h(i,t_k) = [I - \exp(\Delta t H(i,t_k))]p(i,t_k),$$

where I is the identity matrix and H is a diagonal matrix whose jth diagonal entry h_{jj} is given by:

$$h_{jj} = 1/(1+\exp(s_0 - s_1 * s))$$

where SH is the shell height of the mid-point of the size-class. The parameters s_0 and s_1 are derived in Appendix V.

The landings $L(i,t_k)$ for the ith region and kth time step are calculated using the dot product of landings vector $\mathbf{h}(i,t_k)$ with the vector $\mathbf{m}(i)$ representing the vector of meat weights at shell height for the ith region:

$$L(i,t_k) = A_i \mathbf{h}(i,t_k) \bullet \mathbf{m}(i)/(w e_i)$$

where e_i represents the dredge efficiency in the ith region, and w is the tow path area of the survey dredge (estimated as 8/6076 nm^2).

Even in the areas not under special area management, fishing mortalities tend to not be spatially uniform for poorly mobile stocks such as sea scallops (Hart 2001). Fishing mortalities in open areas were determined by a simple "fleet dynamics model" that estimates fishing mortalities in open areas based on area-specific exploitable biomasses, and so that the overall DAS or open-area F matches the target. Based on these ideas, the fishing mortality F_i in the ith region is modeled as:

$$\mathbf{F_i = k*f_i*B_i}$$

where B_i is the exploitable biomass in the ith region, f_i is an area-specific adjustment factor to take into account preferences for certain fishing grounds (due to lower costs, shorter steam times, ease of fishing, habitual preferences, etc.), and k is a constant adjusted so that the total DAS or fishing mortality meets its target. For these simulations, $f_i = 1$ for all areas.

Scallops of shell height less than a minimum size s_d are assumed to be discarded, and suffer a discard mortality rate of d. Discard mortality was estimated in NEFSC (2004) to be

20%. There is also evidence that some scallops not actually landed may suffer mortality due to incidental damage from the dredge. Let F_L be the landed fishing mortality rate and F_I be the rate of incidental mortality. For Georges Bank, which is a mix of sandy and hard bottom, we used $F_I = 0.15F_L$. For the Mid-Atlantic (almost all sand), we estimated $F_I = 0.04F_L$.

Growth in each subarea was specified by a growth transition matrix *G,* based on area-specific growth increment data (see Appendix III).

Recruitment was modeled stochastically, and was assumed to be log-normal in each subarea. The mean, variance and covariance of the recruitment in a subarea was set to be equal to that observed in the historical time-series between 1979-2006 (Mid-Atlantic) and 1982-2006 (Georges Bank). New recruits enter the smallest nine size bins in proportions (1/7,1/7,1/7,1/7,1/7,4/35,3/35,2/35,1/35) at a rate r_i depending on the subarea *i,* and stochastically on the year. Area-specific recruitment rates are given in Table 1. These simulations assume that recruitment is a stationary process, i.e., no stock-recruitment relationship is assumed (NEFSC 2004). At the current high biomass levels, it is likely that any stock-recruitment relationship would have asymptoted, so that this assumption is reasonable provided that biomass remain at or above the target level.

The population dynamics of the scallops in the present model can be summarized in the equation:

$$p(i,t_{k+1}) = \rho_i + G\exp(-M\Delta tH)p(i,t_k),$$

where ρ_i is a random variable representing recruitment in the *i*th area. The population and harvest vectors are converted into biomass by using the shell-height meat-weight relationship:

$$W = \exp[a + b\ln(s)],$$

where *W* is the meat weight of a scallop of shell height *s*. For calculating biomass, the shell height of a size class was taken as its midpoint. A summary of model parameters is given in Table 2.

Commercial landing rates (LPUE) were estimated using an empirical function based on the observed relationship between annual landing rates, expressed as number caught per day (NLPUE) and survey exploitable numbers per tow. At low biomass levels, NLPUE increases roughly linearly with survey abundance. However, at high abundance levels, the catch rate of the gear will exceed that which can be shucked by a seven-man crew. The is similar to the situation in predator/prey theory, where a predator's consumption rate is limited by the time required to handle and consume its prey (Holling 1959). The original Holling Type-II predator-prey model assumes that handling and foraging occur sequentially. It predicts that the per-capita predation rate *R* will be a function of prey abundance *N* according to a Monod functional response:

$$R = \frac{\alpha N}{\beta + N},$$

where α and β are constants. In the scallop fishery, however, some handling (shucking) can occur while foraging (fishing), though at a reduced rate because the captain and one or two crew members need to break off shucking to steer the vessel during towing and to handle the gear during haulback. The fact that a considerable amount of handling can occur at the same time as foraging means that the functional response of a scallop vessel will saturate quicker than that predicted by the above equation. To account for this, a modified Holling Type-II model was used, so that the landings (in numbers of scallops) per unit effort (DAS) *L* (the predation rate, i.e., NLPUE) will depend on scallop (prey) exploitable numbers *N* according to the formula:

$$L = \frac{\alpha N}{\sqrt{\beta^2 + N^2}}. \qquad (*)$$

The parameters α and β to this model were fit to the observed fleet-wide LPUE vs. exploitable biomass relationship during the years 1994-2004 (previous years were not used because of the change from port interviews to logbook reporting). The number of scallops that can be shucked should be nearly independent of size provided that the scallops being shucked are smaller than about a 20 count. The time to shuck a large scallop will go up modestly with size. To model this, if the mean meat weight of the scallops caught, g, in an area is more than 20 g, the parameters α and β in (*) are reduced by a factor $\sqrt{20/g}$. This means, for example, that a crew could shuck fewer 10 count scallops per hour than 20 count scallops in terms of numbers, but more in terms of weight.

An estimate of the fishing mortality imposed in an area by a single DAS of fishing in that area can be obtained from the formula $F_{\text{DAS}} = L_a/N_a$, where L_a is the NLPUE in that area obtained as above, and N_a is the exploitable abundance (expressed as absolute numbers of scallops) in that area. This allows for conversion between units of DAS and fishing mortality.

Initial conditions for the population vector **p** *(i,t)* were estimated using the 2006 NMFS research vessel sea scallop survey, with dredge efficiency chosen so as to match the 2006 CASA biomass estimates. The initial conditions from the 2006 survey were bootstrapped using the bootstrap model of Smith (1997), so that each simulation run had both its own stochastically determined bootstrapped initial conditions, as well as stochastic recruitment stream.

APPENDIX B11 Table 1 – Mean and covariance of area specific log-transformed recruitment

Mid-Atlantic	HC	VB	ET	DMV	NYB	LI
Means	4.14	3.88	4.41	4.01	3.39	3.14
Covariance Matrix						
HC	1.48	0.54	1.14	0.97	0.93	0.65
VB	0.54	2.04	0.58	1.32	0.06	-0.20
ET	1.14	0.58	1.96	1.20	0.75	0.74
DMV	0.97	1.32	1.20	1.84	0.70	0.34
NYB	0.93	0.06	0.75	0.70	1.17	0.81
LI	0.65	-0.20	0.74	0.34	0.81	0.98

Georges Bank	CL1-NA	CL1-Acc	CL2-NA	CL2-Acc	NLS-NA	NLS-Acc	Sch	NEP	SEP
Means	3.67	3.51	2.87	3.34	-2.15	3.41	4.62	3.16	2.38
Covariance Matrix									
CL1-NA	2.92	0.03	0.34	0.32	-1.03	-0.45	0.75	-0.22	-0.47
CL1-Acc	0.03	1.83	0.94	0.77	2.24	0.58	0.61	0.52	0.38
CL2-NA	0.34	0.94	1.98	0.89	-0.40	0.27	0.53	0.33	0.34
CL2-Acc	0.32	0.77	0.89	2.63	2.22	1.34	0.76	1.00	0.77
NLS-NA	-1.03	2.24	-0.40	2.22	11.03	1.22	0.18	2.09	2.52
NLS-Acc	-0.45	0.58	0.27	1.34	1.22	5.07	0.25	0.72	0.39
Sch	0.75	0.61	0.53	0.76	0.18	0.25	1.27	0.20	0.01
NEP	-0.22	0.52	0.33	1.00	2.09	0.72	0.20	0.82	0.57
SEP	-0.47	0.38	0.34	0.77	2.52	0.39	0.01	0.57	1.42

APPENDIX B11 Table 2. Model parameters

Parameter	Description	Value
Δt	Simulation time step	1 y
M	Natural mortality rate	0.1 y^{-1}
A	Shell height/meat wt parameter	-10.70 (GB), -12.01 (MA)
B	Shell height/meat wt parameter	2.94 (GB), 3.22 (MA)
s_0	Logistic selectivity parameter	9.692
s_1	Logistic selectivity parameter	0.1016
s_d	Cull size	90 mm
D	Mortality of discards	0.2
E	Dredge efficiency	0.311 (GB), 0.394 (MA)
α	LPUE/biomass relationship	43183
β	LPUE/biomass relationship	30626