

Appendix B1: Invertebrate Subcommittee meetings for the SAW/SARC-51 assessment of *Loligo*.

The Invertebrate Subcommittee met on September 28-29 and on October 18-20 at the Northeast Fisheries Science Center in Woods Hole, MA to work on the SAW/SARC-51 stock assessment for *Loligo pealeii*. Members attended in person and by Webex/conference call. The Subcommittee met again briefly by WebEx/conference call on the morning of October 25 to complete its work. The following persons attended one or more of the meetings.

- Lisa Hendrickson, Northeast Fisheries Science Center (NEFSC), Assessment Lead
- Larry Jacobson, NEFSC, Subcommittee Chair
- Toni Chute, NEFSC, Rapporteur
- Dan Hennen, NEFSC, Rapporteur
- Aja Peters-Mason, NERO (SMB Plan Manager)
- Chris Legault, NEFSC
- DJ Kowalske, NEFSC, Cooperative Research
- Fred Serchuk, NEFSC
- Greg DiDomenico (Industry Advisor)
- Jason Didden (MAFMC, SMB staff person)
- Jason Link, NEFSC
- Jeff Kaelin (Lunds Fisheries, Cape May, NJ)
- Jeff Reichle (Lunds Fisheries, Cape May, NJ)
- Jon Knight (Superior Trawl, Pt. Judith, RI)
- Lars Axelsson (F/V Flicka, Cape May, NJ)
- Mark Terciero, NEFSC
- Paul Rago, NEFSC
- Sam Martin (Atlantic Cape Fisheries, Cape May, NJ)
- Tim Miller, NEFSC
- Vidar Westpestad (Industry consultant)

Appendix B2: Assessment of the effects of solar zenith angle and other environmental factors on the diel catchability of *Loligo* in bottom trawls

Solar zenith at the time and geographic location of each tow was used in place of the more conventional time of day in estimating diel effects on *Loligo* catchability in bottom trawls. Solar zenith is the angle between a line drawn between the center of the sun and the observer and a line drawn directly overhead at the location of the observer (Meeus, 1998). Solar zenith is the primary determinant of the amount of irradiance (watts m⁻²) at the surface of the ocean where the observer is located (Frouin *et al.*, 1989). Solar zenith is more useful than time of day in modeling because irradiance varies by latitude, longitude, Julian date and year (which are all used in calculation of the solar zenith). Although there is a clear general relationship between solar zenith and time of day (Figure 1), tows carried out at the same time but at different geographic locations may have substantially different irradiance levels that might affect survey catchability to different extents.

GAM models were fit to fall and spring survey data from the same strata and years used elsewhere in the assessment, and used to confirm diel catchability patterns as functions of squid size, season and other variable. Based on preliminary analyses, the maximum likelihood GAM models fit using the *R* statistical language were:

$$Y = f[s(L, Z) + s(L, D) + s(T) + region + year] + \varepsilon$$

where Y is the dependent variable for one size group in one tow, $f()$ is the link function (see below), and ε is a statistical error. The continuous variables are L (DML in 1 cm increments), Z (solar zenith at the time and location of tow, degrees), D (tow depth, m), and T (bottom temperature, °C). The categorical predictor variables are region (Gulf of Maine, Georges Bank, Southern New England, Mid-Atlantic Bight, and Chesapeake Bay to Cape Hatteras) and year. One $s(x)$ and two dimensional $s(x,y)$ nonlinear spline functions were used to model the continuous predictor variables. The two dimensional splines allow interaction between size and solar zenith or between size and depth. The degree of nonlinearity in the spline functions were chosen using by minimizing of an AIC-type statistic (Wood, 2006).

Modeling mimicked delta-distribution methods in which the probability of a positive survey tow (catch > 1 squid) was estimated in presence-absence models and the catch in positive tows was estimated separately in catch number models. In presence absence modeling, the dependent variable was $Y=0$ or 1 (if at least one squid was taken in the tow), $f()$ was the logit link function, likelihood was calculated assuming errors were from a binomial distribution, and data for all size groups in each tow were included. In catch numbers models, the dependent variable was the survey catch, $f()$ was the log link function was used, likelihood was calculated assuming that the errors were from a negative binomial distribution with estimated shape and scale parameters, and only data for positive tows and size groups were used. Spring and fall survey data were modeled separately. The linear and nonlinear terms in all of the models were statistically significant.

Predicted values from the models showed clear diel effects on the probability of a positive tow and catches in positive tows. Diel effects were size and season dependent (Figures 2-5).

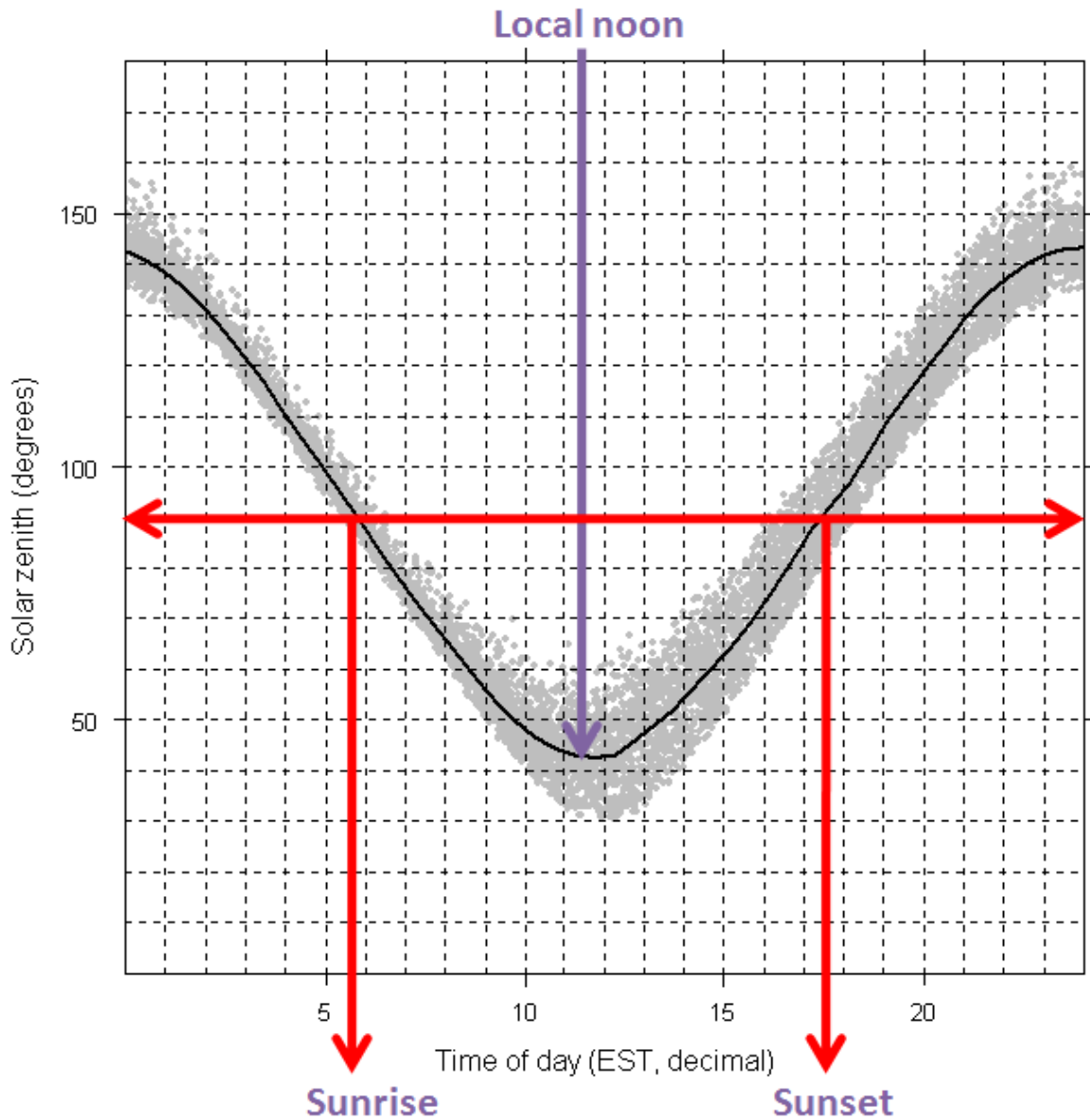
Objective criteria for defining daytime tows

All preliminary choices of solar zenith cutoffs to define daytime tows resulted in higher mean survey abundance and biomass levels and similar or smaller CVs. However, there was uncertainty about whether to include data collected around noon and data collected around dawn/dusk. Criteria for defining daytime tows were therefore defined objectively using performance scores based on an approximate mean squared error (MSE) approach. In particular, if the bias in a measurement is b and the variance of the measurements is σ^2 , then $MSE=b^2+\sigma^2$. We chose criteria with minimum values of the MSE in order to reduce bias (due to night time tows) and variance of mean numbers and weight per tow. This analysis was not based on GAM or any other model results. Rather, annual mean numbers and weight per tow were calculated from survey data for a wide range of possible criteria. Spring and fall surveys were analyzed separately.

The score used to choose solar zenith criteria was:

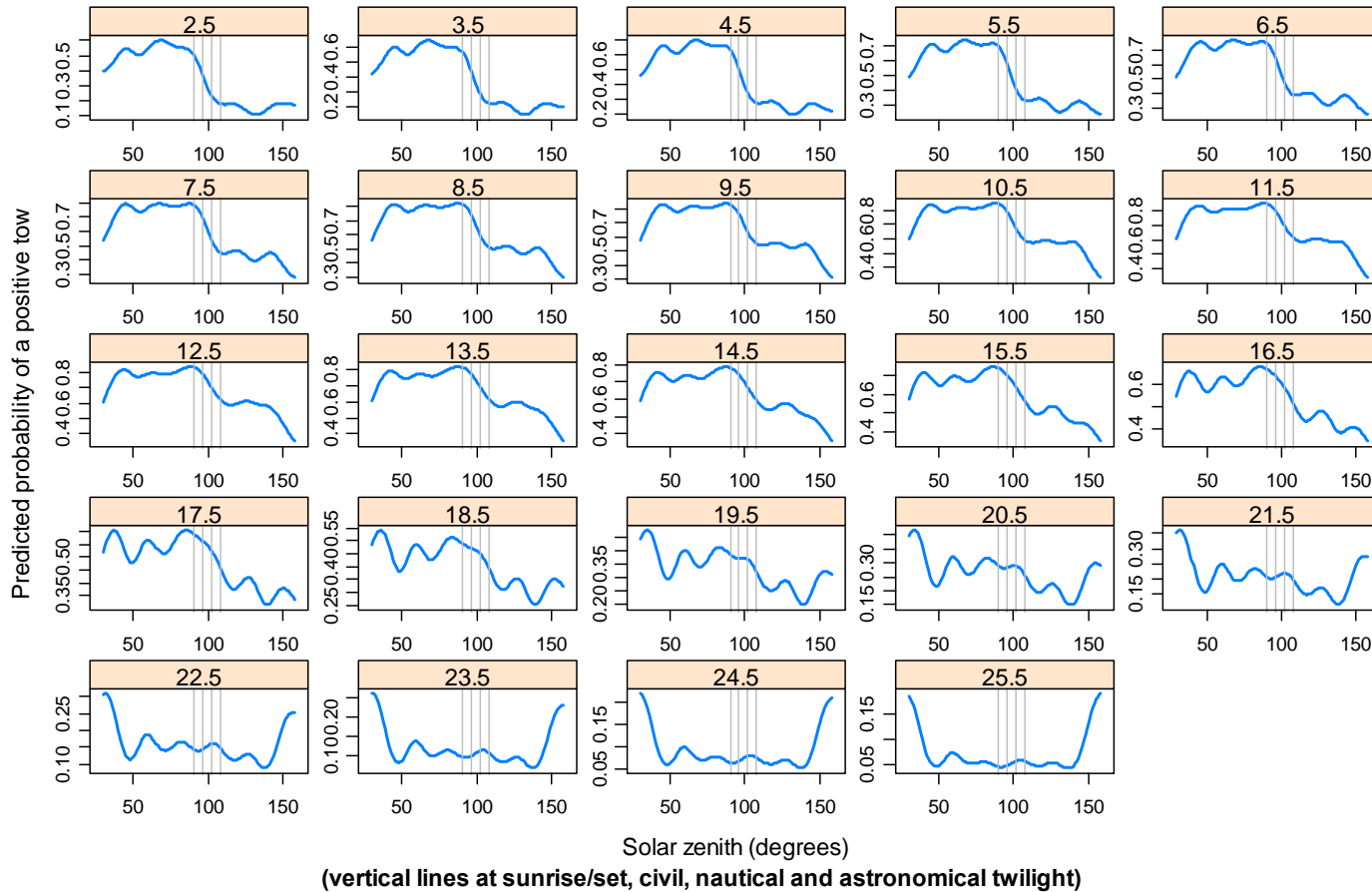
$$X_{\text{test}}^n = [\bar{c}v_{\text{test}} - (\bar{n}_{\text{test}} - \bar{n}_{24})^2] + \left[\frac{\bar{c}v_{\text{test}}}{\bar{c}v_{24}} - \frac{\bar{n}_{\text{test}}}{\bar{n}_{24}} \right]$$

where X_{test}^n was the score for mean numbers per tow and a particular set of minimum and maximum values for solar zenith (Z_1 and Z_2 , one possible set of criteria for defining daytime tows), \bar{n}_{test} and \bar{n}_{24} were the average (over all years) of the annual stratified random mean numbers per tow for the test criteria and using all tows (day and night), $\bar{c}v_{\text{test}}$ and $\bar{c}v_{24}$ were the average (over all years) CVs of the annual stratified mean numbers per tow. The terms $(\bar{n}_{\text{test}} - \bar{n}_{24})$ and $\frac{\bar{c}v_{\text{test}}}{\bar{c}v_{24}}$ are approximate absolute and relative measures of the reduction in bias using the test criteria relative to using all tows. The terms $\bar{c}v_{\text{test}}$ and $\frac{\bar{c}v_{\text{test}}}{\bar{c}v_{24}}$ are approximate absolute and relative measures of variance. A similar score X_{test}^b was calculated for mean weight per tow. The combined score $X_{\text{test}} = X_{\text{test}}^n + X_{\text{test}}^b$ was calculated $Z_1=30$ to 45° and $Z_2=75$ to 90° in steps of one degree. The combined score surfaces were very bumpy with a wide range of criteria giving similar performance but inclusion of nighttime tows resulted in poor performance. The resulting grid of calculated values was smoothed using a two dimensional loess regression surface and contoured for graphical analysis. The “best” choice for the criteria Z_1 and Z_2 was the combination with the lowest combined score. The criteria chosen for the fall survey was $Z_1=43^\circ$ and $Z_2=80^\circ$ (Figure 6). The criteria chosen for the spring survey was $Z_1=29^\circ$ and $Z_2=84^\circ$ (Figure 7). Thus, daytime fall survey data used in this assessment are for tows with solar zenith values of $43-80^\circ$ and daytime spring survey data are for tows with solar zenith values of $29-84^\circ$.



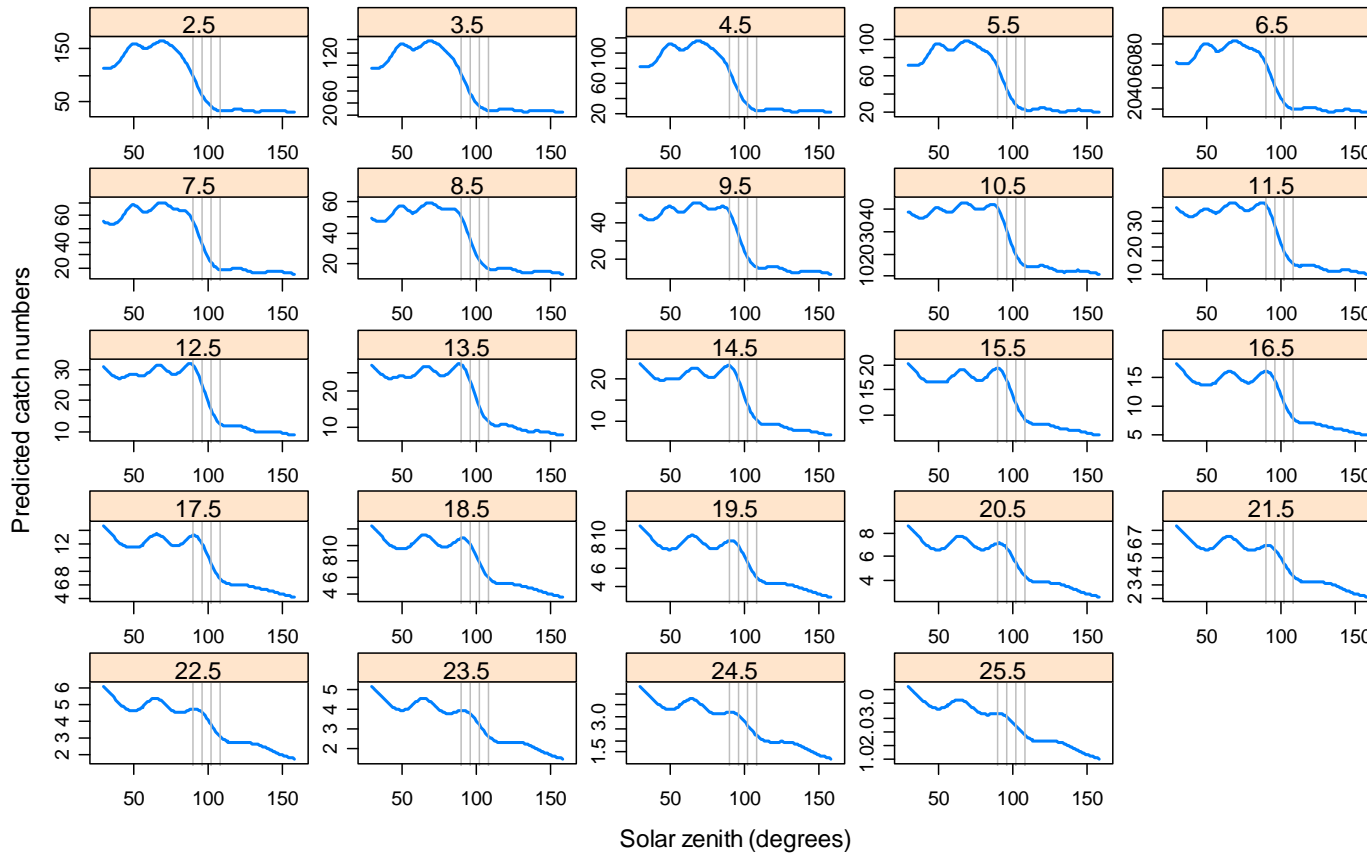
Appendix B2 Figure B1. The relationship between solar zenith and time of day (EST) in fall surveys, 1975-2008. Relationships during the spring survey are similar. The sun rises and sets at a solar zenith of 90.83° when the sun first appears or disappears along the horizon. At local noon, the sun is at its apogee and the solar zenith is at its minimum value.

GAM predicted probability of a positive tow in fall survey (catch~zenith given DML)
posflag ~ s(dml, zensun) + s(dml, avgdepth) + s(bottemp) + georegion + as.factor(est_year)



Appendix B2 Figure2. Predicted probability of a positive tow from a GAM model fit to fall survey data for an arbitrary location and date. The labels at the top of each frame are dorsal mantle length groups in cm (e.g. 19.5 means 19-19.9 cm DML).

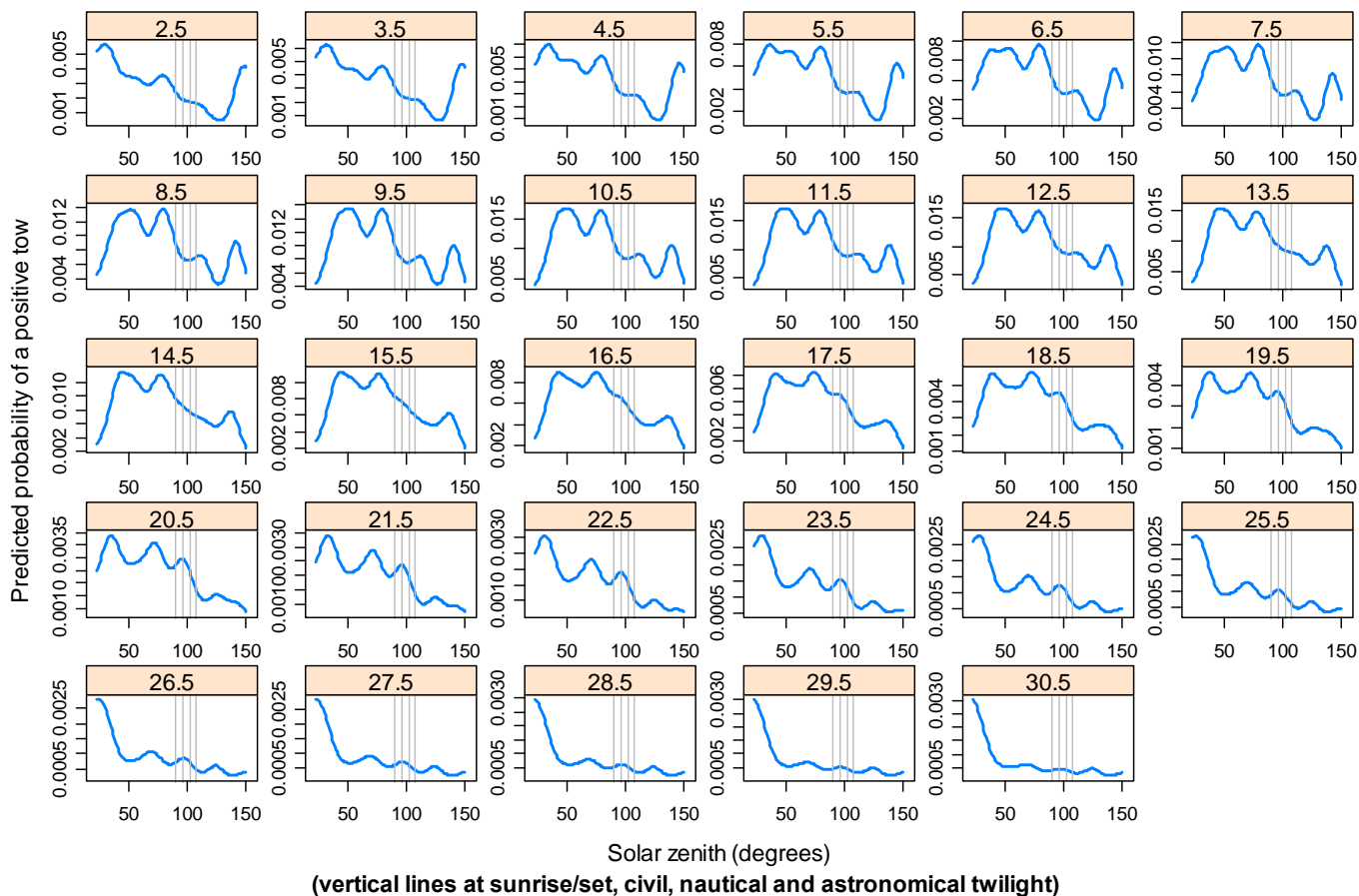
GAM predicted catch numbers in fall survey (catch~zenith given DML)
expnumlen ~ s(dml, zensun) + s(dml, avgdepth) + s(bottemp) + georegion + as.factor(est_year)



(vertical lines at sunrise/set, civil, nautical and astronomical twilight)

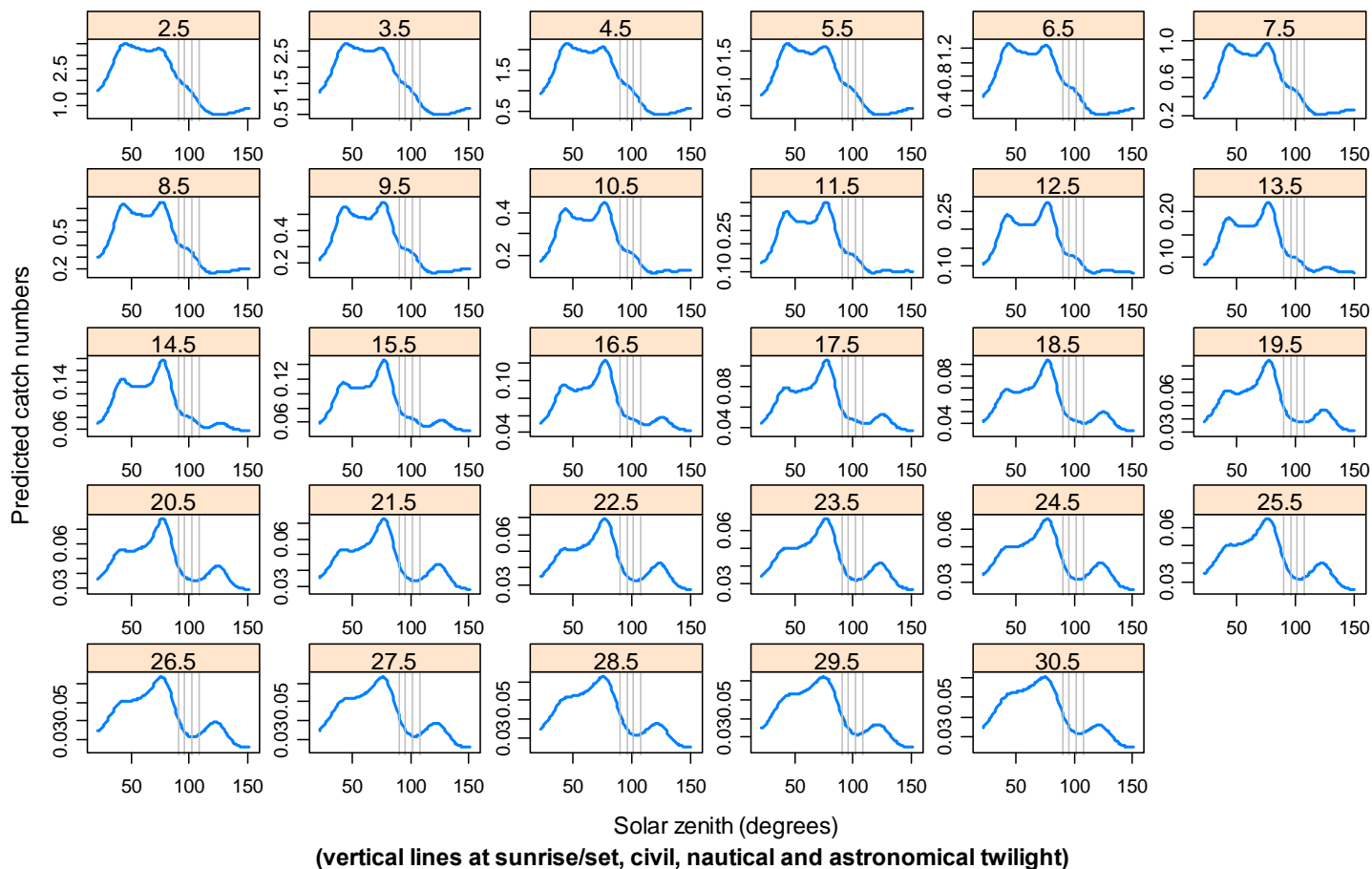
Appendix B2 Figure 3. Predicted catch in positive tows from a GAM model fit to fall survey data for an arbitrary location and date. The labels at the top of each frame are dorsal mantle length groups in cm (e.g. 19.5 means 19-19.9 cm DML).

GAM predicted probability of a positive tow in spring survey (catch~zenith given DML)
posflag ~ s(dml, zensun) + s(dml, avgdepth) + s(bottemp) + georegion + as.factor(est_year)



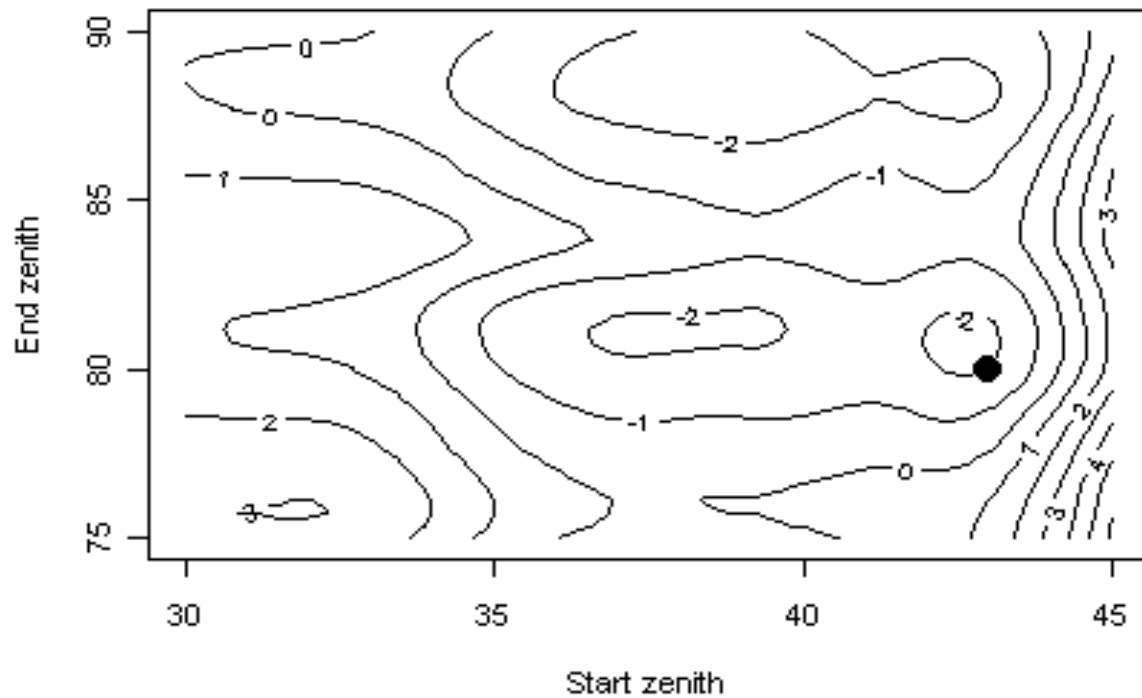
Appendix B2 Figure 4. Predicted probability of a positive tow from a GAM model fit to spring survey data for an arbitrary location and date. The labels at the top of each frame are dorsal mantle length groups in cm (e.g. 19.5 means 19-19.9 cm DML).

GAM predicted catch numbers in spring survey (catch~zenith given DML)
expnumlen ~ s(dml, zensun) + s(dml, avgdepth) + s(bottemp) + georegion + as.factor(est_year)



Appendix B2 Figure 5. Predicted catch in positive tows from a GAM model fit to spring survey data for an arbitrary location and date. The labels at the top of each frame are dorsal mantle length groups in cm (e.g. 19.5 means 19-19.9 cm DML).

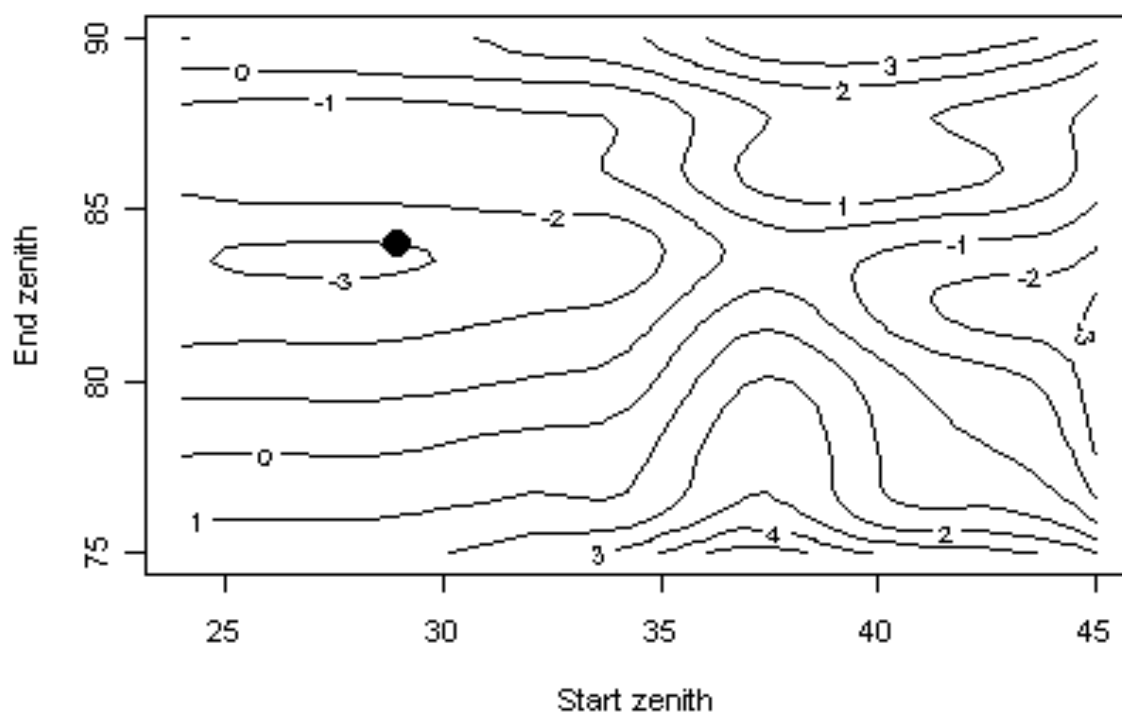
Mixed score for n and wt/tow in fall survey



(Best at 43 - 80 deg., score= -6)

Appendix B2 Figure 6. Contours showing lowess smoothed overall scores for solar zenith criteria used to choose daytime cutoff points for fall survey tows.

Mixed score for n and wt/tow in spring survey



(Best at 29 - 84 deg., score= -7)

Appendix B2 Figure 7. Contours showing loess smoothed overall scores for solar zenith criteria used to choose daytime cutoff points for spring survey tows.

Appendix B3: Calculation of SRV *H. B. Bigelow* calibration coefficients for *Loligo pealeii*

In 2009 the *FRV Henry B. Bigelow* replaced the *R/V Albatross IV* as the primary vessel for conducting spring and fall annual bottom trawl surveys for the Northeast Fisheries Science Center (NEFSC). There are many differences in the vessel operation, gear, and towing procedures between the new and old research platforms (NEFSC Vessel Calibration Working Group 2007). To merge information collected in 2009 onward with that collected previously, we need to be able to transform indices (perhaps at size and age) of abundance from the *FRV Henry B. Bigelow* into those that would have been observed had the *R/V Albatross IV* still been in service. The general method for merging information from these two time series is to calibrate the new information to that of the old. Specifically we need to predict the relative abundance that would have been observed by the *Albatross IV* (\hat{R}_A) using the relative abundance from the *Henry B. Bigelow* (R_B) and a “calibration factor” (ρ),

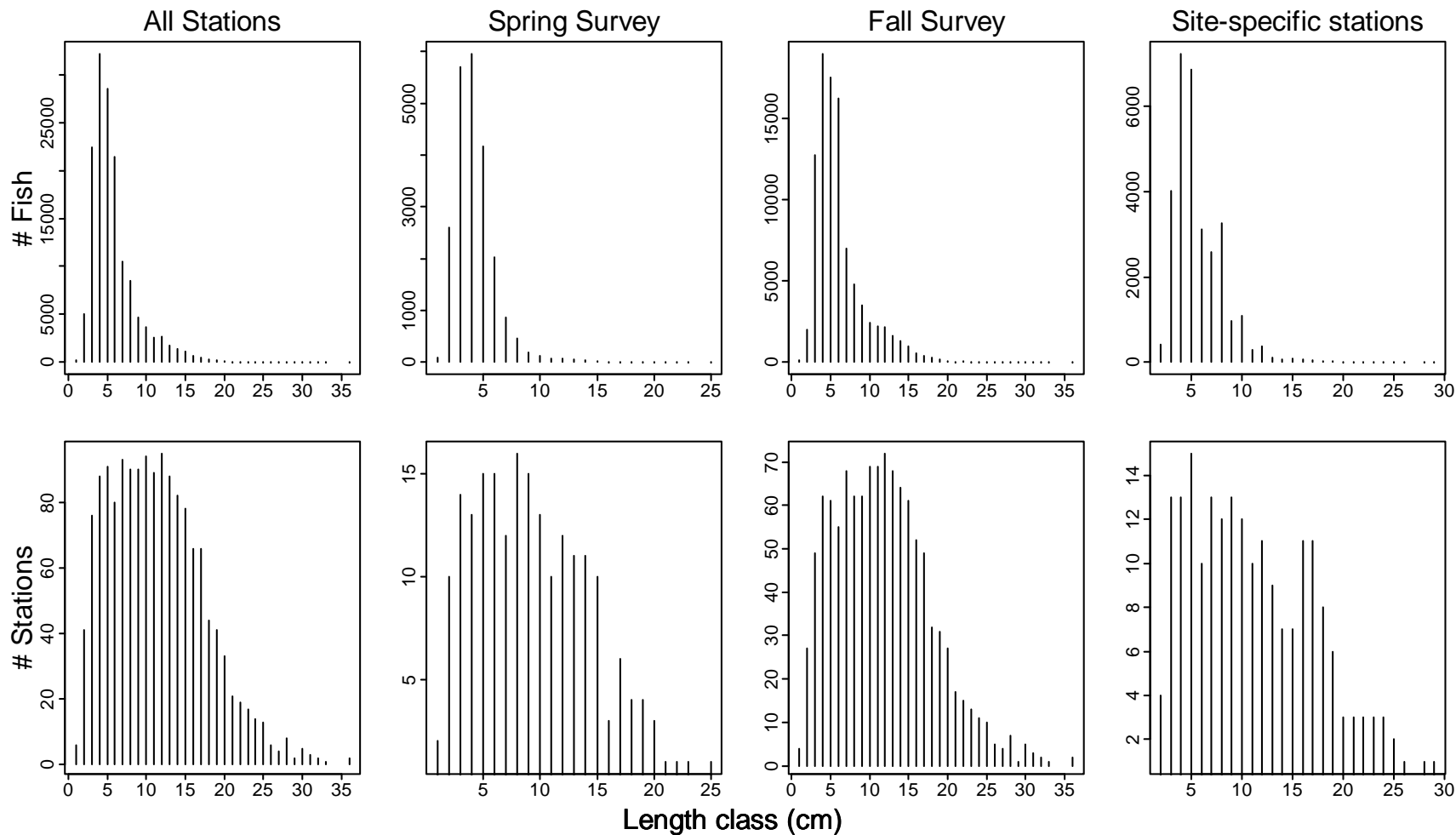
$$\hat{R}_A = \rho R_B. \quad (2)$$

To provide information from which to estimate calibration factors for a broad range of species, 636 paired tows were conducted with the two vessels during 2008. Paired tows occurred at many stations in both the spring and fall surveys. Paired tows were also conducted during the summer and fall at non-random stations to improve the number of non-zero observations for some species. Protocols for the paired tows are described in NEFSC Vessel Calibration Working Group (2007).

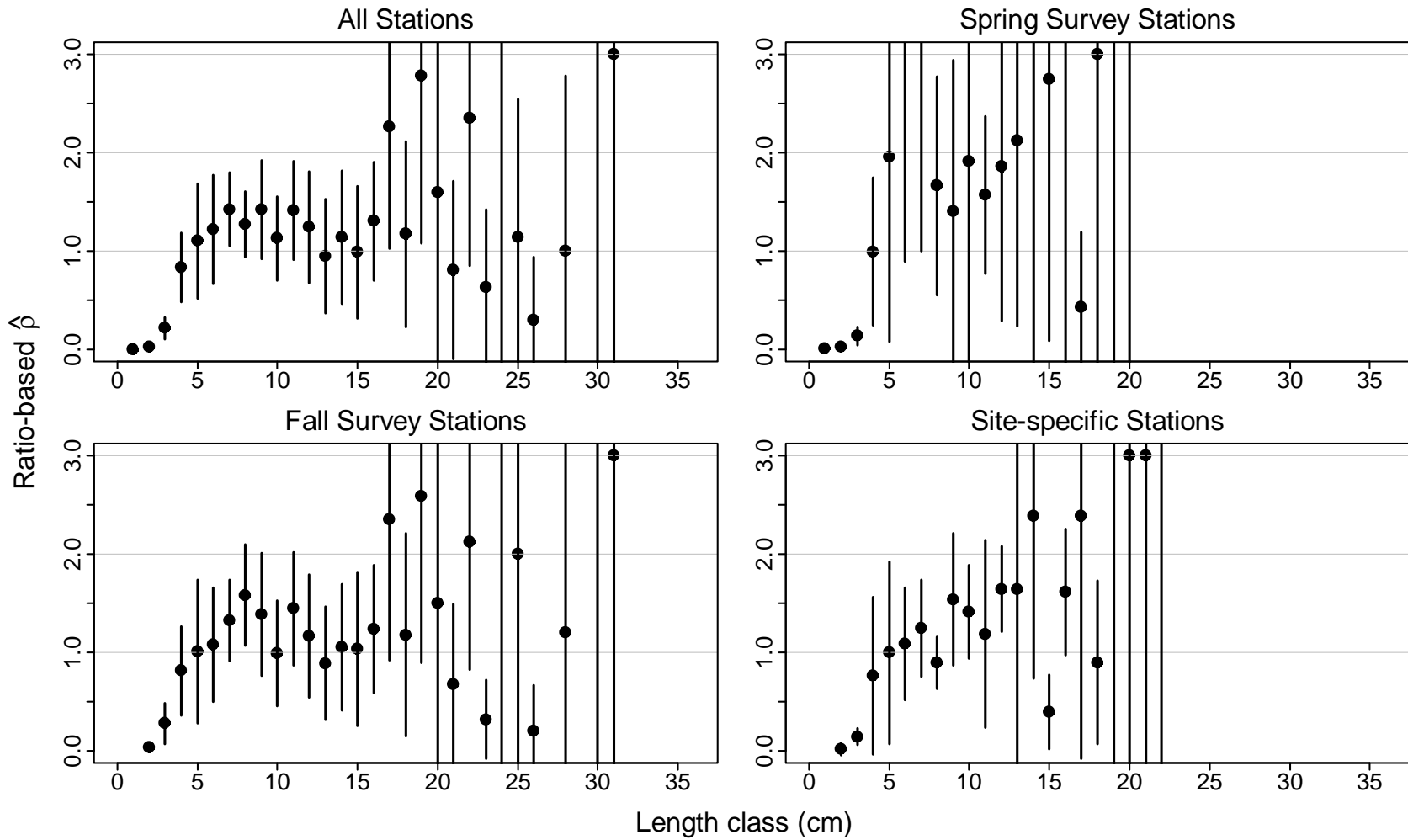
The methodology for estimating the calibration factors was proposed by the NEFSC and reviewed by a panel of independent scientists in 2009. The reviewers considered calibration factors that could potentially be specific to either the spring or fall survey (Miller *et al.* 2010). They recommended using a calibration factor estimator based on a beta-binomial model for the data collected at each station for most species, but also recommended using a ratio-type estimator under certain circumstances and not attempting to estimate calibration factors for species that were not well sampled.

Since the review, it has become apparent that accounting for size of individuals can be necessary for many species. When there are different selectivity patterns for the two vessels, the fraction of available fish of a given size taken by the two gears is different. Therefore, the ratio of the mean catches by the two vessels will change with size. Under these circumstances, the estimated calibration factor that ignores size reflects an average ratio weighted across sizes where the weights of each size class are at least in part related to the number of individuals at that size and the number of stations where individuals at that size were caught. Applying calibration factors that ignore size effects to surveys conducted in subsequent years when the size composition is unchanged should not produce biased predictions (eq. 1). However, when the size composition changes, the frequency of individuals and number of stations where individuals are observed at each size changes and the implicit weighting across size classes used to obtain the estimated calibration factor will not apply to the new data. Consequently, the predicted numbers per tow that would have been caught by the *Albatross IV* will be biased.

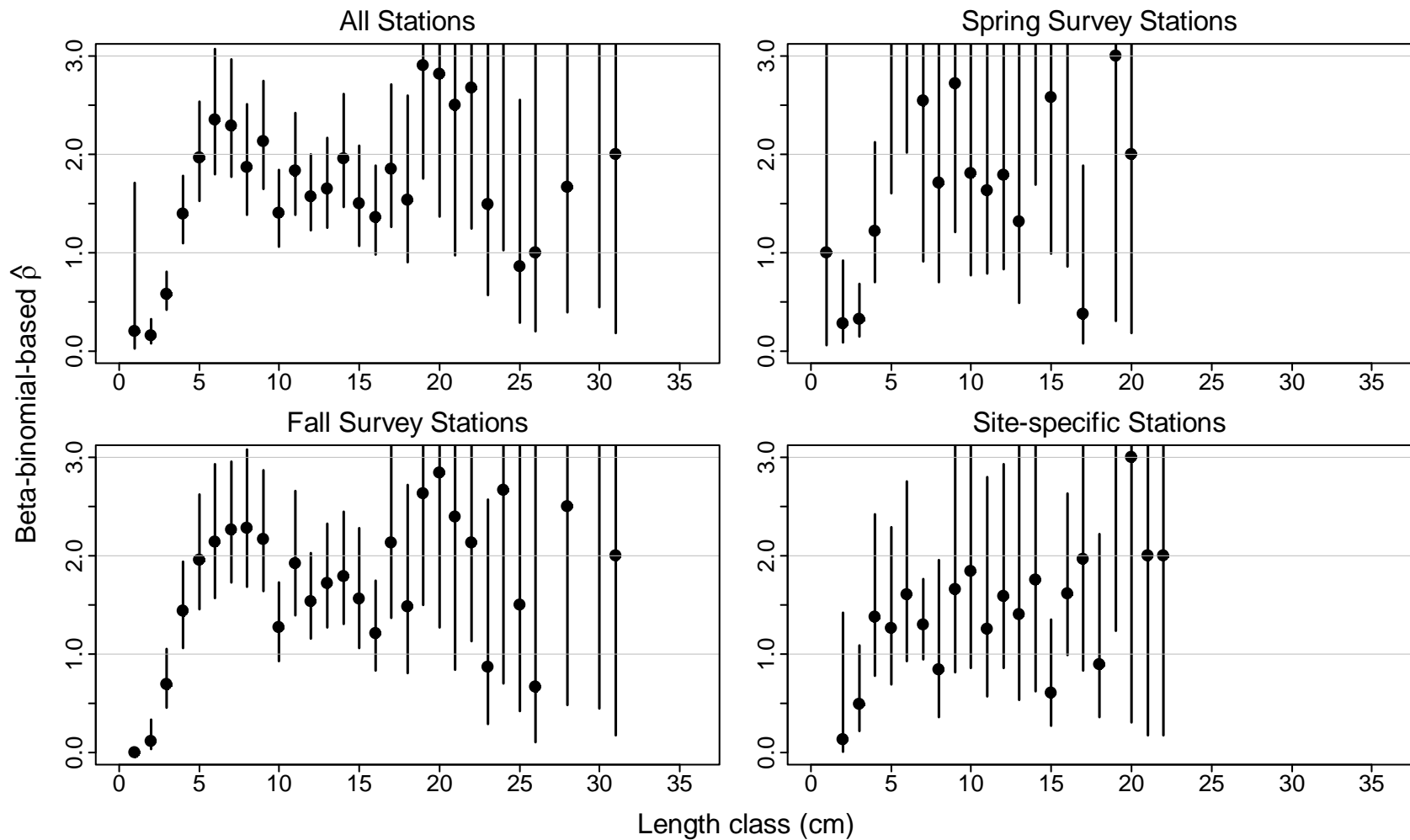
For *Loligo*, there are two primary seasonal cohorts observed each year in the NEFSC bottom trawl surveys and their abundances fluctuate substantially from year to year. Also, the assessment defines two size classes: pre-recruits (≤ 8 cm DML) and recruits (> 8 cm DML). The effects of inter-annual changes in size composition are negligible within each of the pre-recruit and recruit size classes. Therefore, we used a simple size-based calibration model that provided estimates of calibration factors that differ seasonally and are constant within each of the two size classes. Because only tows conducted during the daylight hours (between 0630 and 1630 during the fall and between 0630 and 1730 in the spring) were used in calculating abundance indices, we used the subset of paired tows from the calibration experiment that occurred during the same periods to fit models and estimate the *Loligo* calibration factors.



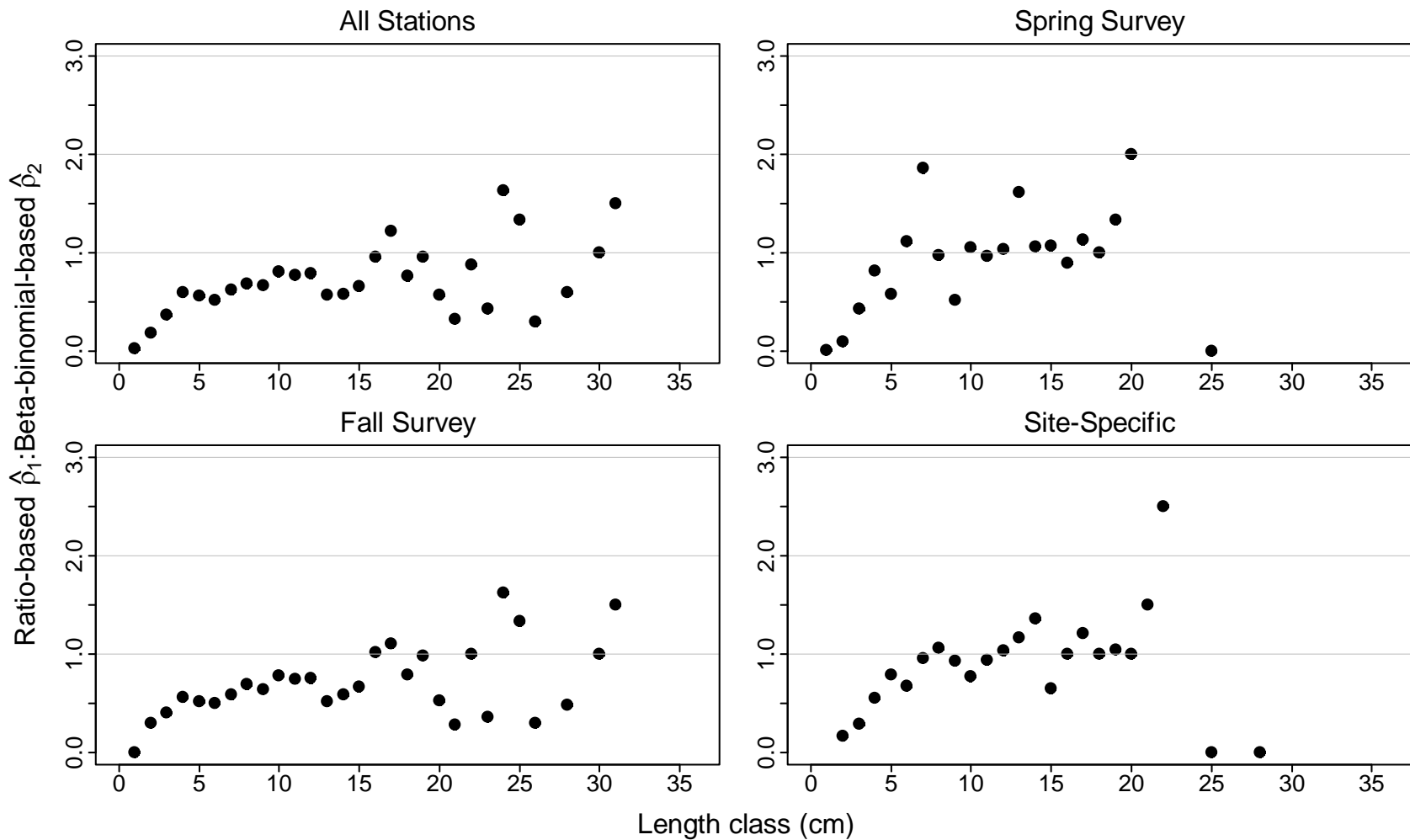
Appendix B3 Figure 1. Numbers of fish and number of stations where some fish were caught by length class for *Loligo* data from Spring and Fall survey stations, site-specific stations and all stations combined.



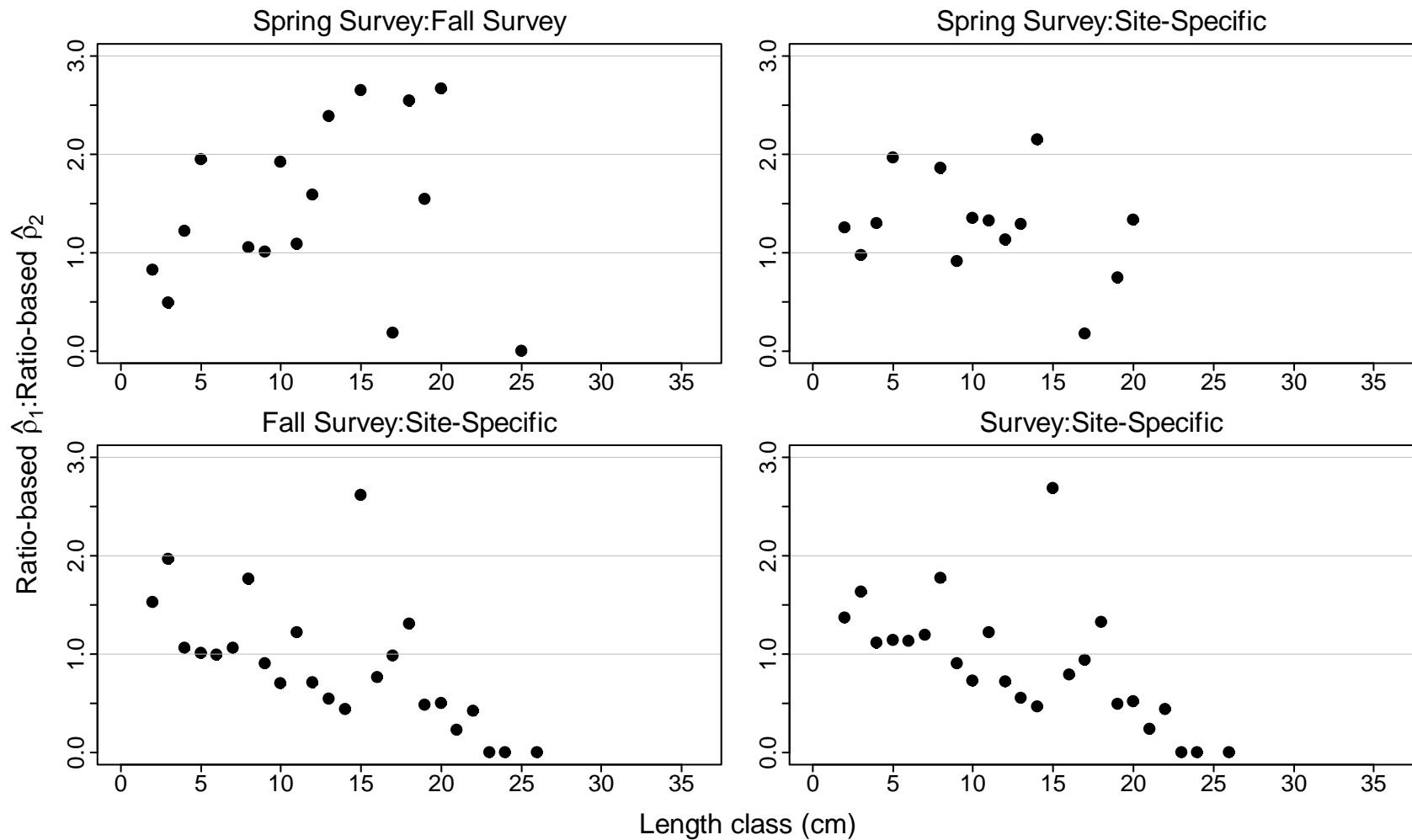
Appendix B3 Figure 2. Calibration factor estimates for *Loligo* catches from the Bigelow and Albatross IV by length bin in different sets of stations based on ratios of mean catches. Lengths are binned in 1 cm intervals.



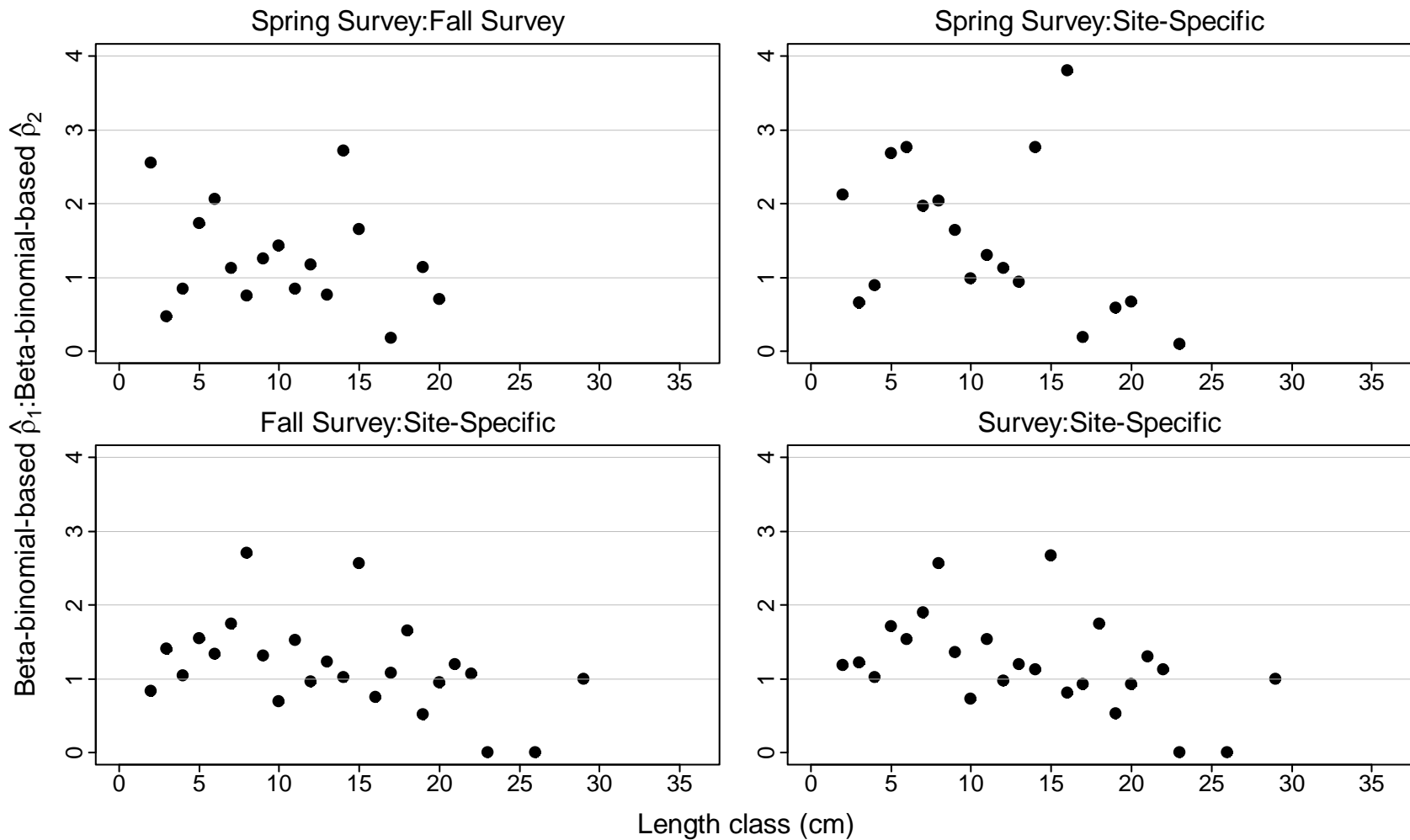
Appendix B3 Figure 3. Calibration factor estimates for *Loligo* catches from the Bigelow and Albatross IV by length bin in different sets of stations based on a beta-binomial model. Lengths are binned in 1 cm intervals.



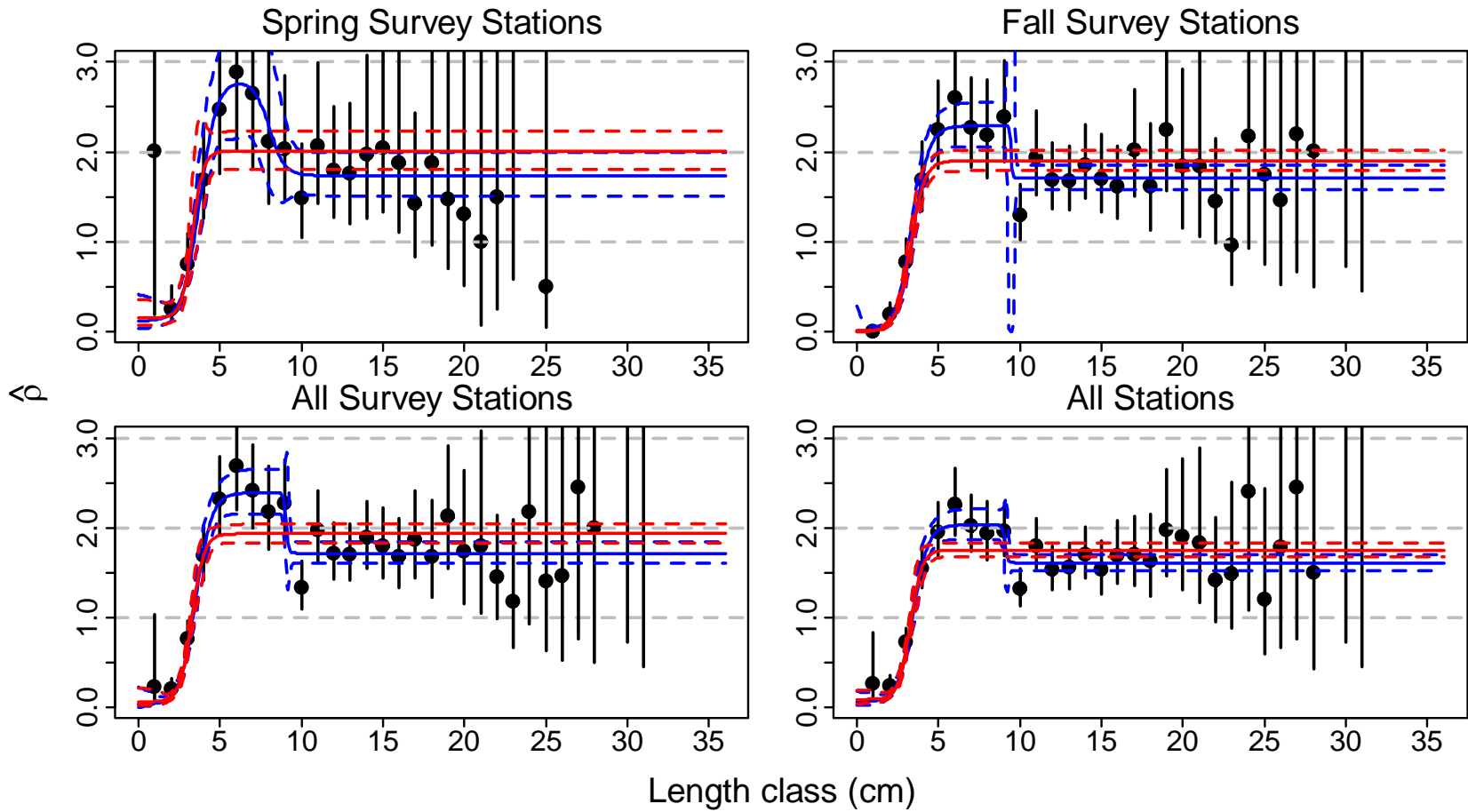
Appendix B3 Figure 4. Ratios of ratio-based to beta-binomial based calibration factors, by length bin, for *Loligo* catches from the Bigelow and Albatross IV in different sets of data. Lengths are binned in 1 cm intervals.



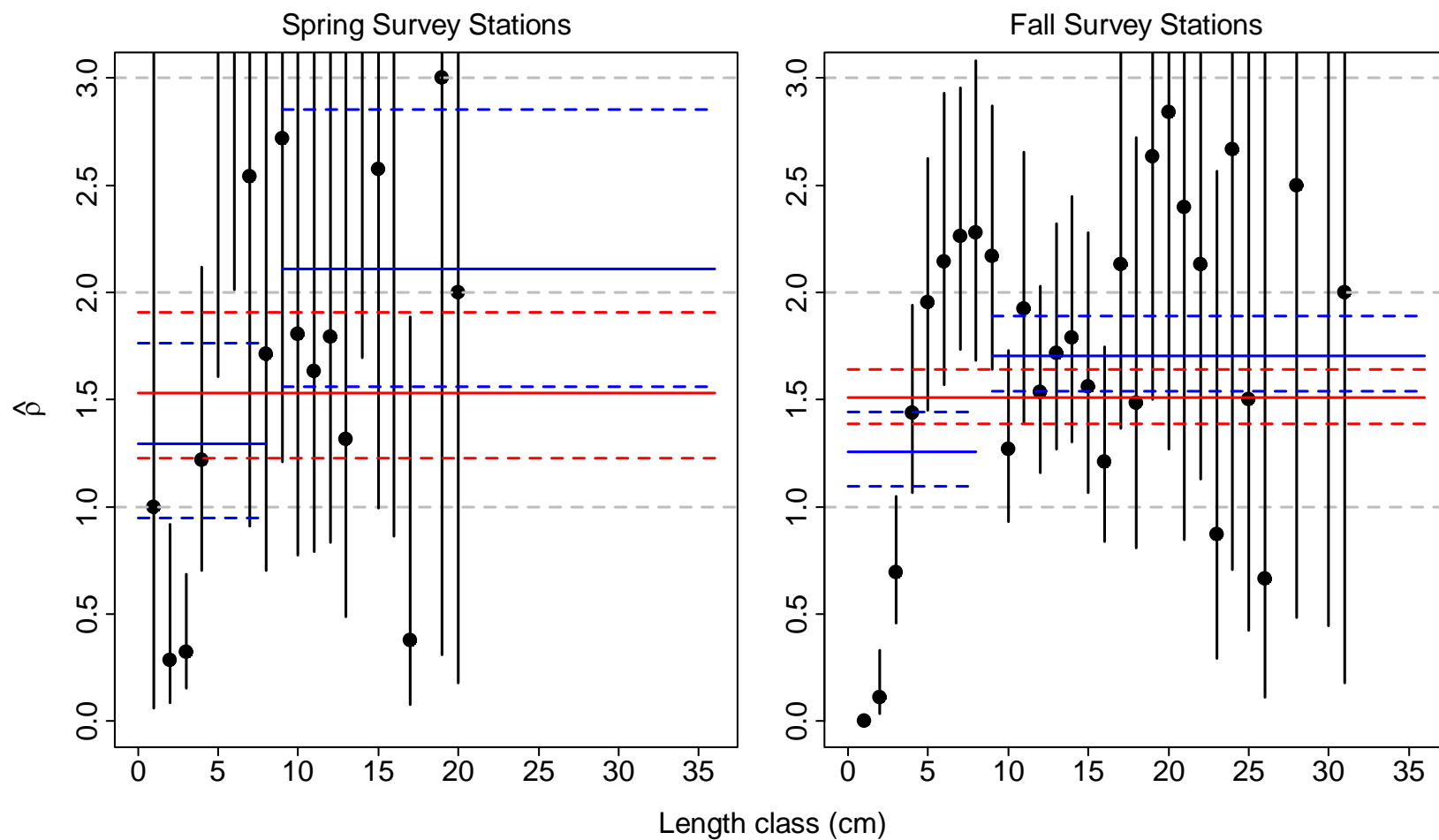
Appendix B3 Figure 5. Ratios of calibration factor estimates for *Loligo* catches from the Bigelow and Albatross IV by length bin in different sets of data based on ratios of mean catches. Lengths are binned in 1 cm intervals.



Appendix B3 Figure 6. Ratios of calibration factor estimates for *Loligo* catches from the Bigelow and Albatross IV by length bin in different sets of data based on a beta-binomial model. Lengths are binned in 1 cm intervals.



Appendix B3 Figure 7. Calibration factors for *Loligo* at length based on a logistic (red) or double-logistic (blue) functional form fit to data from spring, fall, and all survey stations, and all stations combined.



Appendix B3 Figure 8. Calibration factors for pre-recruit (≤ 8 cm DML) and recruit (> 8 cm DML) *Loligo* for stations sampled during daytime hours.

Appendix B3 Table 1. AIC values for models fit to *Loligo* length data.

Model	# parameters	-LL	AIC _c	Δ (AIC _c)	AIC _c Weights
Constant	2	10804.69	21613.37	539.7736	0.0000
Survey, S-S, constant	4	10790.77	21589.55	515.9484	0.0000
S,F,S-S, constant model	6	10787.28	21586.58	512.9762	0.0000
Logistic model	5	10562.58	21135.17	61.5728	0.0000
Survey, S-S logistic	10	10538.09	21096.22	22.6256	0.0000
S, F, S-S, logistic	15	10529.00	21088.10	14.5053	0.0006
Double logistic model	8	10551.54	21119.11	45.5072	0.0000
Survey, S-S, double-logistic model	16	10522.42	21076.96	3.3617	0.1569
S,F,S-S, double-logistic model	24	10512.67	21073.60	0.0000	0.8425

The constant model that ignores length is

$$\rho(l) = e^\gamma$$

and the logistic model is

$$\rho(l) = e^\gamma + \frac{e^\alpha}{1 + e^{-(\beta_0 + \beta_1 l)}}$$

which allows the lowest calibration factors to asymptote at a value greater than zero and the difference between the lowest and greatest values to be different than 1.

The double-logistic model is

$$\rho(l) = e^\alpha \left(e^{\gamma_1} + \frac{1 - e^{\gamma_1}}{1 + e^{-(\beta_0 + e^{\beta_1} l)}} \right) \left(e^{\gamma_2} + \frac{1 - e^{\gamma_2}}{1 + e^{(\beta_2 + e^{\beta_3} l)}} \right)$$

which allows the lowest calibration factors to asymptote at a value greater than zero at both small and large size classes and the difference between the lowest and greatest values to be greater than 1. In all models, the exponentiation of various parameters avoids boundary conditions during estimation. The parameters may differ for data obtained at spring or fall survey stations or the site-specific stations.

Letting the full set of calibration factor parameters be θ (which depends on the above models used), the beta-binomial likelihood we maximized is

$$L(\theta, \phi) = \prod_{i=1}^S \prod_{j=1}^M \frac{\text{Beta}(a_j + N_{Bij}, b_j + N_{Aij})}{\text{Beta}(a_j, b_j)} \binom{N_{Aij} + N_{Bij}}{N_{Bij}}$$

where Beta() is the beta function, and N_{Aij} and N_{Bij} are the numbers caught at station i in length class j by the Albatross IV and Bigelow, respectively. The likelihood is parameterized with parameters a and b which are functions of the calibration factor and dispersion parameter ϕ ,

$$a_j = \rho(l_j | \theta) \phi$$

and

$$b_j = \phi / (1 + \rho(l_j | \theta)).$$

Appendix B4. *Loligo* habitat outside the range of the survey strata set used in the assessment

The following analyses were conducted to determine the likelihood that substantial amounts of *Loligo pealeii* exist outside the range of the NEFSC bottom trawl survey strata used in the assessment during the survey time periods.

Density-depth relationships for *Loligo*

One set of analyses used catch-per tow data from the *Loligo* fishery and NEFSC spring and fall surveys to characterize daytime catch rates of *Loligo* as a function of depth. The analyses included only daytime tows based on the solar zenith criteria described in Appendix B2.

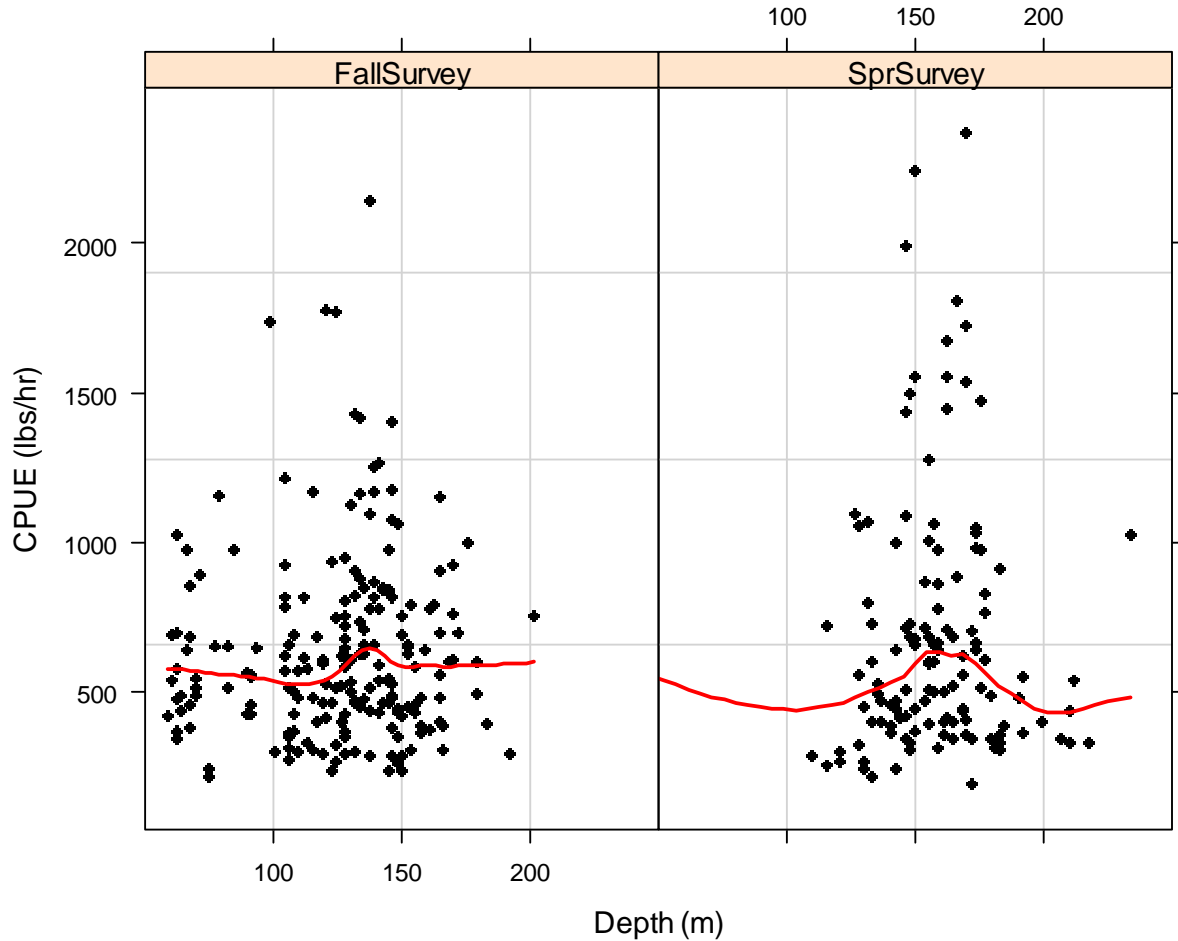
Commercial data were subset for spring (March-April, the time period of the spring survey) and fall (September-October-November, the time period of the fall survey). The data set included bottom trawl tows conducted during 1996-2009, with *Loligo* catches ≥ 2500 lbs, and with *Loligo* identified as the target species. The data for each tow included the time and location at the beginning and end of each haul, in addition to *Loligo* catch. The following variables were computed for each tow: tow duration (hours), CPUE (lbs hour⁻¹), and time, location and solar zenith for the middle of the tow. Tows were excluded if the solar zenith at the middle of the tow failed to meet the criteria for daytime tows. Categorization of daytime commercial tows was more difficult than for survey tows because commercial tows ranged from 1.2 to 6.8 hours in duration, often beginning in the day and ending at night or vice-versa. The commercial data used in the analysis were from 200 daytime tows in the fall and 129 daytime tows in the spring. CPUE was plotted against depth and smoothed with a loess regression line to identify trends. Results for fall were equivocal because there were no tows at depths beyond about 200 m. Results for spring indicated declining CPUE at depths beyond 175 meters (Figure 1), although data for deep water tows were limited.

Survey catches at depth were predicted for *Loligo* of different sizes using the GAM models that were also used to characterize diel patterns in survey catches. As described in Appendix B2, the GAM models predicted survey catches in positive tows (tows catching at least one individual). The predictor variables included *Loligo* length (DML, in 1 cm increments), solar zenith, depth, temperature, region and year as well as interactions between size and solar zenith and size and depth. Spring and fall survey data were modeled separately.

Results for all size groups indicated that the predicted daytime catches declined to low values with increasing depth during fall and spring surveys (Figures 2-3). These trends suggest that high densities of *Loligo* at depths greater than those included in this assessment are unlikely.

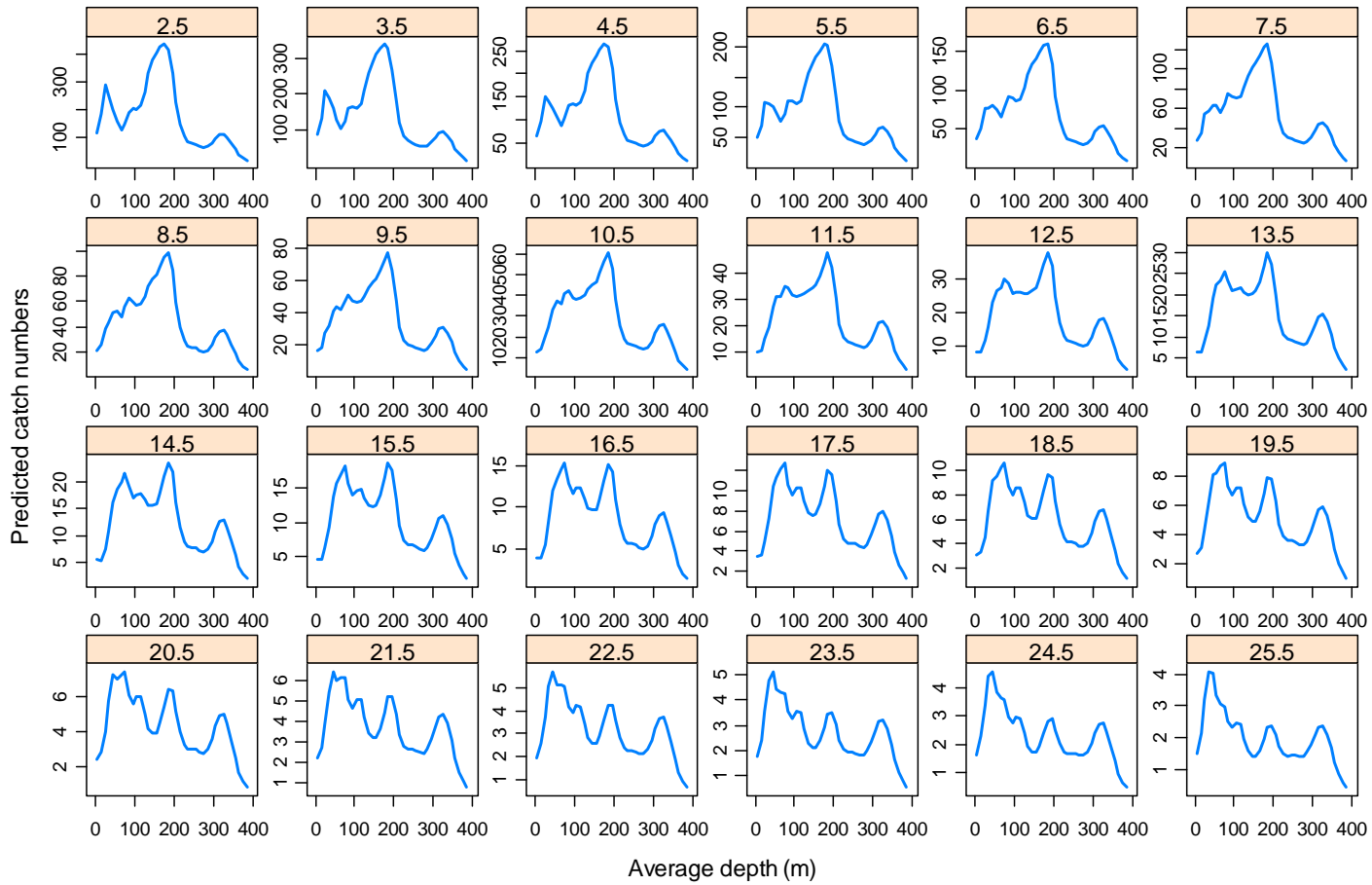
A third analysis used information from seasonal bottom trawl surveys that were conducted at depths greater than the limit of NEFSC surveys (366 m), by Rutgers University, during 2003-2007. Stations along transects located parallel to Baltimore and Hudson Canyons were sampled using a commercial *Loligo* bottom trawl. However, stations located at depths greater than 274 m were sampled at night. Catch rates of *Loligo pealeii* (kg per tow) in these surveys also show declines with increasing depth, similar to the analysis of catch rates with depth for daytime tows from NEFSC surveys. During some years, catch rates decline to very low levels at depths < 274

m which were sampled during the day (i.e., Hudson Canyon March 2003 and Nov. 2004 and 2007, Figure 4). Catch rates of *Loligo* were very low at depths greater than 366 m during January, March and November, but this result may be an artifact of nighttime sampling.



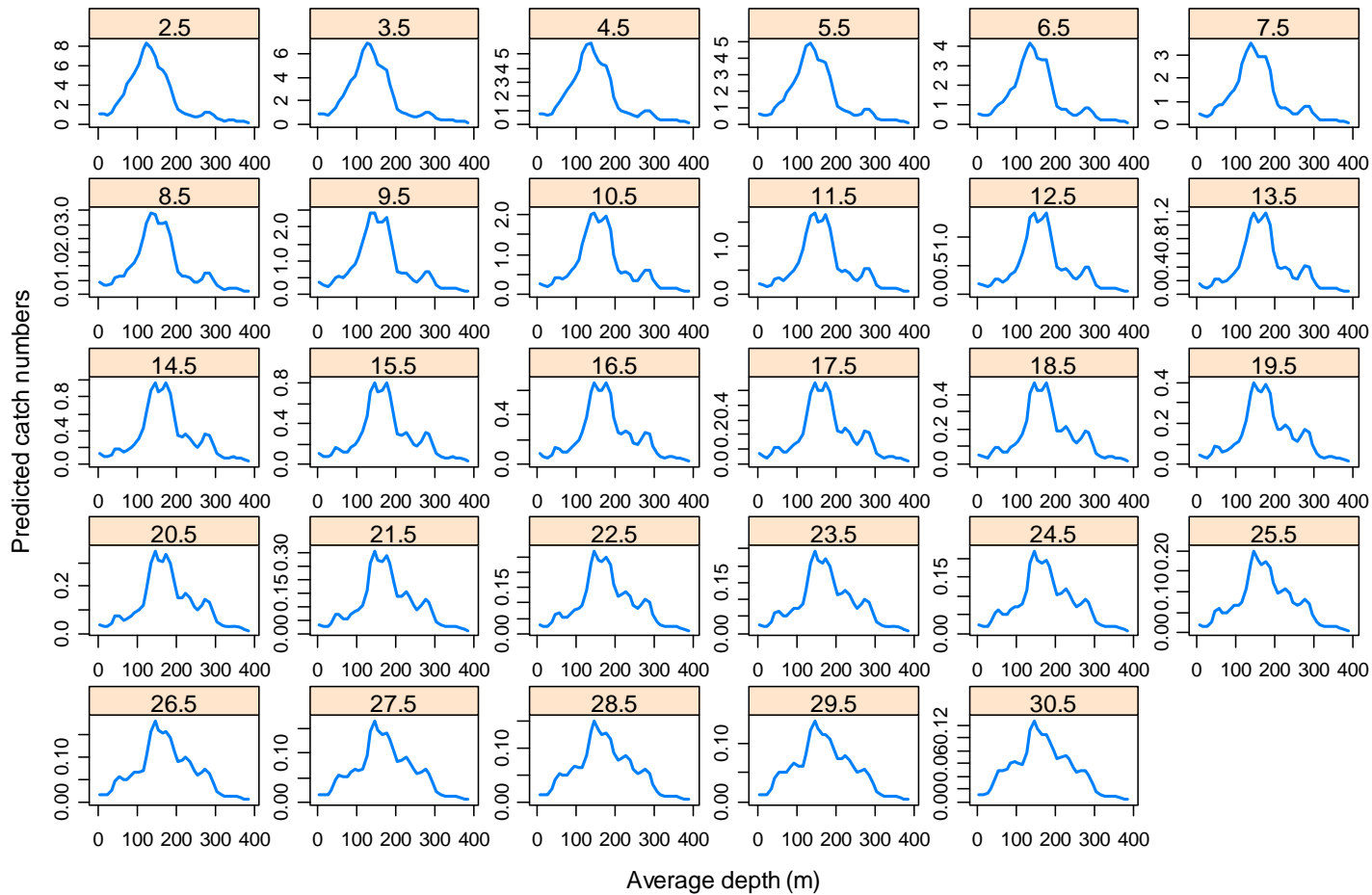
Appendix B4 Figure 1. CPUE for commercial tows targeting *Loligo* during the daytime vs. depth of tow, based on NEFOP observer data. The red line was fit by loess regression and is meant to show underlying trends.

GAM predicted catch numbers in fall survey

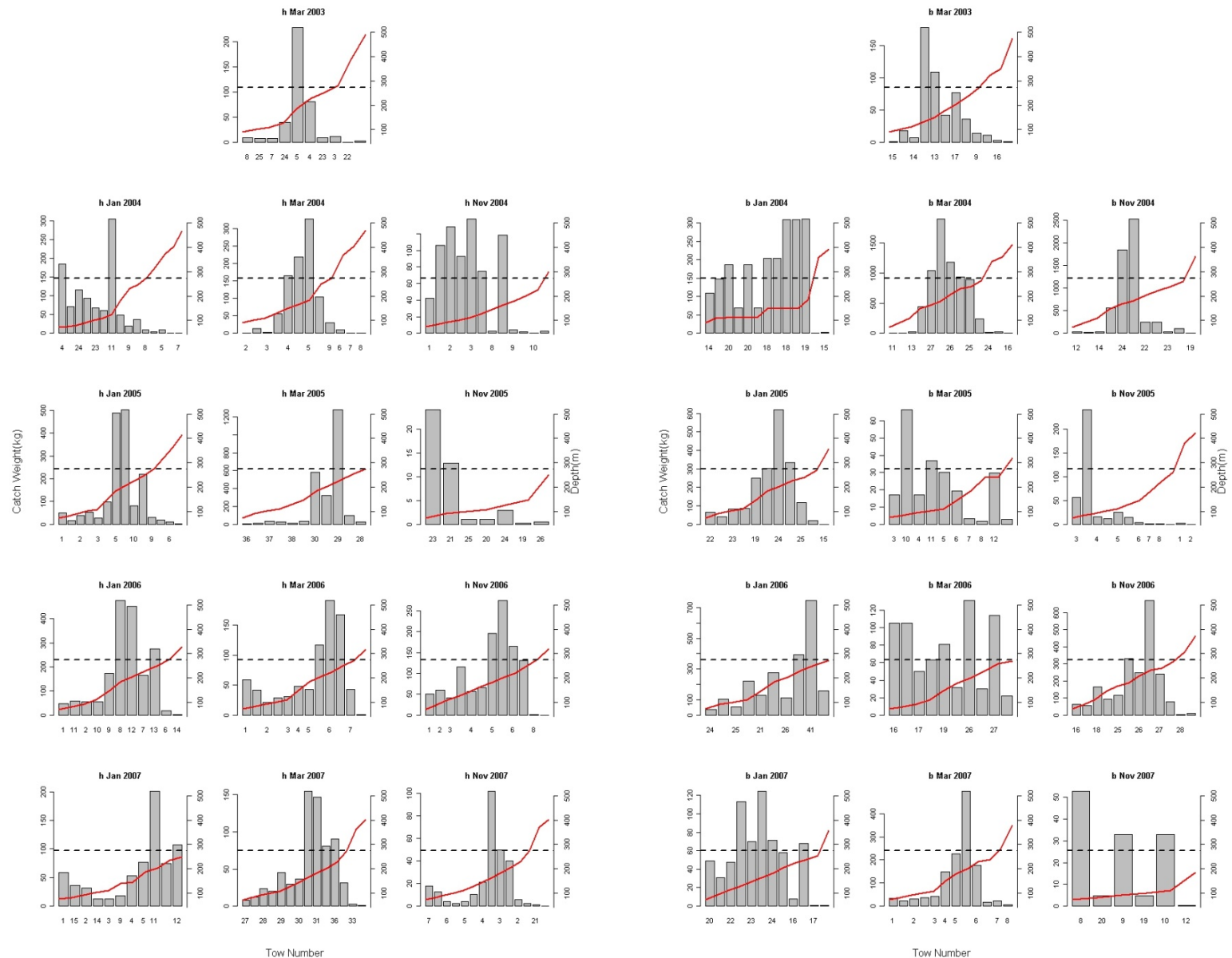


Appendix B4 Figure 2. Predicted catch numbers in positive tows for NEFSC fall bottom trawl surveys as a function of depth from, GAM modeling. The label at the top of each panel is squid size (DML, in 1 cm intervals).

GAM predicted catch numbers in spring survey



Appendix B4 Figure 3. Predicted catch numbers in positive tows for NEFSC spring bottom trawl surveys as a function of depth, from GAM modeling. The label at the top of each panel is squid size (DML, in 1 cm intervals).



Appendix B4 Figure 4. Relationship between *Loligo pealeii* catch rates (kg per tow) and depth based on seasonal bottom trawl transect surveys conducted by Rutgers University during 2003-2007. The red lines indicate station depths (m) and the black dashed line indicates the depth (274 m) beyond which stations were sampled at night. The titles indicate the transect identifier (b = Baltimore Canyon and h =Hudson Canyon).

Appendix B5. Estimation of natural mortality

Hendrickson and Hart (2006) developed an age-based cohort model for estimating the spawning mortality of semelparous cephalopods (a “maturation-natural mortality model”). The model was designed to estimate spawning and non-spawning natural mortality rates and maturity parameters based on maturity and age samples for another semelparous squid species, *Illex illecebrosus*. The model was used for *Loligo* for the first time in this assessment. The approach appears promising for estimation of maturity and mortality parameters but model estimates in this assessment should be regarded as preliminary due to data limitations and other uncertainties. Mortality and maturity rates in this analysis are weekly rates, unless stated otherwise.

Natural mortality rates for semelparous, short-lived squid species like *Loligo* tend to be very high (Hendrickson and Hart 2006). However, this is not unusual since *Loligo* serve as prey for many marine species and natural mortality rates increase at the time of spawning. The traditional approach to estimating maturity-at-age is misleading for squid species like *Loligo* because mature individuals are underrepresented in samples due to increased mortality rates after spawning. Similarly, age composition data are difficult to interpret because maturation rates (and total mortality) increase with age. Thus, in principle, a simple catch curve (log-transformed abundance vs. age) should be nonlinear (concave) and it is necessary to account for maturity and mortality rates in the same model.

Materials and methods

The data for the model are assumed to consist of a random sample from the cohort or population over a range of ages, including spawning ages and ages completely recruited to the sampling gear. Age and maturity were recorded for each individual in the sample.

Two data sets were available and only results for females are reported here. The first (N=128 with 37 mature females) was collected during NEFSC and Connecticut (Long Island Sound) spring bottom trawl surveys in March (mostly) and May, respectively, during 1996-1998. The second set (N=68 with 51 mature females) was collected in March and May (mostly), during 1991-1993, in the offshore *Loligo* fishery and the Massachusetts weir fishery, respectively.. It was necessary to combine sampling locations and years because data were limited.

Ignoring gender, the maturity-mortality model assumes that maturation rates R_a are a quadratic function of age a :

$$R_a = r_0 + r_1 a + r_2 a^2$$

where r_0 , r_1 and r_2 are potentially estimable maturation parameters. In this assessment, the statistical significance of each of the maturation parameters is evaluated with the goal of omitting imprecise parameters and simplifying the model. Population dynamics are based on the differential equations:

$$\frac{dN}{dt} = -(M_{ns} + R)N$$

and

$$\frac{dS}{dt} = RN - (M_{ns} + M_{sp})S$$

where N is the number of immature individuals, S is the number of spawners, M_{ns} is the non-spawning (immature) mortality rate, M_{sp} is the spawning (mature) mortality rate, and the mortality parameters (M_{ns} and M_{sp}) are potentially estimable. Hendrickson and Hart (2006) give exact solutions for these differential equations.

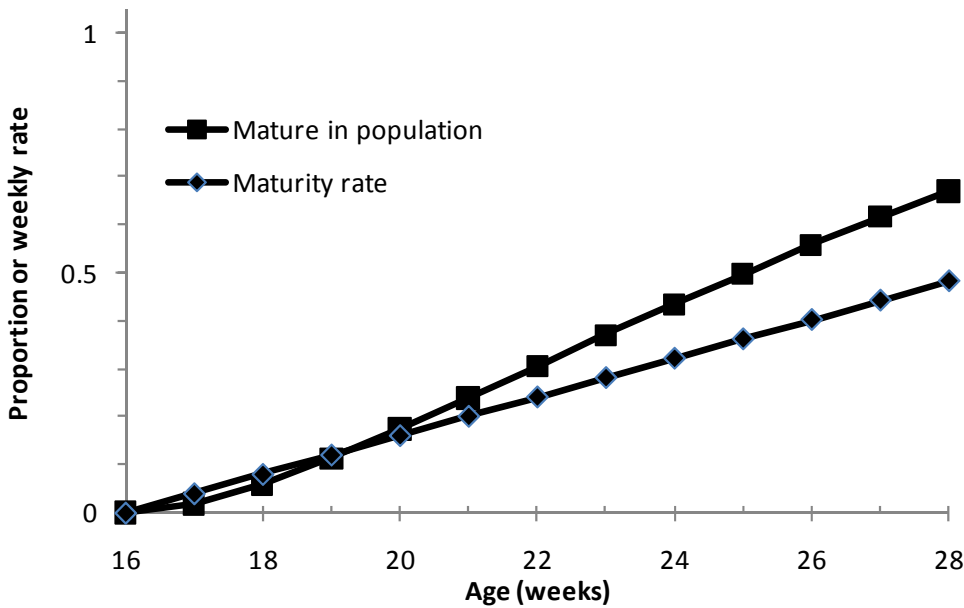
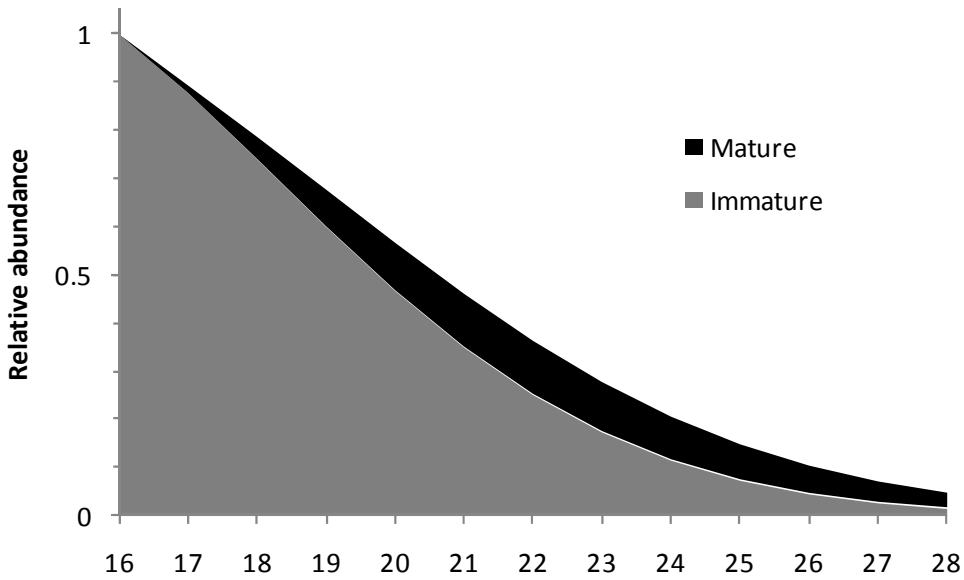
The maximum likelihood objective function used in fitting the model assumes that the age composition data (for fully recruited ages only) are multinomial with predicted age composition for mature and immature *Loligo* from the model (i.e., predicted age composition proportional to $N_a + S_a$), conditioned on the sample size. The objective function assumes that the observed proportions of mature individuals in each age group are independent binomials with sample size equal to the number of maturity samples in each age group, and predicted values from the model [i.e. predicted values = $S_a / (N_a + S_a)$]. There are five potentially estimable parameters ($r_0, r_1, r_2, M_{ns}, M_{sp}$). The parameters r_0, M_{ns} and M_{sp} were estimated as log transformed parameters and therefore constrained to be positive. The remaining maturity parameters were estimated directly so that estimates might be either positive or negative.

Hendrickson and Hart (2006) used data from a special age reader experiment to quantify aging precision. The predicted values from the model were smeared to account for ageing imprecision, before comparison to the data. Maturity parameter estimates for *Illex illecebrosus* were sensitive to assumptions about ageing imprecision, but natural mortality parameters were not. Ageing precision was not included for *Loligo* due to lack of experimental data.

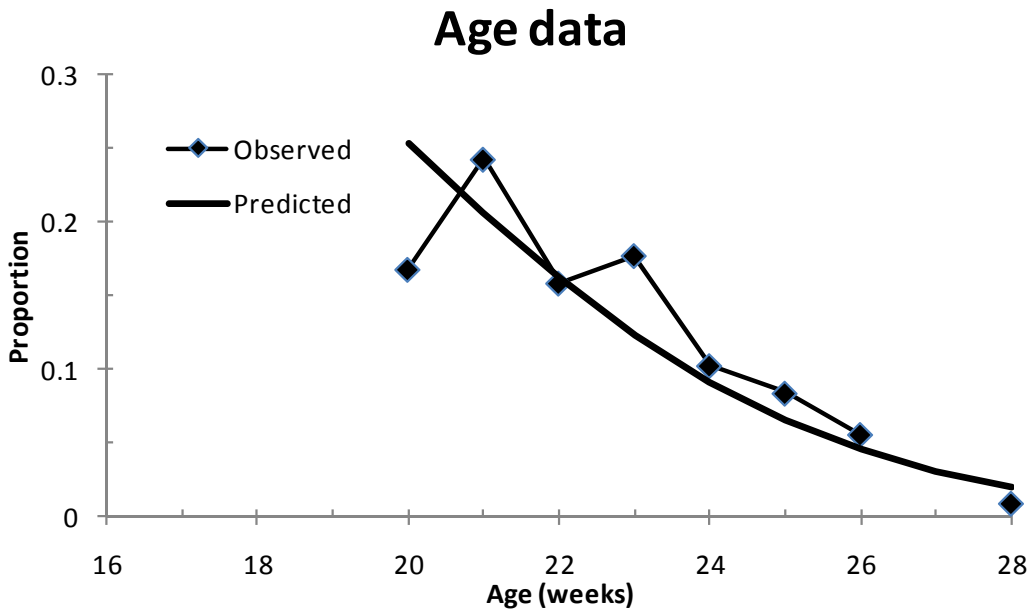
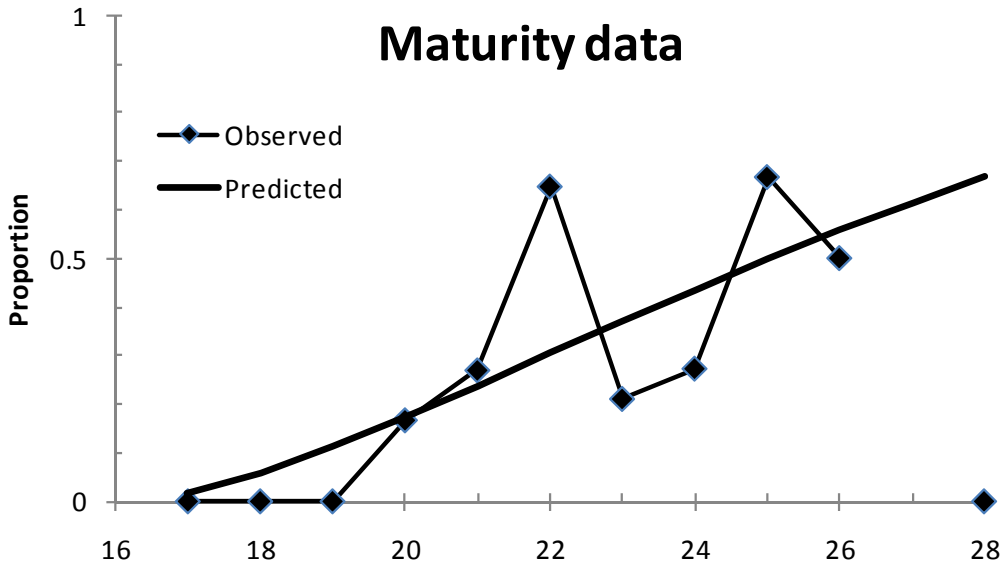
Results

As in Hendrickson and Hart (2006), preliminary model runs indicated that it was not possible to estimate both M_{ns} and M_{sp} simultaneously. Following Hendrickson and Hart, M_{ns} was estimated using Caddy's (1996) gnomonic approach (= 0.11) and assumed in the model while fitting other parameters. As suggested by Hendrickson and Hart's (2006) results, only one (r_1 for data set 1) or two (r_0 and r_1 for data set 1) maturity parameters were statistically significant. Other maturity parameters were "turned off" and did not affect model estimates.

The best models for each data set (after fixing $M_{ns} = 0.11$ and omitting unnecessary maturity parameters), gave estimated maturation rates ≤ 0.8 at all ages (Appendix B5 Figure 1). However, the shapes of the estimated relationships between age and maturity rates were different for the two data sets. M_{sp} estimates ranged 0.19 (CV 0.40) to 0.48 (CV 0.11). There were no trends in the residual plots (Appendix B5 Figure 2).



Appendix B5 Figure 1. Biological estimates for *Loligo* from the best maturation-natural mortality model fit to data set 1. Estimates for data set 2 were generally similar although the maturity rate for data set 2 declined with age.



Appendix B5 Figure 2. Example residual plots for *Loligo* from the best maturation-mortality model fit to data set 1. Goodness of fit to data set 2 was generally similar.

Appendix B6: Estimates of minimum consumption of *Loligo pealeii*

Food habits were evaluated for 15 fish predators that consume *Loligo pealeii* consistently and commonly occur in NEFSC spring and fall bottom trawl surveys. The amount of food eaten, the type of food eaten and estimates of predator abundance were used to compute per capita consumption (*Loligo* consumed per predator) and total consumption of *Loligo*.

Loligo consumption estimates in this paper are minimum estimates and may represent a small fraction of total consumption because predation by other *Loligo*, birds, marine mammals and large pelagic fish area was not included. Predation by predators outside the survey area was not included either. Moreover, swept-area biomass estimates for many of predators were based on bottom trawl survey data without adjustments for survey bottom trawl catchability, resulting in underestimates of predator abundance and consumption. Finally, formulas used to compute per capita consumption probably produce conservative (biased low) estimates.

Results suggest that minimum consumption estimates for 15 fish predators in the survey area is relatively large in comparison to catches in most years (Figure 1). Consumption appears highest during fall when *Loligo* are most abundant and are widely distributed across the continental shelf and when predators which migrate south of the survey area during the spring surveys (e.g., bluefish and weakfish) are within the survey area.

Methods

Every predator that contained *Loligo* was identified in the NEFSC Food Habits Database. From that original list, a subset of key predators (Table 1) was according to several “rules of thumb”. In particular, the selected predators had *Loligo*: 1) amounting to more than 1% of prey composition during at least one five year block; as prey in more than 10 tows for each two year block; and in at least 10 stomachs for each three year block (Tables 2 and 3).

Food habits data collection is a routine part of NEFSC spring and fall bottom trawl surveys (Azarovitz 1981; NEFC 1988). Annual consumption for each predator species was estimated on a seasonal basis (January-June = “spring” and July-December = “fall”) using data from spring and fall bottom trawl surveys during 1977-2009. Although food habits sampling was quantitative beginning in 1973, not all *Loligo* predators were sampled prior to 1977 (Link and Almeida (2000)). Consumption was calculated separately based on two size groups (≤ 20 cm and > 20 cm) for large predators. Total consumption for a predator was estimated as the sum of the estimates for each size group. Annual consumption was computed as the sum of estimates for spring and fall.

Methods were similar to previously described methods for estimating consumption using an evacuation rate model (Durbin *et al.* 1983; Ursin *et al.* 1985; Pennington 1985; Overholtz *et al.* 1991, 1999, 2000, 2008; Tsou & Collie 2001a, 2001b; Link & Garrison 2002; Link *et al.* 2006,

2008, 2009; Methratta & Link 2006; Link & Soseebe 2008; Overholtz & Link 2007, 2009; Tyrrell *et al.* 2007, 2008; Link and Idoine 2009, Moustahfid *et al.* 2009; NEFSC 2006, 2007a, 2007b, 2008, 2010a, 2010b). The main input data are: mean stomach contents (S_i) for each *Loligo* predator i ; diet composition (D_i , proportion of total stomach contents consisting of *Loligo*), and bottom temperature records T from the bottom trawl surveys (Taylor *et al.* 2005). Units for stomach estimates are in grams.

As noted above, the gastric evacuation rate method was used to calculate per capita consumption (Eggers 1977, Elliott and Persson 1978). The two main parameters were fixed at $\alpha = 0.004$ and $\beta = 0.115$, based on previous studies and sensitivity analyses (NEFSC 2007a, 2007b). However, α was set at 0.002 for elasmobranch predators to reflect relatively high metabolic costs in sharks and rays. As in most other studies, an additional parameter γ was set to one and had no effect on consumption estimates (Gerking 1994).

Per capita consumption rates C_{it} were calculated:

$$C_{it} = 24 \cdot E_{it} \cdot \bar{S}_{it}^{\gamma}$$

where 24 is the number of hours in a day and the evacuation rate E_{it} is:

$$E_{it} = \alpha e^{\beta T}$$

where t is a subscript for time period (season and year). Due to lack of data and to limit variability in the results, stomach contents data for some predators were averaged in blocks of two or three years (Table 1).

Estimated daily per capita consumption rates were scaled up to seasonal per capita consumption estimates for each *Loligo* predator. This was done by multiplying per capita consumption by the diet composition D_{ij} for *Loligo*, and then by the number of days in each half year. The seasonal per capita estimates were summed to estimate annual per capita consumption. Annual per capita consumption was multiplied by the abundance of each predator to estimate the minimum amount of *Loligo* consumed on an annual basis.

Abundance estimates from stock assessments were available for six of the fifteen predators (Table 1). A crude estimate of the survey catchability parameter was derived by comparison of simple swept-area and stock assessment abundance estimates. The catchability parameter was used to scale minimum swept area estimates for the six predators to estimates of total abundance. Predator species without stock assessments used minimum swept area abundances without adjustment for catchability.

We used a simple and crude approach to approximate variance in *Loligo* consumption estimates (Link and Almeida 2000). Previous studies indicate that the largest source of variance is associated with the estimates of abundance. We therefore took the largest CV (with slight modifications) for abundance of each predator as a variance measure for total consumption. These CVs ranged from 0.1 to 1.0 and were mostly in the range 0.35-0.50.

Length compositions of *Loligo* prey present in predator stomachs were plotted for each predator

and season and compared to *Loligo* size composition data from the surveys and fishery data. These comparisons show the extent to which surveys, the fishery and predators sample the same size groups.

Results

The consumption estimates from this analysis are considered preliminary because further research is needed regarding the multiple sources of uncertainty noted below and because ecosystem and predator dynamics in relation to the complex life history and high turnover rates of squid populations are poorly understood. Minimum estimates of consumption for *Loligo* were 16,000-219,000 mt per year during 1977-2009 (Figure 1 and Table 4). During most years, consumption was higher during the fall than during the spring (Figure 2).

Most of the *Loligo* consumed were <10 cm DML (Figures 3 and 4) although some predators (summer flounder and goosefish) consumed larger individuals. In general, *Loligo* size compositions from stomachs samples were similar to survey size compositions indicating that predators may “sample” the *Loligo* stock in a representative manner. The fishery targets *Loligo* > 8 cm DML (annual modal size = 12 cm), which are larger than the bulk of *Loligo* prey found in predator stomachs.

Ignoring the differences in length composition that reduce the comparability of fishery and consumption data, minimum estimates of annual consumption removals were larger (often substantially) than annual catches (Figures 1 and 5). The exception was 1997 to 1998, when minimum consumption and catch were about equal.

Sources of Uncertainty

1. Stock assessment estimates of abundance were not available for all predators resulting in underestimation of *Loligo* consumption.
2. The assumed value $\alpha = 0.004$ is in the range used in other studies, but may be too low resulting in underestimation of consumption.
3. The distribution of *Loligo pleii* overlaps with *L. pealeii* near Cape Hatteras and the two species cannot be distinguished between using gross morphology. Therefore, the amount of *Loligo pealeii* consumption may be overestimated in geographic range where the two species overlap.
4. Some fish predators that did not consistently consume *Loligo* (e.g. some of the skates) were not included in the analysis resulting in underestimation of consumption.
5. Consumption of *Loligo* by seabirds, squids and marine mammals and cannibalism by other *Loligo* was not included resulting in underestimation of consumption.
6. Squid beaks are not enumerated in food habits sampling and *Loligo* probably digest rapidly. Thus per-capita consumption estimates may be biased low.
7. The analysis assumed complete spatial-temporal overlap of predators and *Loligo*.

Appendix B6 Table 1. *Loligo* predators included in minimum consumption estimates. Abundance information was from either from minimum swept area calculations (SWA) or from stock assessments (SA). The temporal resolution of the data (annual, 2 yr, or 3 yr) indicates the number of years used to average stomach contents and diet composition data.

Common name	Scientific name	Source of abundance estimates	Time blocks
Pollock	<i>Pollachius virens</i>	SA	2 yr
Bluefish	<i>Pomatomus saltatrix</i>	SA	2 yr
Weakfish	<i>Cynoscion regalis</i>	SA	2 yr
Summer Flounder	<i>Paralichthys dentatus</i>	SA	3 yr
Goosefish	<i>Lophius americanus</i>	SA	3 yr
Atlantic cod	<i>Gadus morhua</i>	SA	Annual
Red hake	<i>Urophycis chuss</i>	SWA	2 yr
Spotted hake	<i>Urophycis regia</i>	SWA	2 yr
Smooth dogfish	<i>Mustelus canis</i>	SWA	3 yr
Fourspot flounder	<i>Paralichthys oblongus</i>	SWA	3 yr
Spiny dogfish	<i>Squalus acanthias</i>	SWA	Annual
Little skate	<i>Raja ocellata</i>	SWA	Annual
Winter skate	<i>Raja erinacea</i>	SWA	Annual
Silver Hake	<i>Merluccius bilinearis</i>	SWA	Annual
White hake	<i>Urophycis tenuis</i>	SWA	Annual

Appendix B6 Table 2. Numbers of tows in which *Loligo* was detected during spring survey food habits sampling. Figures are given starting in 1975, instead of 1977 when consumption estimates begin, because data were averaged in three year blocks for some species.

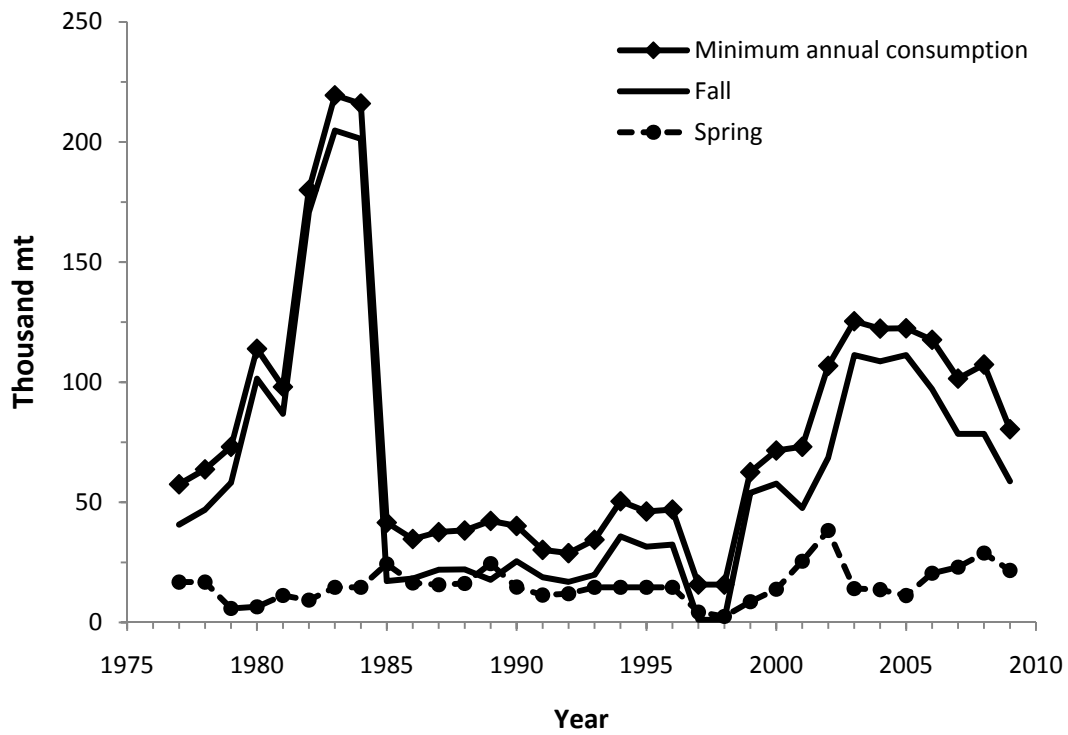
Year	COD	BLUEFISH	FOURSPOT FLOUNDER	GOOSEFISH	LITTLE SKATE	POLLOCK	RED HAKE	SILVER HAKE	SMOOTH DOGFISH	SPINY DOGFISH	SPOTTED HAKE	SUMMER FLOUNDER	WEAKFISH	WHITE HAKE	WINDOWPANE	WINTER SKATE
1975	2	0	1	0	7	1	2	14	0	0	1	0	0	0	0	0
1976	40	0	7	0	26	33	18	37	0	0	11	0	0	11	0	0
1977	22	0	5	31	15	8	39	36	3	50	0	9	0	3	16	11
1978	15	0	3	26	18	6	35	42	7	44	0	6	1	5	21	11
1979	17	2	4	21	7	2	30	27	7	50	0	23	3	5	28	22
1980	22	3	5	29	3	11	18	25	9	37	0	14	3	3	20	14
1981	47	0	1	13	2	7	5	45	20	111	0	2	0	13	11	0
1982	70	2	3	40	10	24	23	65	12	102	5	21	3	35	10	16
1983	24	2	6	31	10	22	59	35	6	115	3	16	0	47	6	5
1984	3	0	1	11	6	36	60	0	7	114	0	1	0	28	2	5
1985	115	3	12	17	27	38	50	150	8	115	1	18	6	33	23	29
1986	82	7	31	30	52	28	51	148	6	137	15	48	3	57	36	40
1987	85	0	30	23	77	17	51	115	2	134	6	24	0	44	35	57
1988	83	1	20	17	50	15	43	90	1	109	1	21	0	44	1	57
1989	106	0	37	24	120	27	67	138	3	139	29	19	3	43	87	92
1990	91	1	1	16	97	24	48	103	5	147	9	12	4	36	37	79
1991	100	1	41	55	149	52	61	146	8	167	30	43	7	53	42	100
1992	72	4	55	38	130	29	70	133	7	149	23	50	10	53	79	94
1993	89	6	70	43	160	37	92	149	10	150	37	49	12	52	84	103
1994	81	1	56	45	141	29	85	144	8	145	45	58	9	62	90	98
1995	70	0	75	60	143	33	105	158	8	177	50	45	13	57	75	82
1996	72	6	62	40	153	20	90	121	13	165	41	61	1	50	87	114
1997	82	4	73	26	127	40	85	142	7	178	60	61	2	35	59	68
1998	74	3	71	76	184	50	134	185	12	195	73	72	7	62	114	97
1999	68	5	83	80	155	40	117	181	14	185	83	78	4	53	96	88
2000	82	7	73	71	170	43	101	156	12	171	67	80	17	56	97	101
2001	66	3	80	81	146	32	103	162	11	150	63	71	6	51	64	68
2002	90	8	85	75	146	39	109	184	27	210	87	85	22	56	79	71
2003	69	5	67	56	163	31	111	134	12	160	70	73	3	47	81	101
2004	81	2	59	50	138	33	98	151	9	143	60	72	1	49	70	104
2005	73	5	63	58	129	31	88	130	13	141	59	64	6	49	69	71
2006	69	10	79	44	132	37	130	177	15	200	82	78	9	56	76	90
2007	79	5	84	49	148	34	122	153	12	183	89	75	7	50	77	101
2008	67	5	63	40	120	42	114	164	15	180	85	75	12	54	74	89
2009	91	3	117	131	209	30	200	272	19	198	113	118	1	103	120	187
Total	2299	104	1523	1447	3370	981	2614	4112	328	4651	1298	1542	175	1455	1866	2265

Appendix B6 Table 3. Numbers of tows in which *Loligo* was detected during fall survey food habits sampling. Figures are given starting in 1975, instead of 1977 when consumption estimates begin, because data were averaged in three year blocks for some species.

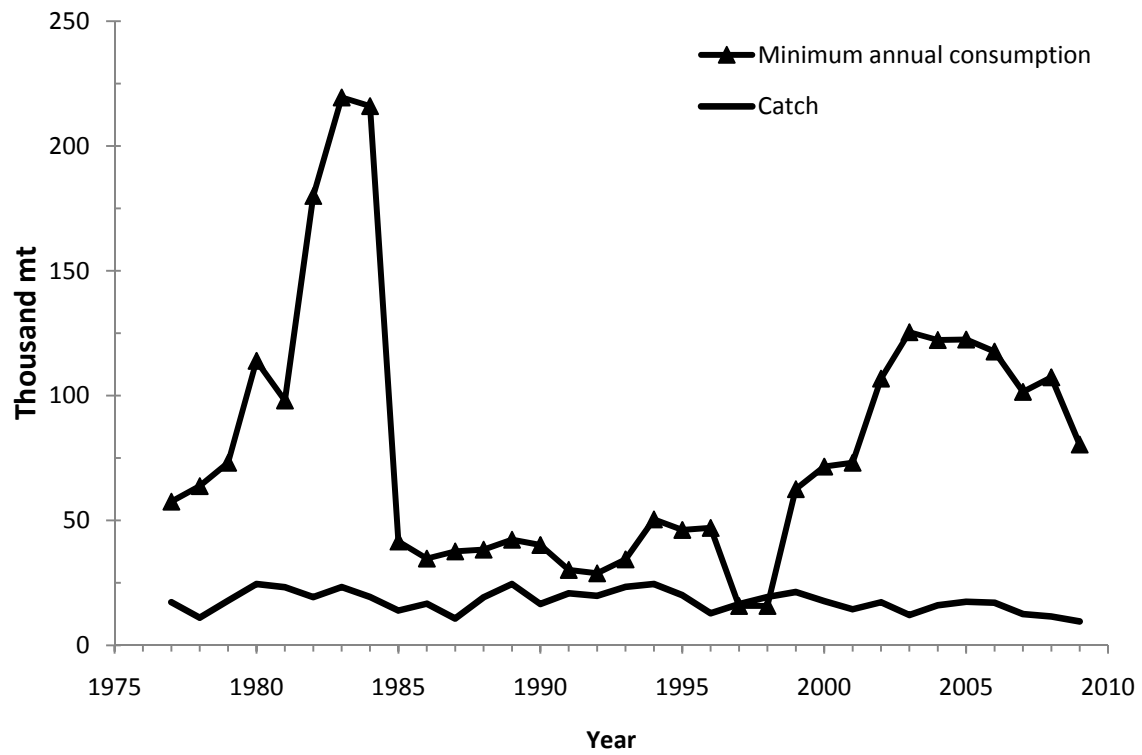
Year	COD	BLUEFISH	FOURSPOT FLOUNDER	GOOSEFISH	LITTLE SKATE	POLLOCK	RED HAKE	SILVER HAKE	SMOOTH DOGFISH	SPINY DOGFISH	SPOTTED HAKE	SUMMER FLOUNDER	WEAKFISH	WHITE HAKE	WINDOWPANE	WINTER SKATE
1975	34	0	3	0	17	18	7	41	0	0	6	0	0	14	0	0
1976	30	0	9	0	17	13	16	43	0	0	12	0	0	11	0	0
1977	0	1	0	32	11	1	31	34	10	34	0	9	0	3	12	11
1978	4	19	4	50	14	0	28	26	21	35	0	17	11	2	8	11
1979	2	40	7	44	3	1	31	19	32	36	2	49	13	1	33	9
1980	1	15	0	29	1	0	18	7	4	17	0	14	4	0	9	13
1981	26	27	4	14	2	5	6	24	11	38	3	19	2	12	3	1
1982	0	20	5	32	1	21	54	10	15	64	7	10	9	45	6	5
1983	0	7	0	24	0	24	47	2	12	97	0	1	0	60	0	3
1984	23	24	11	17	9	19	61	26	16	72	1	4	5	58	6	25
1985	45	42	18	24	16	26	55	115	25	78	17	40	25	50	11	6
1986	63	32	18	13	30	12	39	112	25	65	8	15	15	73	15	21
1987	43	47	30	24	24	14	36	99	25	46	43	31	8	53	28	20
1988	55	23	40	17	14	23	52	115	26	63	47	29	4	52	0	26
1989	60	60	51	24	60	19	73	132	40	63	55	40	38	68	38	41
1990	55	46	76	21	74	22	76	160	43	94	53	53	23	96	50	45
1991	55	43	63	65	95	30	75	153	42	87	63	63	21	121	62	62
1992	54	54	96	47	106	25	70	177	45	97	85	72	36	86	75	59
1993	49	48	93	66	111	24	98	186	45	82	72	65	24	88	78	62
1994	0	3	90	10	122	18	101	173	39	89	75	6	34	80	79	65
1995	51	4	82	65	116	23	102	147	52	90	77	77	60	69	80	84
1996	66	54	95	60	108	26	99	146	51	123	89	70	44	59	82	67
1997	55	53	68	52	85	30	92	138	45	124	58	81	25	71	65	56
1998	81	54	99	55	125	34	132	182	56	156	95	94	37	88	86	86
1999	64	69	92	69	126	36	104	147	57	137	81	107	62	80	79	73
2000	49	59	91	72	114	42	101	134	47	105	72	96	51	66	72	60
2001	56	61	85	81	110	54	101	163	61	116	103	94	41	60	70	70
2002	42	64	91	84	120	27	90	129	62	119	84	94	50	54	64	60
2003	52	65	99	75	120	39	118	166	82	111	131	92	66	60	97	57
2004	49	57	66	59	76	38	83	156	60	96	69	97	38	75	56	47
2005	51	58	99	64	105	41	115	136	63	126	97	79	44	60	79	68
2006	62	86	95	63	114	25	108	180	80	166	104	93	65	72	84	71
2007	54	61	99	46	103	23	111	155	61	119	70	96	43	79	71	67
2008	55	69	95	45	106	27	112	178	60	131	97	96	59	81	77	64
2009	45	50	152	136	134	14	150	206	49	129	141	97	21	96	71	58
Total	1431	1415	2026	1579	2389	794	2592	4017	1362	3005	1917	1900	978	2043	2905	1473

Appendix B6 Table 4. Minimum annual consumption estimates (000s mt) and CVs for *Loligo*.

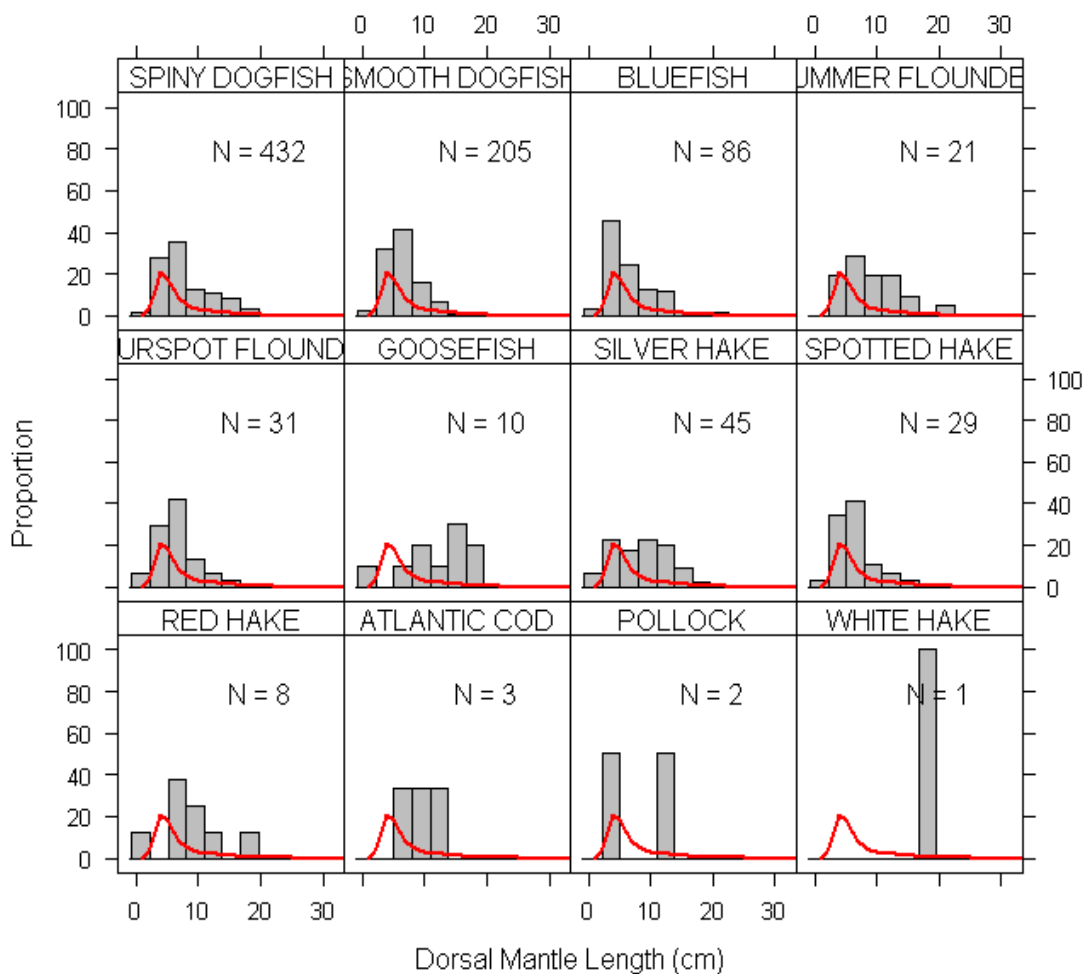
Year	Mimumum consumption (1000 mt)	CV
1977	57.5	0.35
1978	63.7	0.35
1979	73.1	0.35
1980	113.9	0.35
1981	98.1	0.35
1982	180.0	0.68
1983	219.4	0.63
1984	216.0	0.60
1985	41.6	0.75
1986	34.7	0.81
1987	37.6	0.42
1988	38.3	0.47
1989	42.3	0.58
1990	40.2	0.47
1991	30.2	0.48
1992	28.9	0.37
1993	34.4	0.38
1994	50.4	0.61
1995	46.2	0.37
1996	47.0	0.58
1997	15.8	0.50
1998	15.8	0.45
1999	62.6	0.69
2000	71.6	0.39
2001	73.1	0.63
2002	106.8	0.35
2003	125.4	0.35
2004	122.3	0.66
2005	122.5	0.46
2006	117.7	0.43
2007	101.5	0.43
2008	107.4	0.45
2009	80.5	0.45



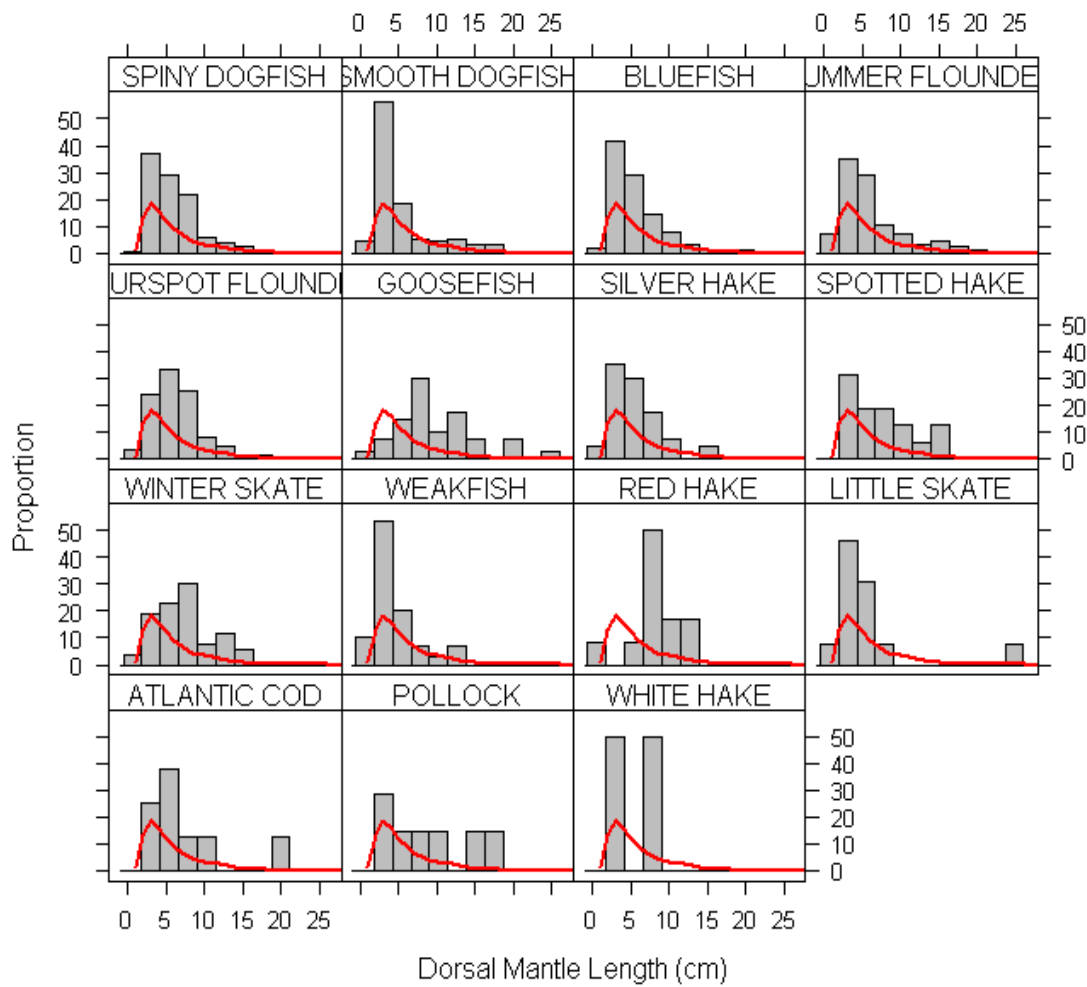
Appendix B6 Figure 1. Minimum seasonal and annual estimates of consumption for *Loligo*.



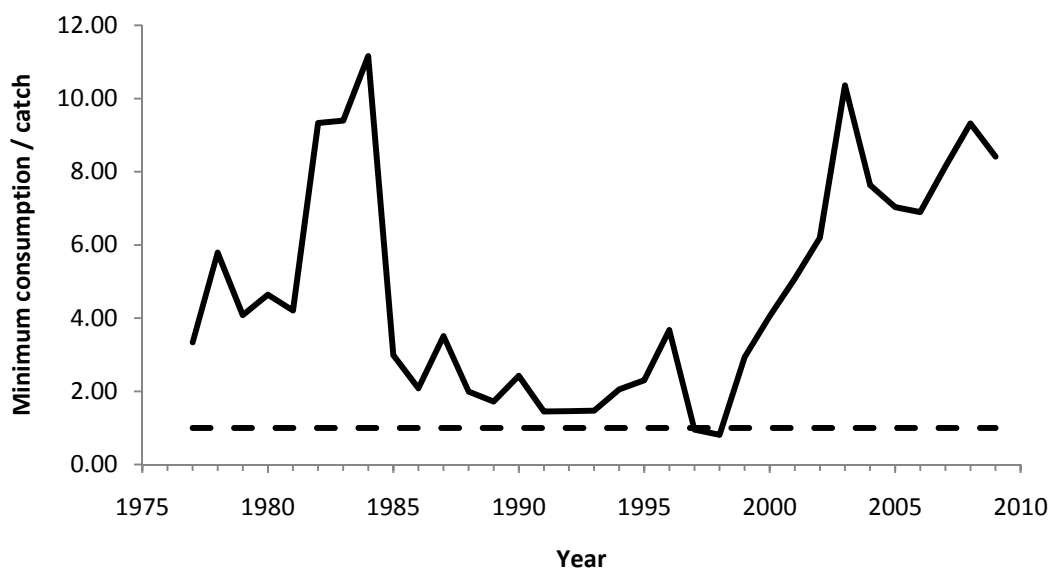
Appendix B6 Figure 2. Annual estimates of minimum consumption and catch for *Loligo*.



Appendix B6 Figure 3. Size frequency of *Loligo* eaten by the predators sampled during spring surveys. The red line shows the average survey length composition during 1975-2009. Numbers in each panel are the number of *Loligo* measured.



Appendix B6 Figure 4. Size frequency of *Loligo* eaten by the predators sampled during fall surveys. The red line shows the average survey length composition during 1975-2009. Numbers in each panel are the number of *Loligo* measured.



Appendix B6 Figure 5. Minimum annual consumption estimates divided by annual catch for *Loligo*. The horizontal line is drawn at one (minimum consumption / catch =1).