Appendix A. A preliminary in-season model for estimating stock size and fishing mortality rates of *Illex illecebrosus* in U.S. waters.

A new model was designed to estimate stock size and fishing mortality rates of the *Illex* population (in numbers), in U.S. waters, 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 C_t (in numbers) in week t was calculated using the catch equation:

$$C_{t+1} = N_t F_t \,[1-\exp(-Z)]/Z$$

The fishing mortality rate, F_t, was calculated by:

$$F_t = qS_tE_t$$

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. The aggregated length composition of all landed squid was used in the calculations given above, but the individual squid lengths (fishery lengths divided by estimated selectivity, Figure A1) were used for the following purposes:

(a) to calculate the selectivity function S_t 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 utilizing the May 2000 survey growth rate (Hendrickson, *In Review*) to estimate one week of growth for a 13-cm squid (the smallest size retained by the fishery) and assuming that recruits consisted of squid that were of lengths between 13 cm and one week of additional growth during the following week;

(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 estimated growth curve. Total natural mortality, m_a (both spawning and non-spawning mortality), for each age group (in weeks) was estimated from the maturation model described previously. 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 that was derived from the May 2000 *Illex* survey (Hendrickson *In Review*) was used in the calculation of equations (b) and (c) above. 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) length, a, from the May growth curve was adjusted upward and estimated as the 95th percentile of the length-frequency distribution of the landings.

The model estimates the initial abundance N_0, and total fishing mortality as:

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

The model estimates the values of these two quantities by minimizing a chi-square statistic:

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

subject to the constraint

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

where $\mathbf{C}_t$ is the observed catch in week t.

<u>Results</u>
When both N_0 and F_{TOT} were allowed to vary in the optimization routine, the best fit was found at N_0 = 390 million squid and F_{TOT} = 1.1. Predicted landings fit well with the exception of week 28 (Figure A2). Examination of fishing records for that week indicated a spatial shift in effort to the southernmost fishing grounds that resulted in increased landings of larger squid (Figure A3). The spike observed in the predicted landings during week 28 was attributable to an increase in the percentage of squid that were vulnerable to the fishery during that week.

A sensitivity analysis was performed by fixing N_0 at various values and fitting just F_{TOT} (Table A1). The analysis 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.

To assess whether the model could be used to determine whether overfishing was occurring in 1999, total fishing mortality was fixed at the most stringent overfishing threshold, $F_{50\%}$ = 0.21 per week, and an M_{NS} value of 0.01 was assumed. During 1999, the duration of the fishing season was 18 weeks. Therefore, in order for overfishing to have occurred, F_{TOT} would have to have exceeded 3.8 ($F_{50\%}$ = 0.21*18). When F_{TOT} was fixed at 3.8, model fit was poor and the χ^2 statistic was more than 50% above its overall minimal value (Figure A2B, Table A1). If the criterion for overfishing is taken on an annual basis, so that the reference point is $F_{50\%}$ = 0.21*52 = 10.9, then the χ^2 statistic at F = 10.9 is several times its overall minimum. Thus, overfishing was not likely to have occurred in 1999, because the model fit for the run that assumed a fishing mortality rate equal to the overfishing threshold was implausible.

Model Uncertainties

The model results should be examined with caution because rigorous testing of the model, with multiple years of data and under varying model assumptions, has not been conducted. A sensitivity analysis for various values of initial stock size indicated that a broad range of N_0 and F_{TOT} values were plausible A major model uncertainty is the use of a May growth curve that underestimates growth later in the fishing season. Despite scaling up the asymptotic length by using a percentile of the observed length from the fishery, empirical length-at-age data must be collected and analyzed to determine seasonal changes in growth rate. As a result of the uncertainties previously described, the Subcommittee recommended that the model results should only be considered to determine whether overfishing was occurring during 1999.

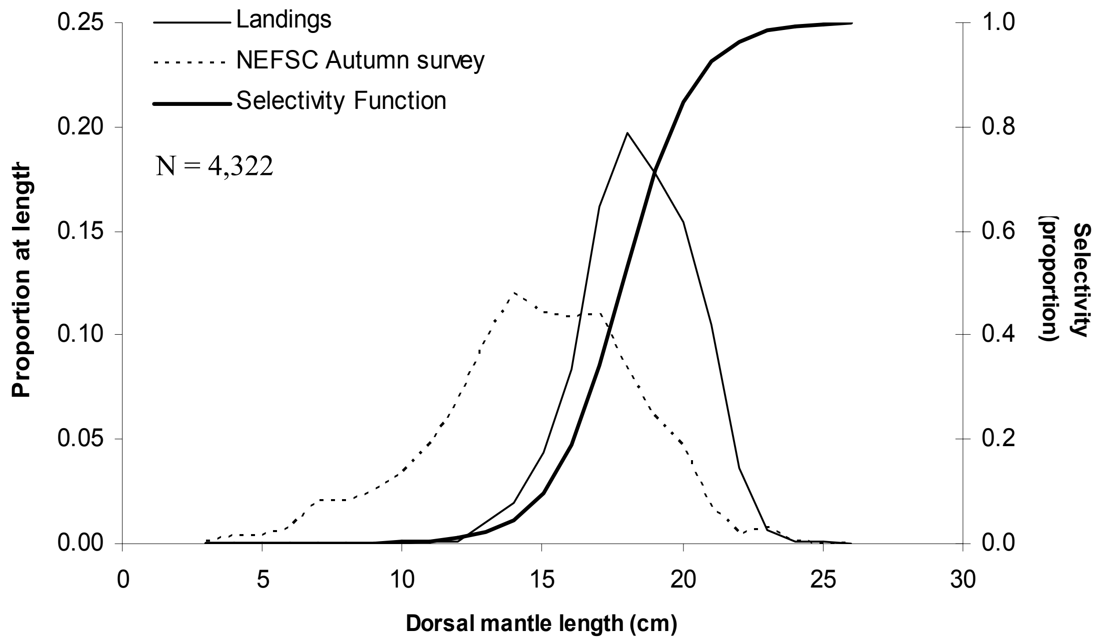
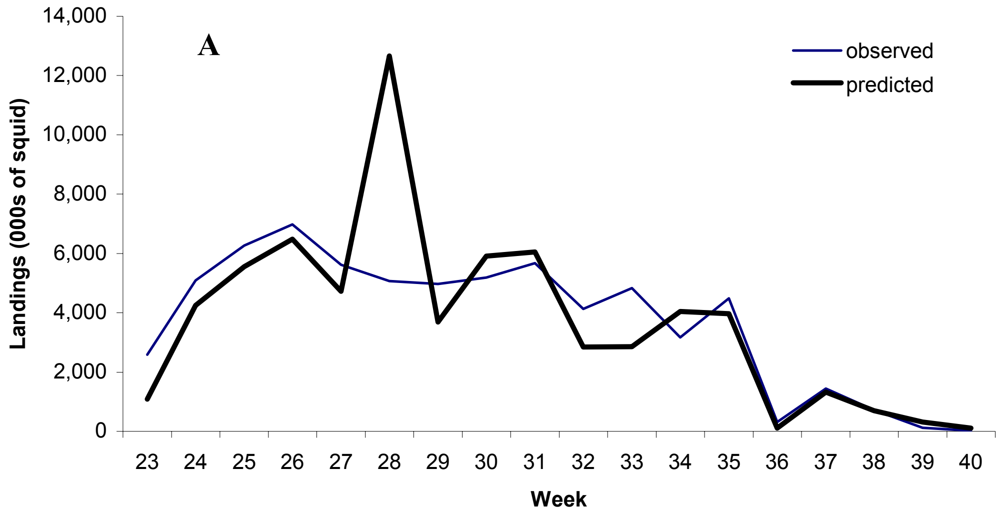


Figure A1. Composite length compositions, for 1999-2002, of *Illex* catches from the NEFSC autumn bottom trawl surveys and *Illex* landings from the directed fishery, during the same range of weeks, and the predicted selectivity curve.



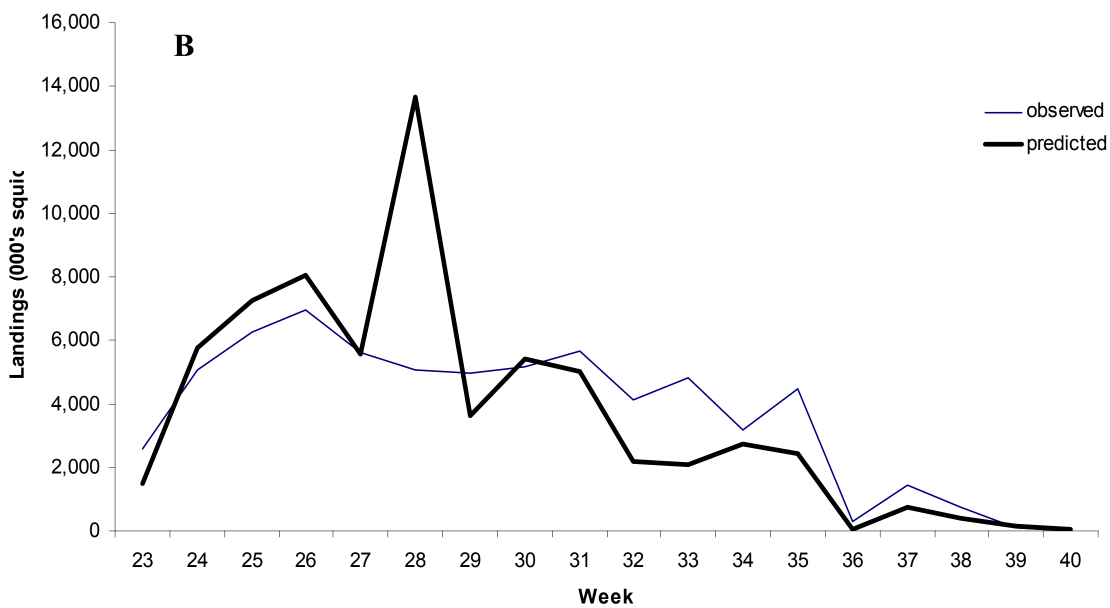


Figure A2 . Observed and predicted weekly landings of *Illex illecebrosus* (000s of squid) during 1999, based on a preliminary stock size estimation model, for (A) the best model fit and (B) and assuming a total fishing mortality rate of 3.8 (= $F_{50\%}$) for an 18-week fishery.

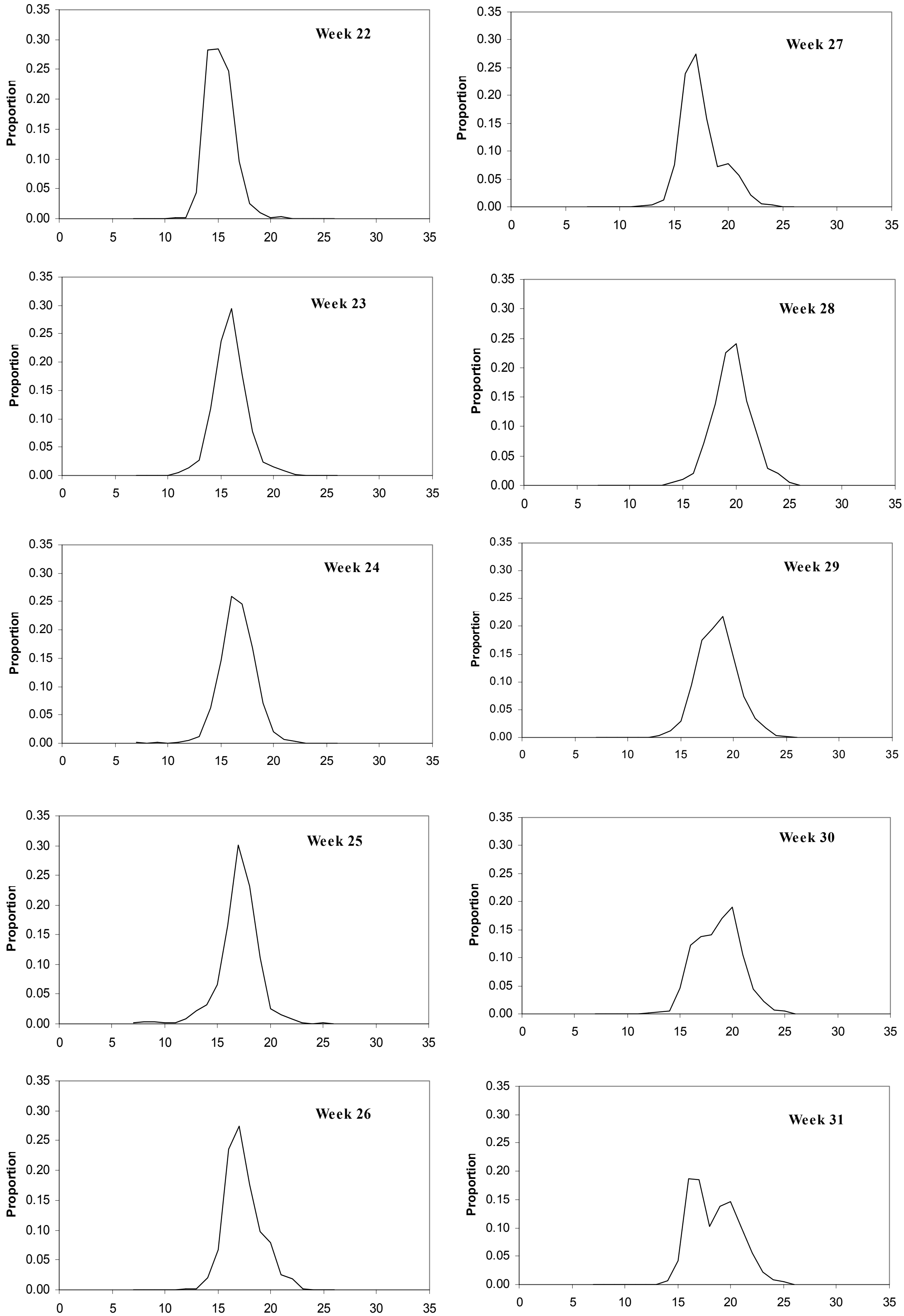


Figure A3. Length composition of *Illex illecebrosus* landings during weeks 22 through 31 of the 1999 fishing season.