Biological Projections

Dvora Hart
NFMS/NEFSC
166 Water St.
Woods Hole MA 02543

Introduction

The model used in Framework 18 is an updated version of the SAMS (Scallop Area Management Simulator) model used to project abundances and landings in Amendment 10 and Frameworks 12-16 (see e.g., the previous sea scallop SAFE report, NEFMC 2000). This model has generally been successful in forecasting sea scallop abundance, landings, and catch rates. In particular, it accurately predicted the increases in these quantities that occurred in the past six years.

The present version of the SAMS model is slightly modified from the version used in Amendment 10. The main modification is that the 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, the southern portion of the New York Bight (from the bottom of Hudson Canyon south to the Elephant Trunk Area, excepting the Hudson Canyon South Access Area), and Long Island. In addition, the recruitment, LPUE, and fleet dynamics submodels have been updated to take into account recent information and the new subarea boundaries.

Methods

The model follows, for each area i and time t, population vectors $\mathbf{p}(i,t) = (p_1, p_2, \ldots, p_n)$, 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 $t_1, t_2, \ldots,$ 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:

$$hjj = 1/(1+\exp(s_0 - s_1 * s))$$

where SH is the shell height of the mid-point of the size-class. The parameters s_0 and s_1 were estimated based on data from W. DuPaul (VIMS) that compared the seletivity of 4” compared to 3.5” rings, and data from the F/V Tradition, which fished a 3.5” ring commercial dredge on one side and the NMFS lined survey dredge on the other, when completing the 1999 NMFS sea scallop survey.

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:

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

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 (Caddy 1975, Hart 2001). Fishing mortalities in 2004-2005 were specified, based on observed and predicted distributions of fishing effort (from VMS and VTR information, and the TACs in the access areas). Fishing mortalities in open areas beyond 2005 are determined by a "fleet dynamics model", which was updated based on recent survey and VMS effort data. This model 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:

$$F_i = k^* f_i^* B_i$$

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. The level at which this occurs depends on the dredge efficiency e and also probably bottom type (Hart 2003). If a fraction c of the scallops remaining on the bottom suffer incidental mortality, then the incidental fishing mortality F_I can be calculated as:

$$F_I = F_L c(1-e)/e,$$

where F_L is capture fishing mortality.

Caddy (1973) estimated that c was about 0.15 to 0.2 in a relatively hard-bottom area in Canadian waters, while Murawski and Serchuk (1989) estimated that $c < 0.05$ in a sandy bottom area off of New Jersey. For Georges Bank, which is a mix of sandy and hard bottom, we used $c = 0.15$ together with a dredge efficiency estimate of $e = 0.4$ to obtain an estimate of $F_I = 0.225F_L$. For the Mid-Atlantic, we used $c = 0.05$ (the maximum possible value from Murawski and Serchuk) together with an efficiency of $e = 0.6$ to estimate $F_I = 0.03F_L$.

The scallops grow according to a von Bertalanffy equation, so that their shell height *s(t)* at age *t* (in years) is given by:

$$s(t) = L_\infty[1 - \exp(-k[t - t_0])].$$

The growth equation is used to construct a matrix *G*, which specifies the fractions of each size class that remains in that size class, or grows to other size classes, in a time Δt.

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 1979-2004 (Mid-Atlantic) and 1982-2004 (Georges Bank). The same random number seed was used in all simulations, so that differences among simulation runs cannot be ascribed to different recruitment streams. New recruits enter the smallest size class (40-45 mm in these simulations) 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 $\rho_i = (r_i \Delta t, 0, 0, \ldots)$. 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. The model also keeps track of egg production, based on the fecundity - shell-height relationship of MacDonald and Thompson (1985). A summary of model parameters is given in Table 2.

Initial conditions for the population vector **p** *(i,t)* were estimated using the 2004 NMFS research vessel sea scallop survey. Catches in the survey were adjusted for catchability of a lined dredge, as described in NEFSC (2004). The initial conditions from the 2004 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.

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 $F_{\mathrm{DAS}} = L_a/N_a$, 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.

The LPUE/biomass functional relationship can also be used to estimate dredge contact time and total area swept. Even when shucking time is not limited, the dredge will not be on the bottom all the time that a vessel's DAS clock is ticking. Observer data indicates that vessels typically steam about 5% of the time. The dredge can be on the bottom for roughly 85% of the remaining time; the rest of the time is needed for dredge set-out, haul-back, and dumping on deck. This implies that at low densities, when shucking is not limiting, that dredge contact time is about 19.5*D hours, where D is the number of DAS charged.

The catch rate per hour contact time should be directly proportional to biomass regardless of biomass levels. Since at low biomass, the relationship (*) reduces to $L = (\alpha/\beta)B$ (see Figure 1), the predicted (numerical) landings L_0 per 19.5 hours contact time is:

$$L_0 = (\alpha/\beta)N. \qquad (**)$$

Thus, the actual bottom contact time C (in hours) per DAS charged is:

$$C = 19.5\frac{L}{L_0} = \frac{19.5\beta}{\sqrt{\beta^2 + N^2}}.$$

Since a typical vessel fishes at about 4.5 knots, and employs two 15 foot dredges, the area swept in an hour of bottom contact time is about: 4.5*2*15/6080 nm^2 = 0.0222 nm^2. Hence, the area swept, A, per DAS charged is:

$$A = \frac{19.5 * 0.0222\beta}{\sqrt{\beta^2 + N^2}}.$$

Simulations were run 400 times starting July 2004 (when the NMFS survey was conducted) and ending July 2020. Model parameters are given in Table 1.

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

Mid-Atlantic

Cov	**HCS**	**VB**	**ET**	**DMV**	**HCN**	**LI**	**Mean**
HCS	1.53	0.53	1.17	0.92	1.05	0.88	4.27
VB	0.53	2.06	0.57	1.28	0.03	-0.13	3.98
ET	1.17	0.57	2.09	1.20	0.84	0.93	4.45
DMV	0.92	1.28	1.20	1.77	0.79	0.58	4.03
NYBS	1.05	0.03	0.84	0.79	1.33	0.95	3.41
LI	0.88	-0.13	0.93	0.58	0.95	1.07	3.21

Georges Bank

	CL1Acc	**CL1NA**	**CL2-N**	**CL2-S**	**NLSAcc**	**NLSNA**	**Sch**	**NEP**	**SEP**	**Mean**
CL1Acc	1.90	0.12	0.92	0.79	0.58	1.59	0.67	0.58	0.38	3.75
CL1NA	0.12	3.11	0.21	0.19	0.59	-0.27	0.76	-0.24	-0.37	3.59
CL2-N	0.92	0.21	1.87	0.72	0.18	-0.32	0.44	0.31	0.43	3.22
CL2-S	0.79	0.19	0.72	2.35	1.18	1.58	0.63	0.81	0.89	3.72
NLSAcc	0.58	0.59	0.18	1.18	3.41	0.86	0.70	0.52	0.26	3.99
NLSNA	1.59	-0.27	-0.32	1.58	0.86	6.29	0.26	1.47	1.88	-0.69
Sch	0.67	0.76	0.44	0.63	0.70	0.26	1.25	0.13	0.02	4.44
NEP	0.58	-0.24	0.31	0.81	0.52	1.47	0.13	0.65	0.59	3.30
SEP	0.38	-0.37	0.43	0.89	0.26	1.88	0.02	0.59	1.53	2.57

Table 1b. Model parameters.

Parameter	Description	Value
Δt	Simulation time step	0.1 y
L_∞	Maximum shell height	152.46 mm (GB), 151.84 mm (MA)
K	Growth parameter	0.3374 y^{-1} (GB), 0.2997 y^{-1} (MA)
M	Natural mortality rate	0.1 y^{-1}
A	Shell height/meat wt parameter	-11.6038 (GB), -12.2484 (MA)
B	Shell height/meat wt parameter	3.1221 (GB), 3.2641 (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	0.4 (GB), 0.6 (MA)
α	LPUE/biomass relationship	43183
β	LPUE/biomass relationship	30626

Model Scenarios

A total of twelve model scenarios were examined, which can be split into five groups, as descibed in detail below. The alternatives are summarized in Table 2a.

I. No Action. The Hudson Canyon Access Area would revert to fully open management on March 1, 2006. The Elephant Trunk Closed Area would become fully opened to fishing on March 1, 2007. Full time limited access vessels would be allocated 67 open area DAS for each year starting in 2006, as specified in Amendment 10 and Framework 16, corresponding to about 24700 aggregate DAS, including an allocation of 3500 DAS to account for general category activity. Two out of the three groundfish closed access areas would continue to be fished at $F = 0.2$, according to the specifications laid out in Amendment 10 and Framework 16. The remainder of the groundfish closed areas would remain closed to scallop fishing.

II. Status Quo. The Hudson Canyon Access Area would revert to fully open management on March 1, 2006. The Elephant Trunk Closed Area would open under controlled access on March 1, 2007 for three years, using the principle of time-averaging, as discussed in Amendment 10. The fishing moratilties during this period would be F = 0.32, 0.4 and 0.48. After these three years, the area would revert to fully open status. Two out of the three groundfish closed access areas would continue to be fished at F = 0.2, according to the specifications laid out in Amendment 10 and Framework 16. The remainder of the groundfish closed areas would remain closed to scallop fishing. Full time limited access vessels would be allocated 67 DAS in FY 2006. Allocations in later years would be made so that the resource-wide fishing mortality equals the Amendment 10 target of $F = 0.2$.

III. Modified Elephant Trunk Reopening and Groundfish Closed Area Access.

In all scenarios in this group, the controlled access period for the Elephant Trunk area would be extended to five years, starting on March 1, 2007 and ending Feburary 29, 2012. Fishing mortalities for the five year period would be ramped up more slowly: $F = 0.16$, 0.24, 0.32, 0.4 and 0.48. In addition, access to the groundfish closed areas would be modified, so that all three areas would be open in 2006 (two trips each to the NLS and CL-II access areas, and one trip to the CL-1 access area), with the 2/3 rotation resuming in 2007. The Hudson Canyon Access Area would revert to fully open status on March 1, 2006. For all but the last scenario in this group, open area DAS for 2007 and beyond were calculated to make the resource-wide fishing mortality 0.2. Four different options were simulated for aggregate open area DAS for FY 2006: 15000, 20000, 25000 and 30000. The fifth alternative in this group assumes 20000 DAS for both FY 2006 and 2007, with open area DAS calculated to result in $F = 0.2$ for 2008 and beyond.

IV. Extended Hudson Canyon Access Program. Policies for the Elephant Trunk and groundfish access areas are the same as III. above. The Hudson Canyon Access Area would remain under controlled access for one or two more years, with no new trips being allocated to the area. Unused trips from 2005 could be used in 2006 or (in the two year extension scenario) 2007. It was assumed that landings from this area would be spread out equally among the two or three year period from 2005 until the end of controlled access. Aggregate open area DAS for 2006 are 24700 for the first scenario and 20000 for the second. DAS for 2007 and beyond were specified to meet the resource-wide $F = 0.2$ target.

V. New Delmarva Closure. The Elephant Trunk and groundfish area access policies would be the same as III. and IV. above. The Hudson Canyon Access Area controlled access program would be extended for two more years, as discussed in IV. above. A new rotational closed area, south of the Elephant Trunk closure, closes when the Elephant Trunk area reopens. This area was identified on the basis of strong recruitment observed during the 2005 NMFS survey, whereas the simulations start with the 2004 survey, and assume typical recruitment for subsequent years. For this reason, these simulations underestimate both the relative and absolute benefits of the new closure. Nonetheless, the simulations give an idea of the impact of the new closure on future landings and on the areas that remain open to fishing. The closure is assumed to last for three years, after which there are three years of controlled access, at $F = 0.32$, 0.4 and 0.48. In the first run of this set, open area aggregate DAS was set at 20000 for 2006 and adjusted to meet the $F = 0.2$ target in subsequent years. Aggregate open area DAS was 20000 for both 2006 and 2007 in the second run, and 18000 for both years in the third run. In both cases, for years beyond FY 2007, open area DAS were allocated to meet the $F = 0.2$ target.

Table 2. Model scenarios

Group	Simulation	OpDAS06	OpDAS07	Op DAS 08-19	GBCARotation	ETopening	HCS	Delmarva
I	NA	24700	24700	24700	A10	Fully Open	Fully open	NoClosure
II	SQ	24700	29700/F=0.2	F=0.2	A10	3yr ramp	Fully open	NoClosure
III	III-15000	15000	26300/F=0.2	F=0.2	Proposed F18	5 yr ramp	Fully open	NoClosure
III	III-20000	20000	25300/F=0.2	F=0.2	Proposed F18	5 yr ramp	Fully open	NoClosure
III	III-25000	24700	25049/F=0.2	F=0.2	Proposed F18	5 yr ramp	Fully open	NoClosure
III	III-30000	30000	24600/F=0.2	F=0.2	Proposed F18	5 yr ramp	Fully open	NoClosure
III	III-20000x2	20000	20000	F=0.2	Proposed F18	5 yr ramp	Fully open	NoClosure
IV	HC1	24700	25307/F=0.2	F=0.2	Proposed F18	5 yr ramp	1yr C. Acc	NoClosure
IV	HC2	20000	25900/F=0.2	F=0.2	Proposed F18	5 yr ramp	2yr C. Acc	NoClosure
V	Delmarva1	20000	28145/F=0.2	F=0.2	Proposed F18	5 yr ramp	2yr C. Acc	Closure
V	Delmarva2	20000	20000	F=0.2	Proposed F18	5 yr ramp	2yr C. Acc	Closure
V	Delmarva3	18000	18000	F=0.2	Proposed F18	5 yr ramp	2yr C. Acc	Closure

Results and Discussion

Performance of the various options can be assessed in the short- (Table 3a) or long-term (Table 3b). Short-term performance measures include biomass at the expiration of Framework 18 (2008), as well as mean annual landings, days-at-sea, and area swept by the fishery during the two years that the framework is in effect. Biomass is highest under the Delmarva3 simulation, which combines a relatively low 18000 aggregate DAS for the open areas each year with the implimentation of the new Delmarva area. The lowest predicted biomass is for simulation III-30000, which has high open area DAS allocations and no new closure or additional protection to the Hudson Canyon Access Area. All scenarios predict record landings in excess of 30000 MT meats during 2006-7. Highest short-term landings are predicted for the III-30000 scenario, which averages nearly 5000 MT/y higher than the No Action alternative. The No Action scenario would product the lowest short-term area swept, due especially to a very small predicted footprint in 2007, when nearly all effort would be concentrated in the Elephant Trunk and groundfish closed areas. Overall mean fishing mortailties during 2006-7 are projected in all alternatives to be at or below the F = 0.2 target. However, this low F is in part due to low fishing mortalities in the groundfish and Elephant Trunk closed areas, which contain a majority of the scallop biomass. For this reason, it is important to examine fishing mortalities in open areas. Georges Bank open area fishing mortality rates are projected to be somewhat higher than optimal under all alternatives during the 2006-2008 period when Framework 18 would be in effect. These fishing mortalities are the highest in the alternatives where more days are allocated to the open areas, and when more areas are taken out of the open areas (e.g., the Delmarva 1 scenario).

Because the model simulations are similar in many respects (e.g., similar groundfish closed area and Elephant Trunk access and long-term open area policies), it is to be expected that there will be only modest differences in the long-term results. The No Action alternative has the highest predicted long-term biomass and lowest long-term area swept because open area effort is more limited long-term than other scenarios. On the other hand, this alternative would produce an average of about 2000 MT/y less landings than any other alternative. Long-term results for all the other alternatives are similar because the same policy for open area allocations is used beyond the expiration of Framework 18 in 2008. Long-term landings are the highest for the Delmarva 3 alternative; this scenario also has one of the lowest mean area swept. The benefits of the Delmarva closure are underestimated in these simulations because they do not take into account the large year class observed during the 2005 survey.

Table 3a – Short Term Summary (2006-7 means except for biomass)

Group	Simulation	Bms08	Landings	Mean DAS	Area Swpt	Overall F	GB Op F
I	NA	10860	32109	31193	3049	0.15	0.28
II	SQ	10684	33874	33653	3739	0.16	0.37
III	III-15000	10829	33355	33671	4193	0.16	0.44
III	III-20000	10669	34551	35660	4846	0.17	0.50
III	III-25000	10506	35775	37887	5627	0.18	0.56
III	III-30000	10347	36927	40340	6568	0.19	0.62
III	III-20000x2	10764	33693	34615	4671	0.16	0.50
IV	HC1	10733	36099	37391	5163	0.17	0.52
IV	HC2	10839	36044	38154	5737	0.17	0.60
V	Delmarva1	10824	36254	39262	6383	0.17	0.67
V	Delmarva2	11077	33932	35014	4880	0.16	0.54
V	Delmarva3	11218	32712	33038	4227	0.15	0.48

Table 3b – Long Term Summary (2006-2020 means)

Group	Simulation	Bms	Landings	LandStdev	Area Swpt	DAS	Overall F
I	NA	10929	33499	2562	2170	30564	0.16
II	SQ	9622	35515	3970	3114	33842	0.20
III	III-15000	9651	35448	3903	3255	33915	0.19
III	III-20000	9583	35392	2994	3344	34029	0.20
III	III-25000	9529	35325	2392	3438	34143	0.20
III	III-30000	9471	35256	2169	3558	34302	0.20
III	III-20000x2	9620	35392	3009	3357	34017	0.19
IV	HC1	9616	35669	2808	3420	34353	0.20
IV	HC2	9668	35817	2994	3400	34449	0.20
V	Delmarva1	9654	35816	3054	3522	34629	0.20
V	Delmarva2	9733	35889	3242	3333	34360	0.19
V	Delmarva3	9805	35911	3513	3233	34204	0.19

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