APPENDIX C3: Maturation-Natural Mortality Model

See Hendrickson and Hart (*2006*).

APPENDIX C4: Per-recruit Models

See Hendrickson and Hart (*2006*).

APPENDIX C5: In-season Assessment Model

In-season assessment model formulation and input data

An in-season stock assessment model that was reviewed at SARC 37 was deemed preliminary and subject to further testing. Additional testing of a revised version of the SARC 37 model was conducted during the current assessment using input data for 2003 and 2004 in addition to output data from simulation analyses. The model revision involved a change to the objective function as described below.

The model was designed to estimate weekly stock size and fishing mortality rates of the *Illex* population (in numbers) on the U.S. shelf according to the equation:

$$N_{t+1} = N_t \exp(-Z) + r_t \exp(-M_{NS}),$$

where N_t is the population numbers in week t, Z is total mortality, r_t is recruitment to the exploitable size classes in week t, and M_{NS} is natural mortality due to causes other than spawning (e.g., predation). The predicted catch $\hat{C}_t$ (in numbers) in week t was calculated using the catch equation:

$$\hat{C}_{t+1} = N_t F_t \,[1\text{-}\exp(-Z)]/Z$$

The weekly fishing mortality rate, F_t, was calculated as:

$$F_t = qS_tE_t$$

where S_t represents the proportion of N_t that is selected by the fishery, E_t is the estimated effort in week t, and q is a constant. Weekly effort (days fished) was computed as the sum of the product of the average tow duration and the number of tows conducted per trip based on data reported by fishermen in the Vessel Trip Report database. Effort was assumed to be proportional to fishing mortality and was standardized according to the methods described in the above section on fishery LPUE. The aggregated length composition from the landings was used in the calculations presented above.

Individual squid lengths were used for the following purposes:

(a) to calculate the selectivity function S_t (Fig. C5.1) via the equation:

$$S_t = \frac{\sum_L s_L n_{L,t}}{\sum_L n_{L,t}}$$

where s_L is the estimated selectivity of the length group L, and $n_{L,t}$ is the number of squid of length group L in week t;

(b) to estimate recruitment, which was done by applying the May 2000 growth rate for combined sexes (Hendrickson 2004) to the numbers of 13-cm squid observed in the landings (the smallest size retained by the fishery) to estimate one week of growth for these individuals. Thereafter, these lengths were divided by the proportion selected by the fishing gear.

(c) and to estimate natural mortality, where the number, $n_{a,t}$, at each age group a and week t was back-calculated from the length composition using the May 2000 growth rate for combined sexes (Hendrickson 2004). Total natural mortality, m_a (both spawning and non-spawning mortality), for each age group (in weeks) was estimated from the maturation-natural mortality model. Total natural mortality was computed as:

$$M_t = \frac{\sum_a m_a n_{a,t}}{\sum_a n_{a,t}}$$

The Gompertz growth curve used in the calculation of equations (b) and (c) above was computed from data collected during a pre-fishery *Illex* survey conducted in May 2000. However, since *Illex* grow larger as the season progresses, the asymptotic size of the May growth curve was exceeded. Nearly all of the squid caught during the last few weeks of the season consisted of lengths that exceeded the estimated maximum length observed in May. In order to address the seasonal growth issue, the maximum (asymptotic) mantle length, *a*, from the May growth curve was adjusted upward each week and estimated as the 95th percentile of the length-frequency distribution of the weekly landings.

The model estimates the initial abundance, N_0, and total fishing mortality, F_{TOT}. F_{TOT} is the sum of the weekly fishing mortality rates of fully-recruited squid for the entire fishing season and was computed as:

$$F_{TOT} = \sum_t qE_t$$

The SARC 37 version of the model estimated the values of these two quantities by minimizing a chi-square statistic:

$$\chi^2 = \sum_t (C_t - \hat{C}_t)^2 / \hat{C}_t$$

subject to the constraint

$$\sum_t C_t = \sum_t \hat{C}_t$$

where C_t is the observed catch in week t.

The revised version of the model allows for the possibility of fitting one of the maturity ogive parameters, α, together with F_{TOT} and N_0. Because there may be prior information regarding these parameters (in particular, α), and because there may be insufficient information to freely fit all three parameters simultaneously, penalty terms were added to allow for deviations from the originally estimated values, so that the new objective function is:

$$\sum_t (C_t - \hat{C}_t)^2 / \hat{C}_t + k_1(N_0 - \hat{N}_0)^2 + k_2(F_0 - \hat{F}_0)^2 + k_3(\alpha - \hat{\alpha})^2 + k_4[\sum_t C_t - \sum_t \hat{C}_t]^2$$

where N_0, F_0, and α are the prior estimates of these parameters, with posterior estimates denoted by circumflexes, and the k_i terms are weightings reflective of the confidence in these values.

In-season model results

Model runs using the 2003 data indicated that the results were sensitive to varying the initial guesses of N_0 and F_{TOT}. The results also indicated that a broad range of N_0 and F_{TOT} values were plausible because the χ^2 statistic was relatively flat over large portions of parameter space. Thus, there is considerable model uncertainty regarding the exact values of these parameters. The model fits were poor for both 2003 and 2004 and are not presented herein.

Simulation model formulation and input data

A simulation model was developed to output simulated data sets to test and calibrate the in-season assessment model. The simulation model works similarly to the per-recruit model that takes into account maturity and spawning mortality, but the simulation model also includes a term for recruitment and is a discrete (weekly) model structured by age and maturity status.

The dynamics of non-mature squid [$N_t(a)$] and mature squid [$S_t(a)$] at week t and age a (in weeks) is (excluding the plus age group):

$$N_{t+1}(a+1) = N_t(a)\exp(-M_{ns}-F_t(a)-R(a)) + r_t$$

$$S_{t+1}(a+1) = S_t(a)\exp(-M_{ns}-M_{sp}-F_t(a))$$
$$+ N_t(a)R(a)[(1-\exp(-M_{ns}-F_n-R(a)))/(M_{ns}+F+R(a))][(1-\exp(-M_{ns} - M_{sp}))/(M_{sp}+M_{ns})]$$

where r_t is recruitment in week t, F_t(a) is fishing mortality in week t on the age a squid, and M_{ns} and M_{sp} are the non-spawning and spawning natural mortality rates, and R is the maturation rate. For the plus group (age a_p),

$$N_{t+1}(a_p) = N_t(a_{p-1}) \exp(-M_{ns}-F_t(a_{p-1})-R(a_{p-1}))+ N_t(a_p)\exp(-M_{ns}-F_t(a_p)-R(a_p)) + r_t$$

$$S_{t+1}(a_p) = S_t(a_p)\exp(-M_{ns}-M_{sp}-F_t(a_p) + S_t(a_{p-1})\exp(-M_{ns}-M_{sp}-F_t(\mathrm{a}_{p-1})$$
$$+ N_t(a_p)R(a_p)[(1-\exp(-M_{ns}-F_t(a_p)-R(a_p))/(M_{ns}+F(a_p)+R(a_p))][(1-\exp(-M_{ns} - M_{sp}))/(M_{sp}+M_{ns})] +$$
$$N_t(a_{p-1})R(a_{p-1})[(1-\exp(-M_{ns}- F_t(a_{p-1})-R(a_{p-1}))/(M_{ns}+F(\mathrm{a}_{p-1})+R(\mathrm{a}_{p-1}))][(1-\exp(-M_{ns} - M_{sp})/(M_{sp}+M_{ns})]$$

Non-spawning and spawning natural mortality parameters were taken from the maturity-natural mortality model (Hendrickson and Hart, 2006) and set to $M_{ns} = 0.06$ and $M_{sp} = 0.55$ for all model runs. Fishing mortality varies by age and the same selectivity-at-age ogive used in the per-recruit models was applied in the simulation models. Landings (in numbers) C_t were calculated from the catch equation:

$$C_t\,(a) = \Sigma_a \,\{N_t(a)F_t(a)[1-\exp(-M_{ns}-F_t(a)]/\,[M_{ns}+F_t(a)] +$$
$$S_t(a)F_t(a)[1-\exp(-M_{ns}- M_{sp}\, -\underline{F}_t(a))]/\,[M_{ns} + M_{sp}+F_t(a)]\}$$

Catches in numbers were converted to weights using a weight-at-age relationship, for combined sexes, from the May 2000 *Illex* survey (Hendrickson 2004):

$$W(a) = \varepsilon a^{\phi},\ 1.12\mathrm{x}10^{-6},\ \phi = 3.6.$$

Simulation model runs were conducted for a fishing season of 19 weeks at various levels of constant fishing mortality, various trends in fishing mortality (increasing, decreasing, and increasing then decreasing), various levels of recruitment, and with observation noise for all variables set to 10%. With the exception of model runs 10 and 11, recruitment was assumed to be constant except for a pulse of recruits which assumed to be twice as large in weeks 7-9 as during other weeks. The outputs from the simulation model were input into the in-season assessment model to evaluate the ability of the in-season model to recover the fishing mortality and N_0 estimates from the simulations.

Simulation model results

In most cases, the in-season model was able to find excellent fits to the data. As often is the case with forward-projecting models, the estimated values of F_{TOT} and N_0 were often estimated with some error, though the product of these two quantities was typically estimated close to the simulated values (Table C5.1). Allowing the in-season model to estimate the maturity parameter with a Bayesian penalty function did not consistently improve the estimates, possibly because the model was already achieving a good fit to the simulated data. Adding noise to the simulated data only mildly worsened the ability of the in-season model to recover the original parameter estimates.

It can be concluded that if the biological and fishing processes are being modeled correctly, the in-season model can usually estimate total fishing mortality and initial abundance to within 50%, and the product of these two quantities is more accurately estimated than either of them individually.

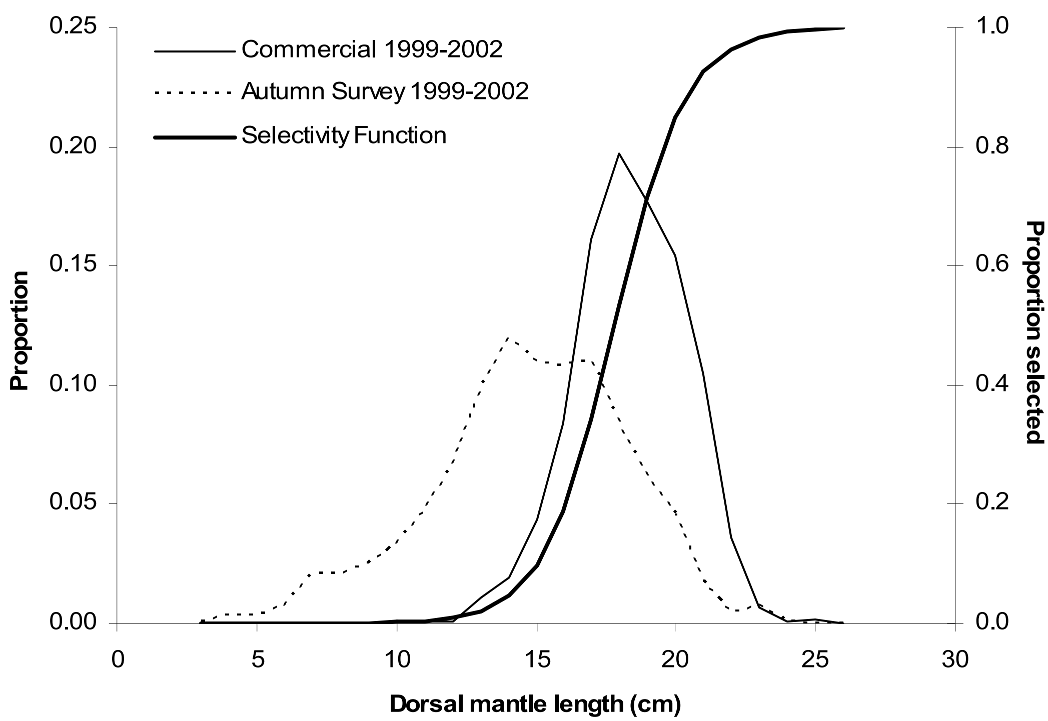

Figure C5.1. Composite length compositions, for 1999-2002, of *Illex illecebrosus* from the NEFSC autumn bottom trawl surveys (strata 1-12 and 61-76) and directed fishery landings.

Length samples from the two sources were subset to include data from similar time periods and geographic areas during each year to derive the selectivity curve shown.

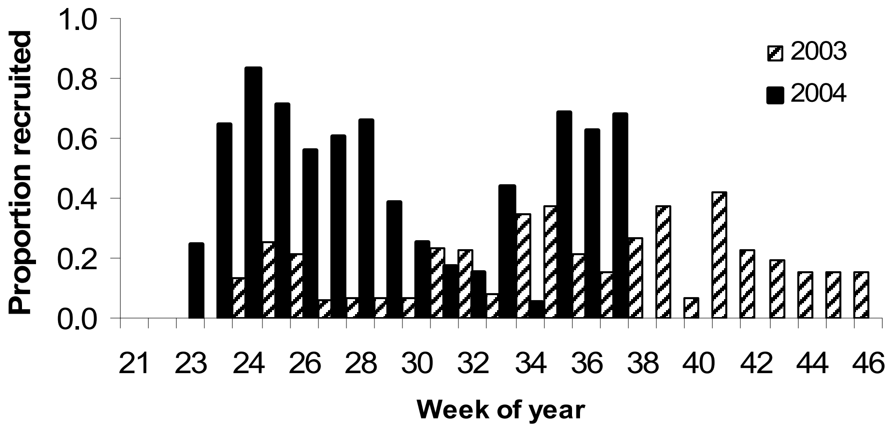

Figure C5.2. Proportion of *Illex illecebrosus* recruitment, by week, during 2003 and 2004.

Table C5.1. Results of simulation model runs under various input scenarios that included maturity ogive parameters of α = -7.93 and β = 0.0435 (Hendrickson, 2004). F_{TOT} is the fishing mortality rate for fully-recruited squid over the entire fishing season.

Model Run	Scenario	Alpha Maturity Parameter	Penalty	F_{TOT}	Estimated F_{TOT}	Estimated N_0	Estimated χ^2	% Error F	% Error N_0	% Error $F*N_0$
1	Constant F	Baseline		0.95	2.53	95,428	45	166.3	61.8	1.7
	N0 = 250 mill.	alpha = -7.95	10	0.95	2.58	93,510	45	171.6	62.6	1.6
2	Constant F	Baseline		1.9	2.49	192,393	89	31.1	23.0	0.9
	N0 = 250 mill.	alpha = -8.056	10	1.9	2.88	166,668	88	51.6	33.3	1.1
3	Constant F	Baseline		3.8	4.33	219,018	178	13.9	12.4	0.2
	N0 = 250 mill.	alpha = -8.03	10	3.8	4.62	205,320	178	21.6	17.9	0.1
4	Constant F	Baseline		5.7	5.52	254,412	262	3.2	1.8	1.4
	N0 = 250 mill.	alpha = -8.09	10	5.7	5.97	235,641	261	4.7	5.7	1.3
5	Constant F	Baseline		11.4	7.92	290,473	402	30.5	16.2	19.3
	N0 = 250 mill.	alpha = -8.67	10	11.4	8.67	256,606	399	23.9	2.6	21.9
6	Constant F	Baseline-Run1		3.8	5.54	166,142	70512	45.8	33.5	3.1
	with noise	Baseline-Run2		3.8	4.59	279,201	121739	20.8	11.7	34.9
	N0 = 250 mill.	Baseline-Run3		3.8	2.71	346,602	63375	28.7	38.6	1.1
		Mean		3.8	4.28	263,982	85209	31.8	28.0	13.0
7	Two-way ramp	Baseline		5.7	5.40	244,486	649	5.3	2.2	7.4
	N0 = 250 mill.	alpha = -6.99	10	5.7	2.22	685,485	357	61.1	174.2	6.8
8	Ramp up	Baseline		5.7	5.17	213,293	502	9.3	14.7	22.6
	N0 = 250 mill.	alpha = -7.25	10	5.7	2.90	451,533	164	49.1	80.6	8.1
9	Ramp down	Baseline		5.7	5.43	285,165	294	4.7	14.1	8.7
	N0 = 250 mill.	alpha = -7.84	10	5.7	5.17	297,526	290	9.3	19.0	7.9
10	Constant F	Baseline		5.7	7.05	190,362	347	23.7	23.9	5.8
	Low recruits	alpha = -8.89	10	5.7	8.99	150,206	304	57.7	39.9	5.2
11	Constant F	Baseline		5.7	4.55	448,721	3093	20.2	79.5	43.3
	High recruits	alpha = -10.55	10	5.7	7.86	252,476	2607	37.9	1.0	39.3