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Size-Selectivity of the Commercial Sea Scallop (Placopecten magellanicus) Dredge: Evaluation the Performance of the New Bedford Style Dredge Configured with 4-Inch Rings and a 10-Inch Twine Top using the SELECT Model

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SIZE-SELECTIVITY OF THE COMMERCIAL SEA SCALLOP (*Placopecten magellanicus*) DREDGE

Evaluating the performance of the New Bedford style dredge configured with 4-inch rings and a 10-inch twine top using the SELECT model

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To my mother,
whose support and encouragement have
made all of the difference

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ABSTRACT

A size-selectivity curve was constructed to characterize the performance of the New Bedford style Atlantic sea scallop (*Placopecten magellanicus)* dredge when it is configured to meet the requirements of Amendment #10 to the Sea Scallop Fishery Management Plan. The curve was generated using the SELECT model on catch-at-length data, obtained by simultaneously towing a New Bedford style dredge and a non-selective National Marine Fisheries Service sea scallop survey dredge from commercial scallop vessels. Data were collected during three cruises in the Northwest Atlantic between 2005 and 2006. One cruise was completed in Georges Bank (Groundfish Closed Area II) and two cruises were completed in the mid-Atlantic (both in the Elephant Trunk Closed Area). The resulting selectivity curve for all cruises combined yielded a 50% retention length of 100.1 mm, a selection range of 23.6 mm and a relative efficiency value of 0.77. A length of 100.1 mm corresponds to an age of 4.6 years in Georges Bank and 5.8 years in the mid-Atlantic and a meat-weight of approximately 16 g. This implies that entry into the fishery is being delayed, potentially increasing yield-per-recruit and the population's total reproductive output. The resultant selectivity curve can assist fisheries managers with stock assessments, mortality calculations and with the interpretation of catch data from government and industry-based surveys. Additionally, the curve can be used to evaluate the effect of future changes to sea scallop dredge design.

SIZE-SELECTIVITY OF THE COMMERCIAL SEA SCALLOP (*Placopecten magellanicus*) DREDGE

INTRODUCTION

At present, the Atlantic sea scallop (*Placopecten magellanicus*) (Appendix 1) supports the second most profitable fishery (Appendix 2) in the United States. In 2004, 65 million pounds of meats were landed yielding an ex-vessel value of (US) $322 million (Van Voorhees 2005). In order to ensure the sustainability of this industry and the longevity of the scallop population, substantial effort has been directed to the management of this resource (Appendix 3). While many factors that affect the health of the sea scallop stock are out of human control, fisheries management is a direct way to control anthropogenic impacts. One management strategy is to delay age at recruitment into the fishery. Although scallops begin to spawn after the deposition of their first growth ring (Naidu 1969, Langton et al. 1987), egg production increases exponentially with shell height (Langton et al. 1987). Between the ages of 2 and 6 shell height more than quadruples in size and meat weight almost triples between the ages of 3 and 4 (Serchuk et al. 1979). Therefore, by reducing fishing mortality on younger, smaller scallops, there is the potential to substantially increase yield-per-recruit in future landings and to increase the population's total reproductive output.

The federal Sea Scallop Fishery Management Plan (SSFMP) regulates the configuration of the commercial scallop gear in order to promoted increased selectivity of under sized scallops (NEFMC 1982). The New Bedford style scallop dredge is of particular concern because this is the predominant gear used by the offshore fleet (Smolowitz and Serchuk 1988). Past restrictions for this gear include minimum mesh size restrictions for the twine top, as well as restrictions on the use of chafing gear and on the internal diameter and spacing of the rings. Under the most recent modification (Amendment #10) to the SSFMP, offshore scallop dredges are required to use twine tops with a minimum mesh size of 10-inches (25.4 cm), restrict chafing gear to the bottom of the dredge, use rings with a minimum internal diameter of 4-inches (102 mm) and use no more than double links between rings, except on the dredge bottom where a maximum of triple links may be used (Figures 1, 2) (NEFMC 2003). With the passing of Amendment #10 in 2003, it became necessary to determine how a gear configured with these specifications would perform and if it would attain the goal of selecting against smaller scallops.

Size-selectivity curves have the potential to address both of these concerns because they model the probability that a sea scallop of length *l*, if contacting the gear, will be retained (Millar 1992). This curve can also assist fisheries managers to translate survey abundance into expected yield and can provide insight into how the gear is interacting with scallops of a given length. Additionally, because gear selectivity measurements are used in connection with fishing mortality calculations, this information can assist fisheries managers in making stock assessments (Wileman et al. 1996). Furthermore, a selection curve provides insight into incidental morality and assists with yield-per-recruit analysis and the estimation of population length frequency (Millar and Fryer 1999).

Several studies have been conducted to evaluate the performance of the New Bedford ("commercial") style dredge (Bourne 1965, Caddy 1972, DuPaul and Kirkley 1994, Brust et al. 1995, Rudders et al. 1998, Rudders et al. 2000, Goff 2002) (Appendix 4); however, an absolute size-selectivity curve for this gear, configured according to current management requirements, has not been created. In order to do this, catch from the commercial (experimental) gear must be compared to that from a non-selective (control) gear. With these data, the Share Each LEngth's Catch Total (SELECT) model developed by Millar (1992) can be used to generate the curve. This model has been successful with evaluating the selection properties of fishing gear, including: traps, dredges, hooks and nets (trawl, gill and seine) (Millar 1992, Millar and Walsh 1992, Xu and Millar 1993, Millar and Holst 1997, Millar and Fryer 1999, Revill and Holst 2004, Gálvez and Rebolledo 2005, Mituhasi et al. 2005).

The SELECT model has become the preferred method for evaluating gear selectivity because it is biologically meaningful, does not require knowledge of the actual population length distribution and, because the model conditions on the total catch, it avoids the problem of dividing by zero and it allows the data to be modeled as binary data. Additionally, the SELECT model incorporates a parameter that denotes relative fishing intensity between the two gears (experimental and control). This is the split parameter, p_j, which accounts for how catch among gears (j=1,..., n) will vary due to affects such as differential fishing effort, fish avoidance behavior and localized fish concentrations (Millar 1992). It is the probability that a fish entered gear j, given that it entered the combined gear. In addition to estimating p_j, the SELECT model can be used to estimate two other factors often used to characterize selection. These are: the 50% retention length (l_{50}), the length at which a scallop has a 50% probability of being retained after entering the gear, and the selection range (SR), the difference between the 75% and 25% retention lengths (l_{75} - l_{25}), which is a measure of how quickly the 100% retention length is approached, i.e., the steepness of the curve.

The objective of this study was to use the SELECT model to generate a size-selectivity curve for the offshore New Bedford style sea scallop dredge configured to meet the requirements of Amendment #10 to the SSFMP. To accomplish this, catch from the commercial dredge was compared to that from the National Marine Fisheries Service (NMFS) survey ("survey") dredge, which served as the control gear in this study. The survey dredge is assumed to be non-selective because there is a liner sewn into the dredge bag which prohibits scallops from escaping.

In order to create a selectivity curve that is representative of the offshore commercial fleet, sampling was conducted aboard commercial scallop vessels, under conditions that mimicked commercial practices and the experiments were performed during different months and in different areas, which contained a variety of substrates. The only aspect of this study that is not representative of commercial practices is tow duration; however, an assessment of how the number of baskets of scallops and trash caught in the commercial dredge affects the parameters of the selectivity curve was made. This served as a proxy for how tow duration might affect the selection process. It must be noted, though, that tow duration does not predict the size of the catch.

MATERIALS AND METHODS

Data Collection

In August, September and October of 2005 and in June of 2006, four cruises were completed aboard commercial sea scallop vessels; two in Georges Bank (one in the Nantucket Lightship Closed Area (NLCA) and one in the Groundfish Closed Area II (CA2)) and two in the mid-Atlantic (both in the Elephant Trunk Closed Area (ETCA)) (Table 1, Figure 3) [The results for the NLCA cruise will be presented separately because the gears used in this area were configured differently than in the others (Appendix 5).] Within each area, pre-determined stations (Figure 4), selected within a systematic random grid, were sampled. At each station, a standard NMFS survey dredge was towed simultaneously with a New Bedford style commercial sea scallop dredge. Simultaneously towing the two dredges from the same vessel allowed for similar type of substrate and population of scallops to be sampled. The survey dredge was 8-feet (2.4 m) in width, was configured with 2-inch (51 mm) rings, a 3.5-inch (89 mm) diamond mesh twine top, and a 1.5-inch (3.8 cm) diamond mesh liner and the commercial dredges were 15-feet (4.6 m) in width, had 4-inch (102mm) rings, a 10-inch (25.4 cm) mesh twine top and no liner. Some aspects of the commercial gear configuration varied on the different vessels used for this study (e.g., length of the sweep chain and hanging ratio), but this is advantageous since this variation exists within the actual commercial fleet. Rock chains and chafing gear were used on both dredges as dictated by the area surveyed and current regulations.

The duration of each tow was approximately 15 minutes and towing speed was 3.8 knots. Depth range varied in each area; however, a 3:1 wire scope (the ratio of the amount of wire out to the vertical distance from the boat to the seafloor) was attempted for all tows (Table 2). In order to determine bottom contact time and to ensure that the gear was fishing correctly, an inclinometer was attached to the survey dredge. Also, high-resolution navigational logging equipment was used to document tow time, vessel position, speed over ground and bearing. During each cruise the survey dredge was towed from the port side of the vessel for the first half of the stations and from the starboard side for the remainder in order to counteract any random effect associated with fishing from a particular side.

Upon completion of each tow, the entire catch from both gears was emptied on deck. Scallops were then sorted out of the catch and placed into baskets. The number of baskets from each side was counted and a fraction of these was measured. Shell height (the longest distance between the umbo and the outer margin of the shell) measurements of the scallops were made in 5 mm increments on counting boards. Additionally, all bycatch was quantified and trash (anything other than scallops or finfish, including rocks and invertebrate bycatch) was counted in baskets.

Data Analysis

Each tow was evaluated and deemed invalid if any of the following conditions were observed: hangs, flips, crossing or tangling of the gear, the tow was not deemed "good" in the comments section of the deck or bridge log, the inclinometer indicated that the gear was not fishing correctly, no scallops were caught or there were fewer than 20 scallops caught in either dredge. A catch of less than 20 suggests that there were actually no scallops present at the station; rather, scallops from a preceding tow may have been lodged in the dredge or left on deck.

The number of scallops caught per length class, from each gear, was multiplied by an expansion factor equal to the number of baskets of scallops caught divided by the number of baskets measured. The tows were then combined by cruise, closed area, year and all tows together. For each tow and combination of tows, a plot was made of the ratio of the number of scallops in each length class in the commercial dredge to the total in both dredges (Commercial/Total) in order to determine if the commercial gear was behaving selectively. This assessment validated proceeding with the analysis.

The catch-at-length data for each tow combination were then analyzed with the SELECT model (Millar 1992). This model equates the proportion of scallops (of length l) that are caught in the commercial gear out of the total catch from both gears ($\Phi(l)$) to:

1. $$\Phi(l) = \frac{p_c r_c(l)}{p_c r_c(l) + (1 - p_c)}$$

Selectivity of the commercial gear, $r_c(l)$, is the probability that a fish of length l will be retained given that it enters the gear and the split parameter, p_c, describes the relative fishing intensity or efficiency of the commercial dredge (Millar 1992).

Dredge selectivity tends to reflect the logistic function; however, alternative models (e.g., the Richards, log-log and complementary-log-log curves) may also be appropriate. An examination of the deviance residuals and the Akaike Information Criterion (AIC) may be used to determine the most appropriate model. If selection of the commercial gear follows the logistic model, it is equal to:

$$2. \qquad r_c(l) = \frac{\exp(a+bl)}{1+\exp(a+bl)}$$

Substituting this into the SELECT model yields:

$$3. \qquad \Phi(l) = \frac{p_c \exp(a+bl)}{(1-p_c)+\exp(a+bl)}$$

where a and b are the logistic parameters and p_c is the split-parameter. Estimates of these parameters are generated by maximizing the likelihood:

4.

$$L(a,b,p_c|data) = \prod_{l=7.5}^{177.5} \left(\frac{p_c \exp(a+bl)}{(1-p_c)+\exp(a+bl)}\right)^{C_C} \left(1-\frac{p_c \exp(a+bl)}{(1-p_c)+\exp(a+bl)}\right)^{C_S}$$

C_C is the number of length l scallops in the commercial gear and C_S is the number of length l scallops in the survey gear. The lengths (l) are the mid-points of each length class (i.e., length “7.5 mm” represents the length class 5-10 mm). To generate the selectivity curve, estimated values for parameters a and b are reinserted into the logistic equation (Equation 2). The resultant curve is symmetric about l_{50} and the shape is determined by the selection range. The l_{50} and the SR relate to parameters a and b by:

$$5. \qquad SR = \frac{2\ln(3)}{b} \qquad \text{and} \qquad l_{50} = \frac{-a}{b}$$

The data were evaluated using the R-Statistical Program for Windows (R). Code to implement this analysis was written by Dr. Russell Millar and can be found on his website (http://www.stat.auckland.ac.nz/~millar/). For validation, the analysis was also completed in Excel using the Solver function.

Due to variation in wind speed, water depth, sea state, scallop density and other factors that cannot be controlled, there is variation in selectivity from one tow to the next. This must be considered when tows are combined. A test for overdispersion (variation exceeding that which is predicted by the model) was completed using the replication estimate of between-haul variation (REP) combined hauls approach discussed in Millar et al. 2004. REP is the Pearson chi-square statistic for model goodness of fit divided by the degrees of freedom, which is the number of terms in the summation minus the number of fitted parameters. If the null hypothesis that there is no extra variation is rejected then REP provides an estimate of the overdispersion in the combined hauls analysis and the standard errors of the parameters are multiplied by the square root of REP (Millar et al. 2004). In order to avoid over-inflating the degrees of freedom for this analysis, only length classes where, when all tows are combined, one dredge has caught at least 20 scallops were used. In order to determine if this affected the estimated parameters, the model was run under this criterion as well as under the criteria that, for each length class, at least one dredge had more than: 1) zero scallops, 2) 60 scallops and 3) 1,000 scallops. In general, with fewer length classes used in the analysis, the 50% retention length, selection range, split parameter and log likelihood values all increased; however, these changes were not substantial (Table 3).

The final analysis was evaluating the effect of increased trash and scallop catch on the estimated selectivity parameters. This approximated how the reduction in duration for the survey tows (as compared to longer commercial tows) might have influenced the results. This ensures that the resultant selectivity curve is representative of commercial practices. For this assessment, tows from all three cruises were grouped into five categories based on the number of baskets of scallops caught in the commercial dredge: 1) fewer than three, 2) three to six, 3) six to twelve, 4) twelve to twenty-four, and 5) more than twenty-four. These increments were chosen because there was a similar number of tows that fit into each group. A selectivity curve was generated for each category, using the same length classes that were used to evaluate all tows combined. A Spearman's rank correlation coefficient analysis was then completed on the resulting l_{50}, SR and p_c values. This procedure was repeated with increasing baskets of trash. Categories for this analysis were based on the number of baskets of trash in the commercial dredge: 1) less than 0.25, 2) 0.25 to one, 3) one, 4) one to two, and 5) more than two.

RESULTS AND DISCUSSION

The catch-at-length data (Table 4, Figure 5) obtained during this study were evaluated with the SELECT model using the logistic as well as Richards, log-log and complementary-log-log curves in order to determine the most appropriate model for the data. The deviance residuals from the logistic fit showed no considerable trends and the curve adequately fit the data. The other three curves did not significantly improve the fit, based on AIC values, and, therefore, the results will only be presented for the logistic SELECT model. Also, the REP assessment for combining multiple tows indicated that there was extra variation for all tow combinations (by cruise, year, area and all combined) and, therefore, the standard errors for the estimated parameters were multiplied by the square root of REP.

Estimated parameters are given in Table 5 and the fitted curves and deviance residuals are in Figure 6. A common feature for all tow combinations is that at the largest sizes the proportion caught in the commercial dredge decreases. This causes a pattern in the residuals, namely that residuals at the larger lengths are negative (Figure 6). This is not of concern since the data points for these sizes are influenced by only a handful of tows which makes them susceptible to outlying information. For example, the "152.5 mm" data point for the ETCA 2005 SELECT curve is influenced primarily by two tows which had only a few scallops at that length in the survey dredge and none in the commercial. When these data were multiplied by the expansion factor the discrepancy between the two dredges was exaggerated. Additionally, patterns in the residuals attributed to this are not significant because when these outlying length classes were removed there is no considerable change in the estimated parameter values (Table 3).

The *a* and *b* parameters estimated for each combination of tows were inserted into the logistic selectivity curve equation (Equation 2). The range of l_{50} values from the different combinations of data was 98.1-105.2 mm (a small difference of 7.1 mm) and of selection range values was 18.6-28.7 (Table 5, Figure 7).

The final results are those that were estimated for all valid tows for the CA2 2005, ETCA 2005 and ETCA 2006 cruises combined since an evaluation of the resulting parameters and confidence intervals from all combinations of data (by cruise, area and year) revealed little significant difference (Figure 8). Additionally, by including tows from multiple cruises on different vessels, during different times of the year and in different areas and substrates the selectivity curve becomes more representative of the commercial fleet. The resulting SR for this analysis is 23.6 mm and the l_{50} is 100.1 mm (Figure 9). The estimated split parameter is 0.77, indicating that the commercial dredge is fishing more efficiently than the survey dredge. If the two gears were equally efficient, then the difference in the number of scallops entering the dredges would be a function of the width of the gears and the split parameter value for the commercial dredge would be equal to $\frac{15}{(15+8)}$ or 0.65. However, the resulting value, 0.77, indicates that other factors are affecting efficiency. A possibility, based on a study conducted by Serchuk and Smolowitz (1980), is that the liner decreases the efficiency of the survey dredge.

Using the Von Bertalanffy growth model and the parameters from Serchuk et al. (1979), the resultant l_{50} value of 100.1 mm indicates that sea scallops that have a 50% probability of retention are 4.6 years old in Georges Bank and are 5.8 years old in the Mid-Atlantic (Figure 10). Also, using the NEFSC 2001 shell height-meat weight parameters this shell height would yield a meat weight of 16.1 g in Georges Bank and 16.2 g in the Mid-Atlantic. These results imply that scallops are being recruited into the fishery after realizing much of their substantial growth potential in their early years of life. This suggests that the current commercial gear being used in sea scallop harvest is promoting higher yield-per-recruit. Additionally, because entry into the fishery is being delayed, harvested scallops have potentially been able to increase their spawning potential based on results from Langton et al. (1987) indicating that gamete production increases exponentially with shell height.

The final analysis was to evaluate how increasing number of baskets of trash and scallops caught in the commercial dredge might affect the estimated selectivity parameters. This served as an indication of whether the results were affected by the reduced tow duration used in this study. The Spearman's rank correlation coefficient significantly indicated that with increasing number of scallops the selection range and the split parameter values increase. While the results for the 50% retention length appear to show a similar trend, the results were not significant (Table 6, Figure 11). These results are not surprising since, as the volume of scallops increases there is increased potential for the rings and inter-rings spaces to clog, resulting in the retention of smaller scallops as well as of more scallops over all length classes. In contrast, none of the evaluated parameters showed a significant relationship with increasing number of baskets of trash; however, the l_{50} values show a decreasing trend with increasing baskets of trash (Table 7, Figure 12). It can be assumed that the selectivity curve generated in this study does represent commercial practices since there is not a significant difference in the l_{50} values with increasing baskets of scallops or trash. Additionally, during the survey cruises, the dredge bag ranged from being empty to completely full, which mirrors the range observed during commercial operations.

Results from this study will benefit sea scallop managers with stock assessments and with the forecast of future yield. Since a comparison between "selectivity curves for two different gear configurations is the only fully satisfactory means of describing how the gear selectivity has changed when developing new towed gears (Wileman et al. 1996)," the resultant selectivity curve will assist in predicting how potential changes to the dredge configuration might affect the resource and industry.

To maximize the effectiveness of the resulting curve from this study, more information is required regarding incidental mortality and the fate of scallops that interact with or escape from the commercial dredge and of the scallops that are landed on deck but are not harvested. Scallops that enter the gear sustain injury from physical contact with the gear and from interactions inside and scallops that pass under the dredge can be damaged or killed. Scallops landed on deck endure prolonged air exposure, handling processes and, if not kept, being shoveled overboard. Additionally, because the gear turns up sediment, sand and mud are dislodged into the animals, which can weaken or kill them. Also, scallops trying to avoid the gear by swimming grow tired and become more vulnerable to predation (Medcof and Bourne 1964, Caddy 1968, 1973, Jenkins and Brand 2001). This effect is worsened by the fact that predatory fish and crabs are attracted to the tracks left by the dredge within an hour of fishing (Caddy 1968, 1973). An assessment on the impact of these variables would enhance the utility of the selection curve.

TABLES

Table 1 Cruise and vessel information.

Cruise	NLCA 2005	CA2 2005	ETCA 2005	ETCA 2006
Location	Nantucket Lightship Closed Area	Groundfish Closed Area II	Elephant Trunk Closed Area	Elephant Trunk Closed Area
Dates of Survey	August 19-24	September 17-23	October 10-12, 18-23	June 5-12
Year	2005	2005	2005	2006
Vessel	F/V *Westport*	F/V *Celtic*	F/V *Carolina Boy*	F/V *Carolina Boy*
Length (ft)	88.1	88.1	85.3	85.3
Gross Tonnage	196	199	195	195
Captain	Edie Welch	Charlie Quinn	Rodney Watson	Rodney Watson

Table 2 **Information regarding valid tows and survey stations and conditions.**

Cruise	NLCA 2005	CA2 2005	ETCA 2005	ETCA 2006
Average Station Depth (fathoms)	36	40	28	28
Station Depth Range (fathoms)	28-43	32-51	18-39	20-38
Average Minimum/Maximum Wind Speed (knots)	7/12	9/15	11/18	11/17
Average Minimum/Maximum Sea State (feet)	2/4	2/4	2/5	3/5
Average Tow Duration (minutes)	14.6	15.8	14.7	15.7
Average Vessel Speed (knots)	3.8	3.8	3.8	3.8
Average Scope	3.1	3.1	3.0	3.0
Number of Tows Used in the Analysis	35	54	50	69

Table 3 **Estimated 50% retention lengths (l_{50}), selection ranges (SR= l_{75} - l_{25}) and relative efficiency split parameter (p_c) values for when the data were analyzed under the criteria that, for each length class, at least one dredge: 1) had scallops, 2) had more than 20 scallops, 3) had more than 60 scallops and 4) had more than 1,000 scallops. The second criterion (entries in bold) represents that which is used for this study. Lengths used in the analyses and the log likelihoods (L) values are given.**

Cruise(s)		≥0	≥20	≥60	≥1000
CA2 2005	**Lengths**	27.5-167.5	**47.5-162.5**	52.5-157.5	62.5-147.5
	l_{50} (mm)	105.154	**105.158**	105.185	105.263
	SR (mm)	18.599	**18.602**	18.623	18.906
	p_c	0.760	**0.760**	0.760	0.761
	L	-44824	**-44814**	-44773	-44384
ETCA 2005	**Lengths**	7.5-172.5	**22.5-152.5**	27.5-152.5	77.5-137.5
	l_{50} (mm)	98.871	**98.918**	98.918	99.379
	SR (mm)	19.992	**20.023**	20.024	20.124
	p_c	0.770	**0.771**	0.771	0.774
	L	-92432	**-92396**	-92396	-90342
ETCA 2006	**Lengths**	27.5-162.5	**27.5-152.5**	32.5-152.5	67.5-142.5
	l_{50} (mm)	104.150	**104.153**	104.153	104.542
	SR (mm)	28.708	**28.710**	28.710	29.049
	p_c	0.798	**0.798**	0.798	0.800
	L	-173215	**-173197**	-173197	-172008
CA2 & ETCA 2005	**Lengths**	7.5-172.5	**22.5-162.5**	27.5-157.5	62.5-147.5
	l_{50} (mm)	98.076	**98.080**	98.088	98.349
	SR (mm)	18.806	**18.809**	18.815	19.218
	p_c	0.758	**0.758**	0.758	0.760
	L	-137466	**-137452**	-137406	-136673
ETCA 2005 & 2006	**Lengths**	7.5-172.5	**22.5-157.5**	27.5-152.5	47.5-142.5
	l_{50} (mm)	101.444	**101.444**	101.478	101.954
	SR (mm)	25.037	**25.037**	25.060	25.492
	p_c	0.785	**0.785**	0.785	0.788
	L	-265847	**-265847**	-265793	-264890
CA2 2005, ETCA 2005 & ETCA 2006	**Lengths**	7.5-172.5	**22.5-162.5**	27.5-157.5	47.5-147.5
	l_{50} (mm)	100.110	**100.113**	100.120	100.353
	SR (mm)	23.608	**23.611**	23.616	23.850
	p_c	0.774	**0.774**	0.775	0.776
	L	-311049	**-311035**	-310987	-310200

Table 4 **Catch-at-length data (all valid tows combined) for the commercial (C) and survey (S) dredges. A length of "7.5" represents the length class 5-10 mm. All values have been scaled up by the expansion factor equal to the number of baskets of scallops caught divided by the number measured.**

	NLCA 2005		CA2 2005		ETCA 2005		ETCA 2006		CA2 & ETCA 05		ETCA 05 & 06		CA2 05, ETCA 05 & 06	
Length	**C**	**S**	**C**	**S**	**C**	**S**	**C**	**S**	**C**	**S**	**C**	**S**	**C**	**S**
7.5						2				2		2		2
12.5						3				3		3		3
17.5						10				10		10		10
22.5						23				23		23		23
27.5						85		20		86		106		107
32.5						287		105		287		392		392
37.5		5				591	2	94		591	2	685	2	685
42.5		33		7	5	593	0	257	5	600	5	850	5	857
47.5		32		31	0	759	53	387	0	791	53	1146	53	1177
52.5	14	68		189	16	675	24	542	16	864	41	1216	41	1405
57.5		96		420	0	393	32	470	0	813	32	863	32	1283
62.5	11	59	40	1013	55	656	121	788	95	1669	176	1444	216	2457
67.5		60	29	1002	62	749	313	1120	91	1750	376	1869	404	2871
72.5	11	71	48	569	234	859	801	1916	281	1428	1035	2776	1083	3344
77.5	31	85	28	242	353	1294	1656	3180	381	1535	2009	4474	2037	4715
82.5	53	168	17	136	1318	2159	3816	5766	1334	2295	5134	7925	5150	8061
87.5	103	427	17	110	2466	3166	6933	8559	2483	3276	9399	11724	9416	11835
92.5	269	388	56	171	4260	4237	12212	11358	4316	4408	16472	15594	16528	15766
97.5	335	354	157	164	6562	5143	15039	11023	6720	5307	21601	16166	21759	16330
102.5	775	294	617	385	11534	5920	21250	11318	12151	6305	32784	17239	33401	17623
107.5	1742	864	2007	1018	16285	6132	22789	9511	18292	7150	39074	15642	41081	16660
112.5	3051	1215	5135	2307	16878	5167	24908	8926	22013	7474	41786	14093	46921	16400
117.5	2635	556	7542	3270	14860	4963	21263	7467	22402	8233	36123	12429	43666	15699
122.5	4332	1505	11317	3781	13419	4156	20545	5592	24736	7937	33965	9747	45282	13529
127.5	7466	2456	11248	3802	9124	3097	17517	5385	20372	6899	26641	8482	37890	12284
132.5	13461	4120	7929	2624	4713	1760	10507	3741	12643	4384	15220	5501	23150	8125
137.5	13146	4141	5188	1610	1771	627	4873	1379	6959	2237	6644	2006	11832	3616
142.5	8768	2656	2547	855	551	234	1491	370	3098	1090	2042	605	4589	1460
147.5	5602	1807	1212	416	273	117	358	129	1485	533	631	246	1843	662
152.5	3404	1180	386	111	55	118	97	62	441	229	152	179	538	290
157.5	1685	499	144	56	3	17	17	7	147	73	20	25	164	81
162.5	468	241	45	20	3	3	8		47	23	10	3	55	23
167.5	142	61	12	5		2			12	7		2	12	7
172.5	27	19				1				1		1		1
177.5	14	18												

Table 5 Estimated parameters from the logistic SELECT analyses on catch-at-length data for all length classes with at least 20 scallops in one of the dredges. Listed are lengths used in the analyses and the starting values to estimate the parameters in both R and Excel. The estimated values (left column) for logistic parameters *a* and *b*, as well as the 50% retention length (l_{50}), the selection range (SR= l_{75}-l_{25}) and the relative efficiency split parameter (p_c) are given. The number of tows (No. Tows) used for each analysis, log likelihood (L) and the replication estimate of between-haul variation (REP) are specified as well as the standard errors (right column), which have been multiplied by the square root of REP.

	CA2 2005		ETCA 2005		ETCA 2006		CA2 & ETCA 2005		ETCA 2005 & 2006		CA2 2005, ETCA 2005 & 2006	
Lengths	47.5-162.5		22.5-152.5		27.5-152.5		22.5-162.5		22.5-157.5		22.5-162.5	
Start values	(-13, 0.13, 0.8)		(-10, 0.1, 0.75)		(-12, 0.12, 0.8)		(-11, 0.11, 0.8)		(-12, 0.12, 0.8)		(-12, 0.12, 0.8)	
a	-12.42		-10.85		-7.97		-11.46		-8.90		-9.32	
b	0.12		0.11		0.08		0.12		0.09		0.09	
p_c	0.76	0.005	0.77	0.006	0.80	0.007	0.76	0.004	0.79	0.005	0.77	0.004
$l_{50\,(mm)}$	105.16	1.11	96.42	0.94	104.14	1.30	98.09	0.63	101.44	0.80	100.11	0.60
SR (mm)	18.61	0.91	20.02	0.92	28.70	1.13	18.82	0.64	25.03	0.74	23.61	0.59
L	-44814		-92396		-173197		-137452		-265836		-311035	
REP	4.54		8.73		8.51		7.09		8.79		7.98	
No. Tows	54		50		69		104		119		173	

Table 6 **Estimated logistic parameters (*a* and *b*), 50% retention lengths (l_{50}), selection ranges (SR= l_{75}- l_{25}), and relative efficiency split parameter (p_c) and log likelihood (L) values for the logistic SELECT analyses on tows in the following categories: tows with 1) fewer than three, 2) three to six, 3) six to twelve, 4) twelve to twenty-four, and 5) more than twenty-four baskets of scallops caught in the commercial dredge. The number of tows used for each analysis is given.**

	<3	3≤ x <6	6≤ x<12	12≤ x <24	≥24
a	-25.18	-17.76	-11.68	-10.73	-7.02
b	0.23	0.16	0.11	0.10	0.07
p_c	0.72	0.75	0.77	0.77	0.81
L	-7151	-17160	-32433	-69566	-179168
l_{50} **(mm)**	108.01	108.66	104.74	105.21	100.68
SR (mm)	9.42	13.44	19.70	21.55	31.49
No. Tows	38	37	32	33	33

Table 7 **Estimated logistic parameters (*a* and *b*), 50% retention lengths (l_{50}), selection ranges (SR= l_{75}- l_{25}), and relative efficiency split parameter (p_c) and log likelihood (L) values for the logistic SELECT analyses on tows in the following categories: tows with 1) less than 0.25, 2) 0.25 to one, 3) one, 4) one to two, and 5) more than two baskets of trash caught in the commercial dredge. The number of tows used for each analysis is given.**

	≤0.25	**0.25< x <1**	**x=1**	**1< x <2**	**≥2**
a	-8.19	-10.41	-8.80	-12.34	-10.04
b	0.08	0.10	0.09	0.12	0.09
p_c	0.79	0.76	0.78	0.78	0.78
L	-96656	-47245	-64144	-46010	-56088
l_{50} (mm)	100.06	99.80	101.37	101.25	107.94
SR (mm)	26.83	21.07	25.30	18.03	23.62
No. Tows	39	38	26	30	40

FIGURES

Figure 1 **Scallop dredge configuration (not drawn to scale): a) top side and b) under side, without chafing gear attached. (Diagrams courtesy of Kevin Goff)**

Top Side

A)

Under Side

B)

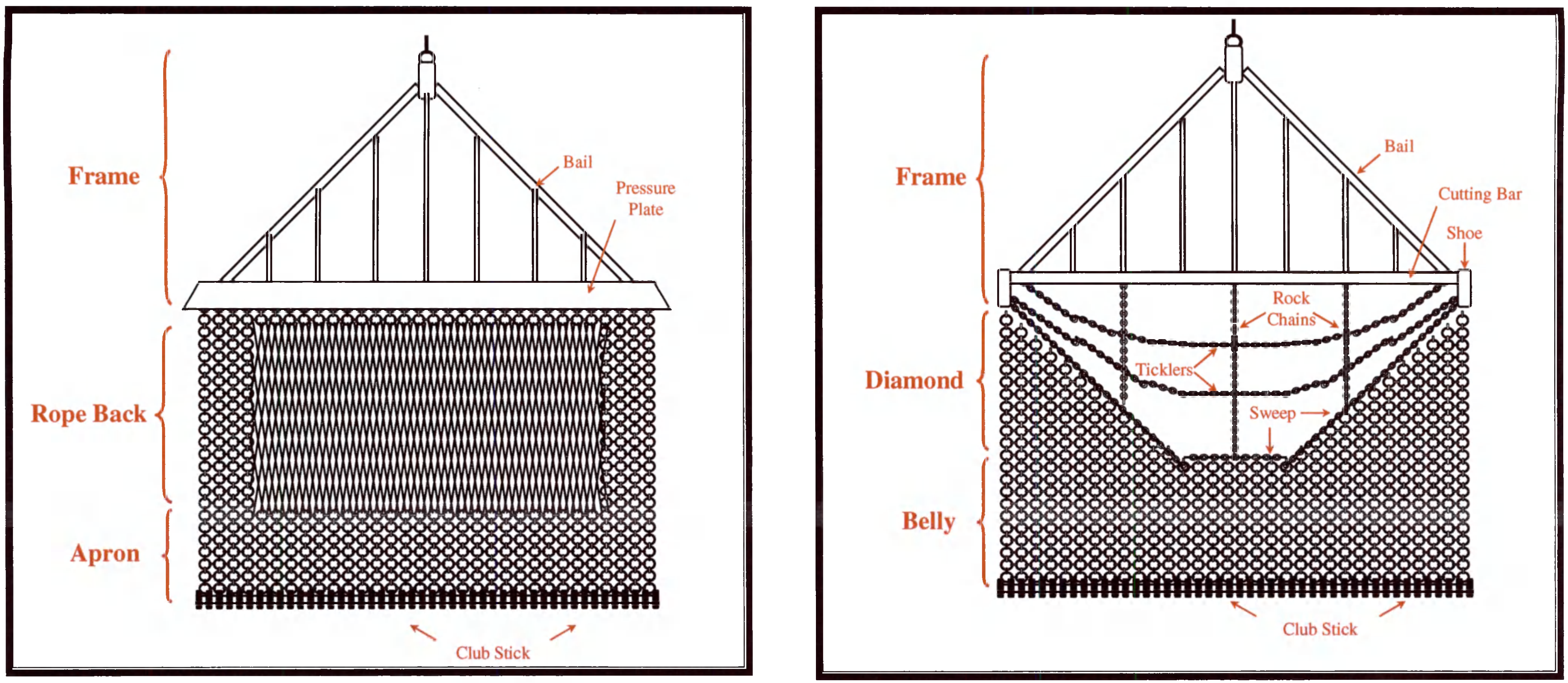
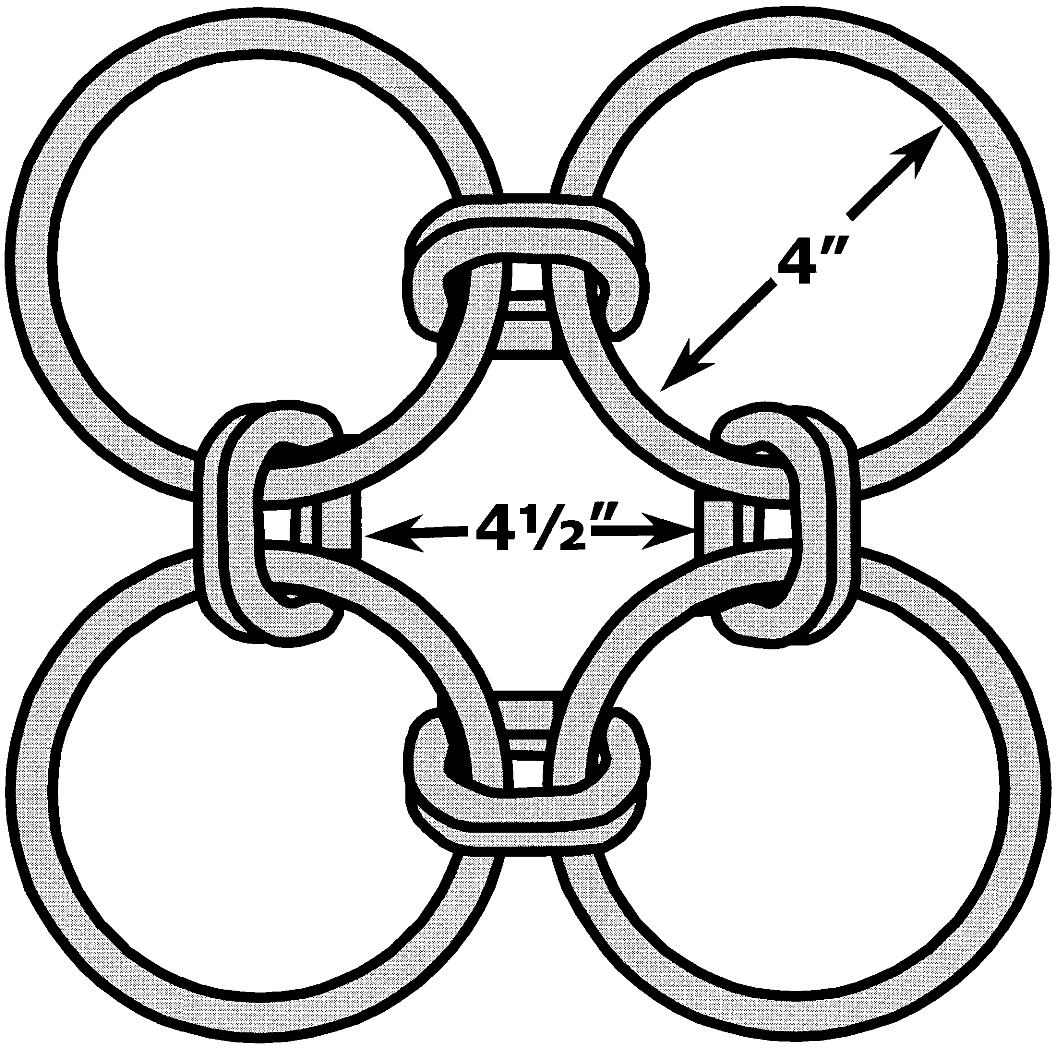
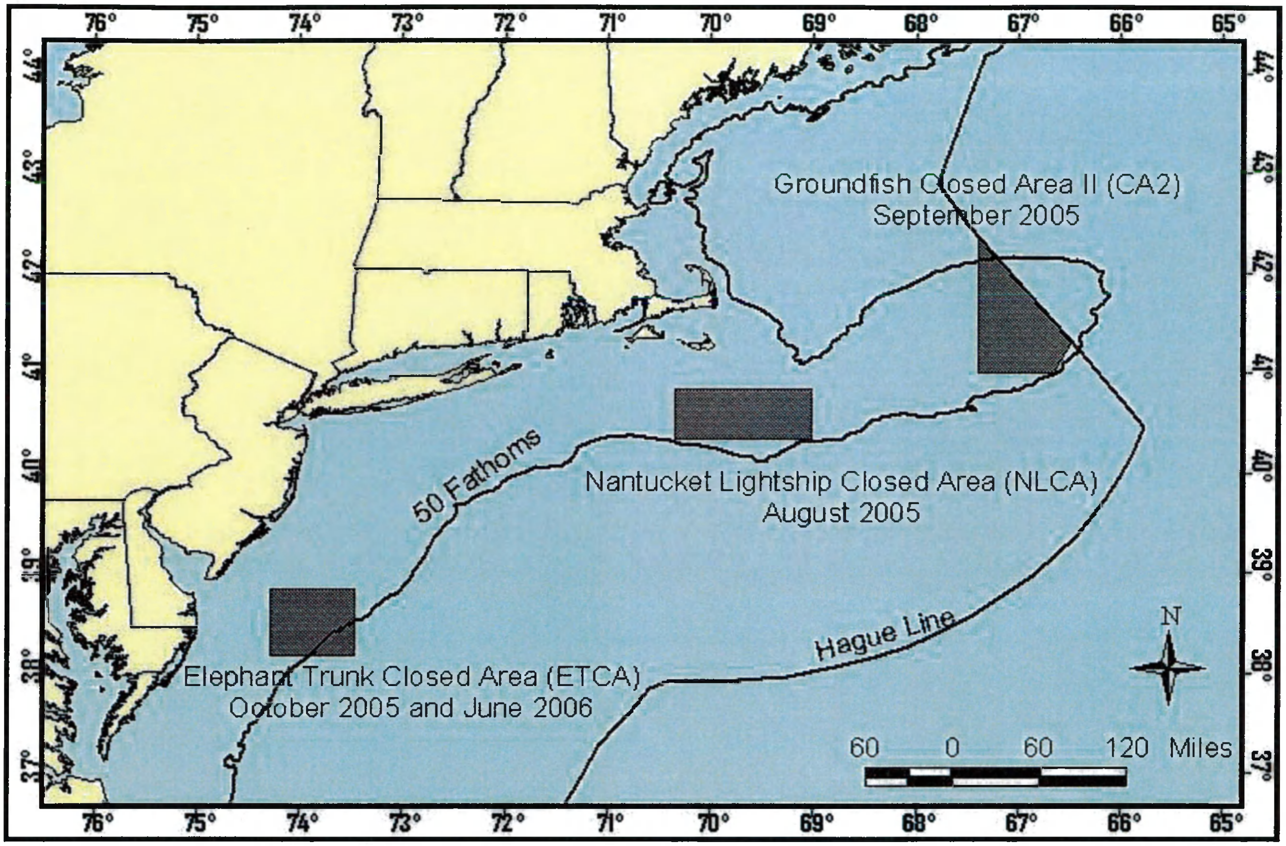


Figure 2 **Ring measurements, including the internal diameter ("ring size") and the inter-ring spacing. 4-inch rings with split links are shown. When lying flat, the inter-ring spacing is approximately 4.5-inches (115 mm). This can be increased up to 6.75-inches (170 mm) if twisted and pulled. Additional links will affect these values. (Diagram courtesy of Kevin Goff)**



4″
4½″

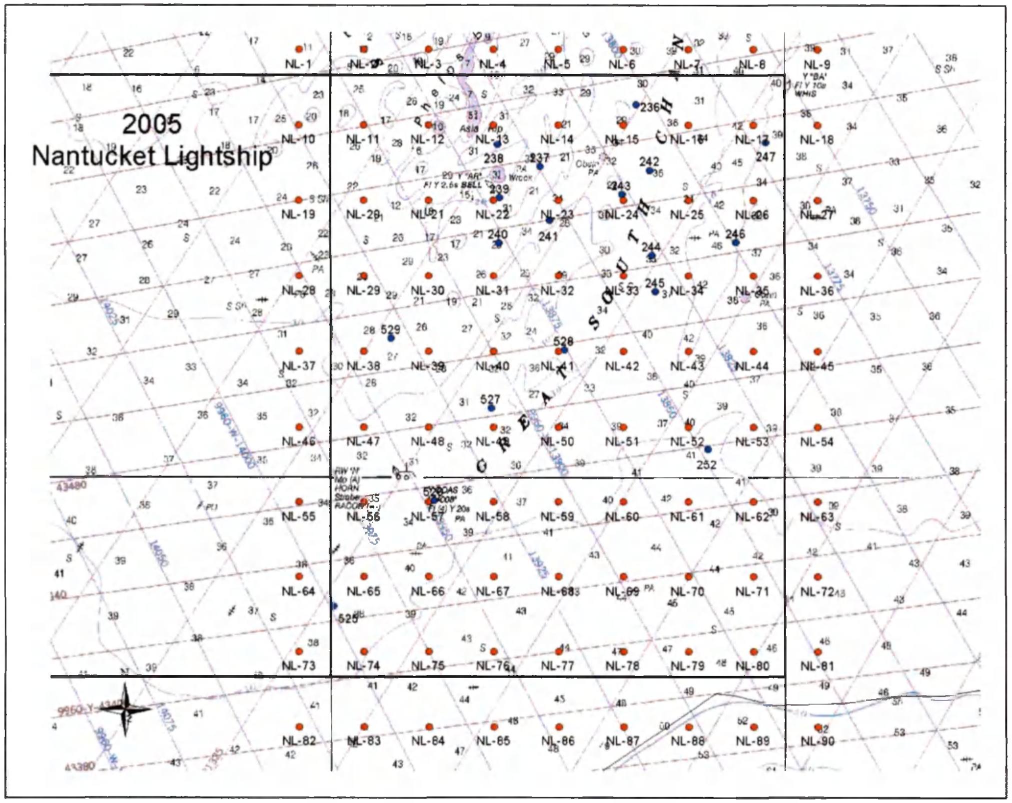
Figure 3 Locations of the closed areas surveyed for this study.



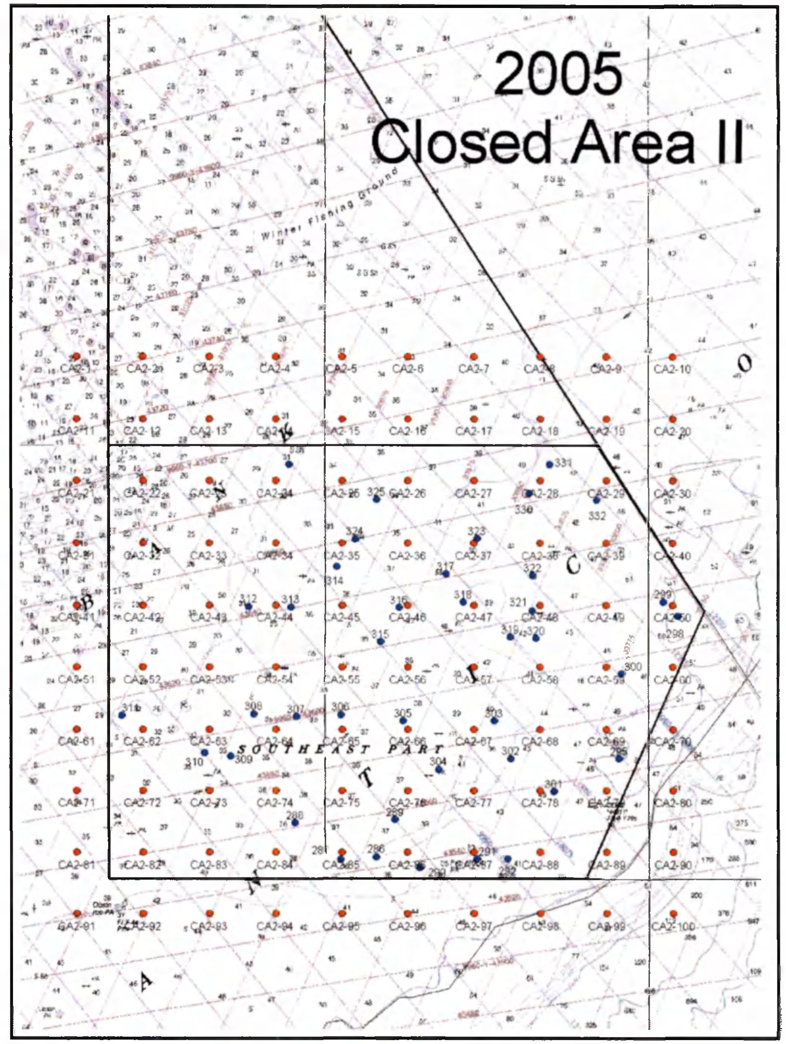
Groundfish Closed Area II (CA2)
September 2005
Nantucket Lightship Closed Area (NLCA)
August 2005
Elephant Trunk Closed Area (ETCA)
October 2005 and June 2006
50 Fathoms
Hague Line
N
60 0 60 120 Miles
76° 75° 74° 73° 72° 71° 70° 69° 68° 67° 66° 65°
44° 43° 42° 41° 40° 39° 38° 37°

Figure 4 **Systematic random stations generated for this study. All stations within the closed area boundary were surveyed for cruises: a) Nantucket Lightship Closed Area 2005, b) Groundfish Closed Area II 2005, c) Elephant Trunk Closed Area 2005, and d) Elephant Trunk Closed Area 2006.**

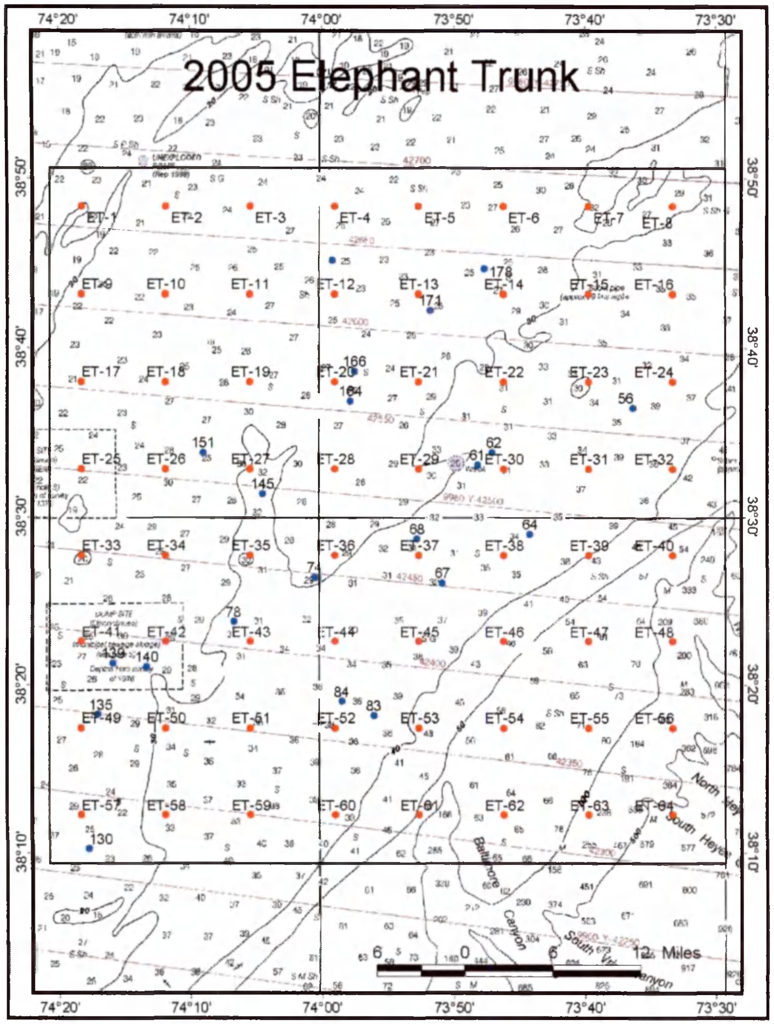
A)



B)



C)


2005 Elephant Trunk
74°20'
74°10'
74°00'
73°50'
73°40'
73°30'
38°50'
38°40'
38°30'
38°20'
38°10'
12 Miles

D)

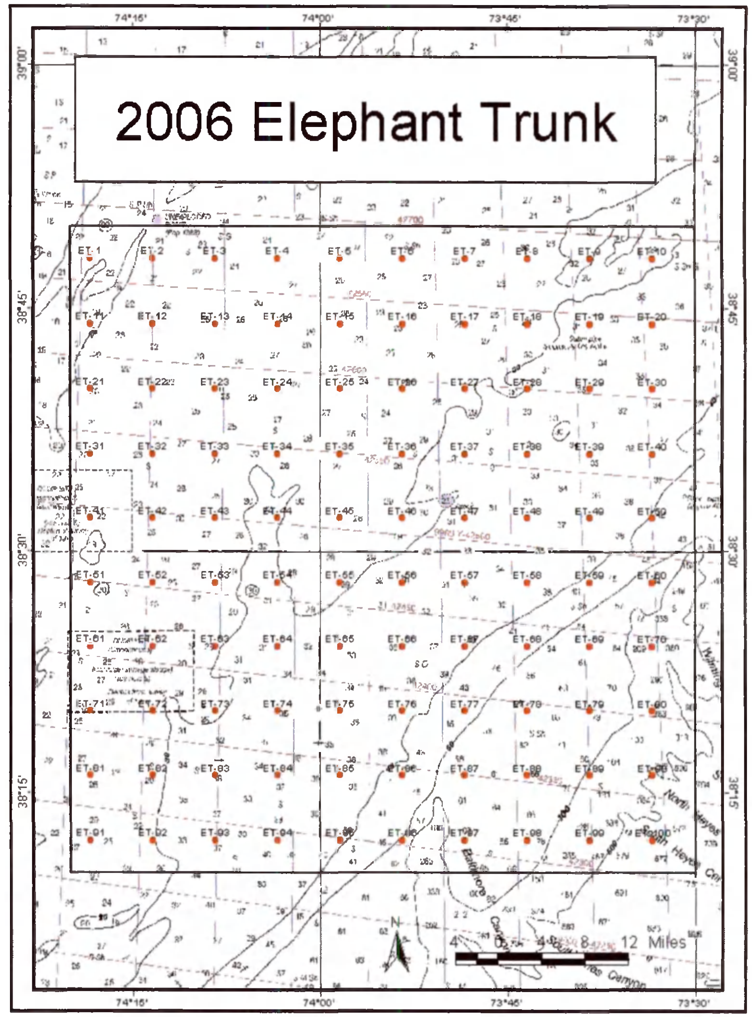
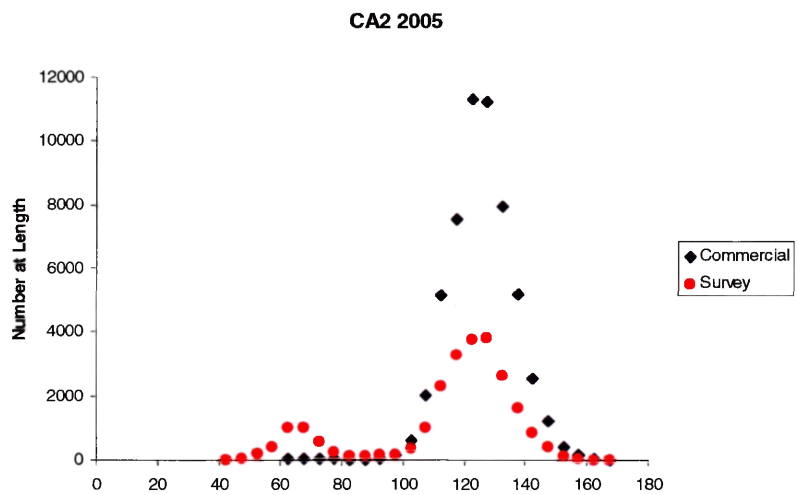
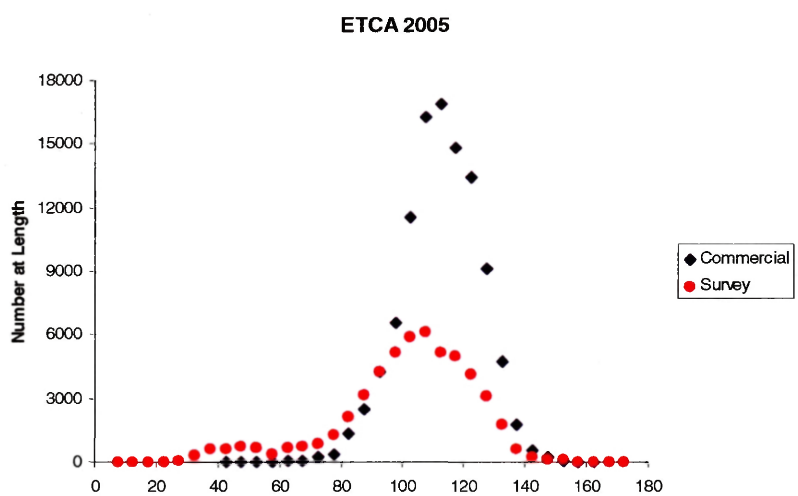

2006 Elephant Trunk
74°15'
74°00'
73°45'
73°30'
39°00'
38°45'
38°30'
38°15'
12 Miles

Figure 5 **Catch-at-length data combined for all valid tows for a) CA2 2005, b) ETCA 2005 and c) ETCA 2006. A length of "7.5" represents the length class 5-10 mm. The values presented here have been multiplied by an expansion factor equal to the number of baskets of scallops caught divided by the number measured.**

A)


CA2 2005
Number at Length
12000
10000
8000
6000
4000
2000
0
0
20
40
60
80
100
120
140
160
180
Commercial
Survey

B)


ETCA 2005
Number at Length
18000
15000
12000
9000
6000
3000
0
0
20
40
60
80
100
120
140
160
180
Commercial
Survey

C)

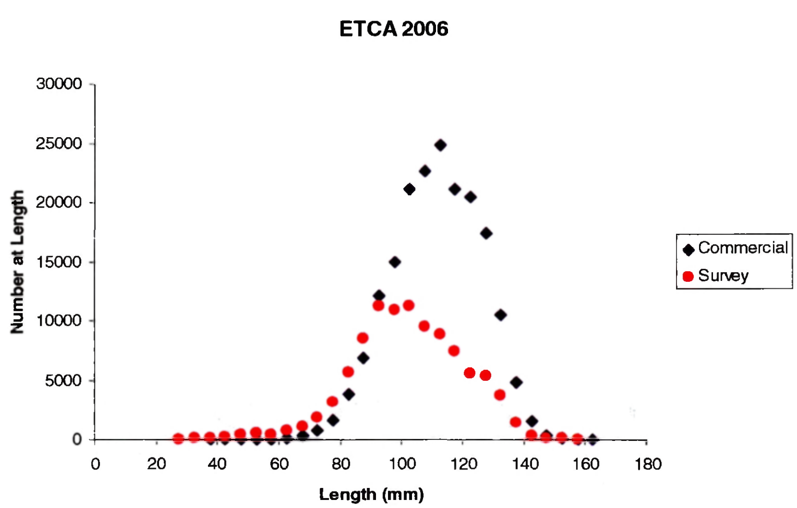
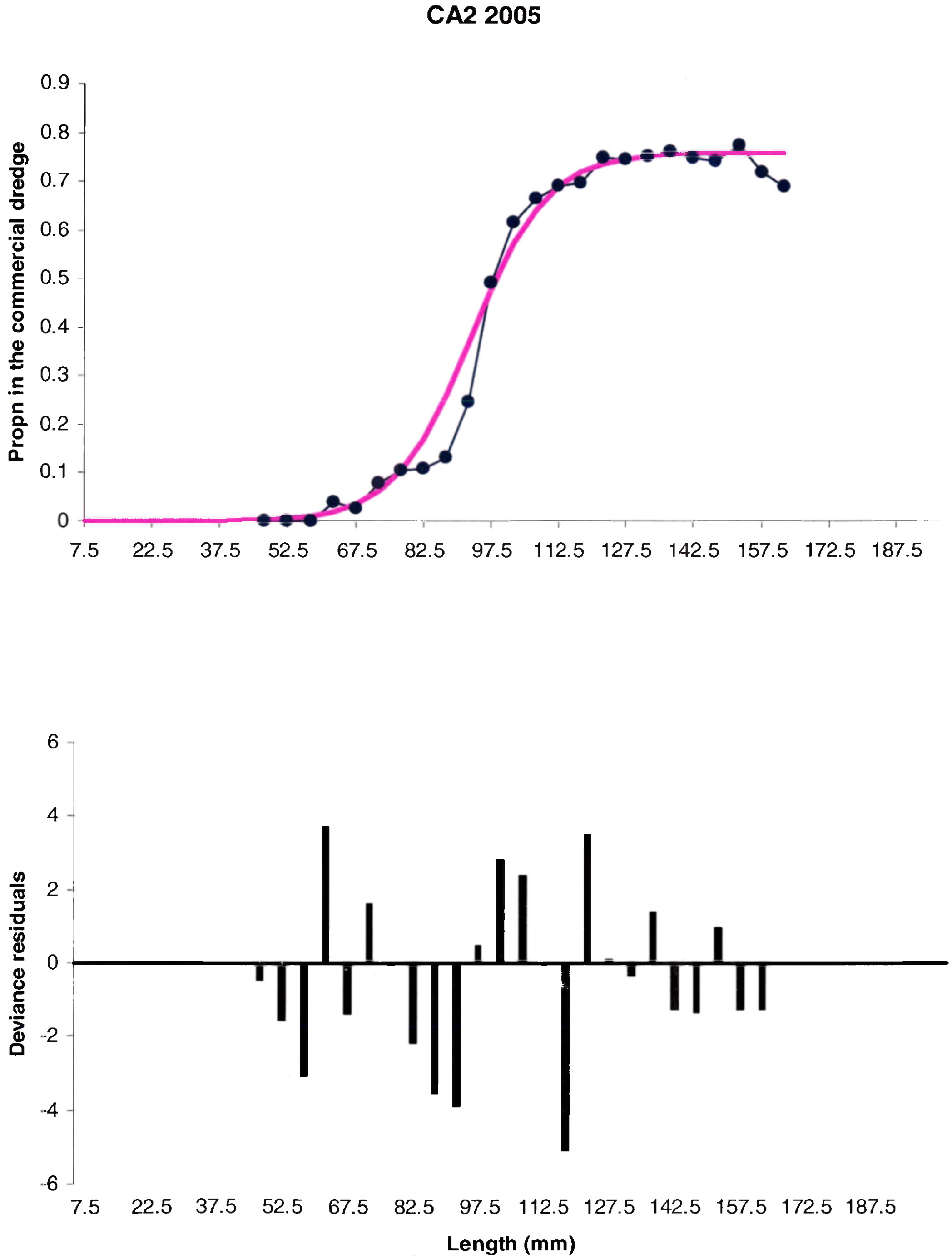

ETCA 2006
Number at Length
30000
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
120
140
160
180
Length (mm)
Commercial
Survey

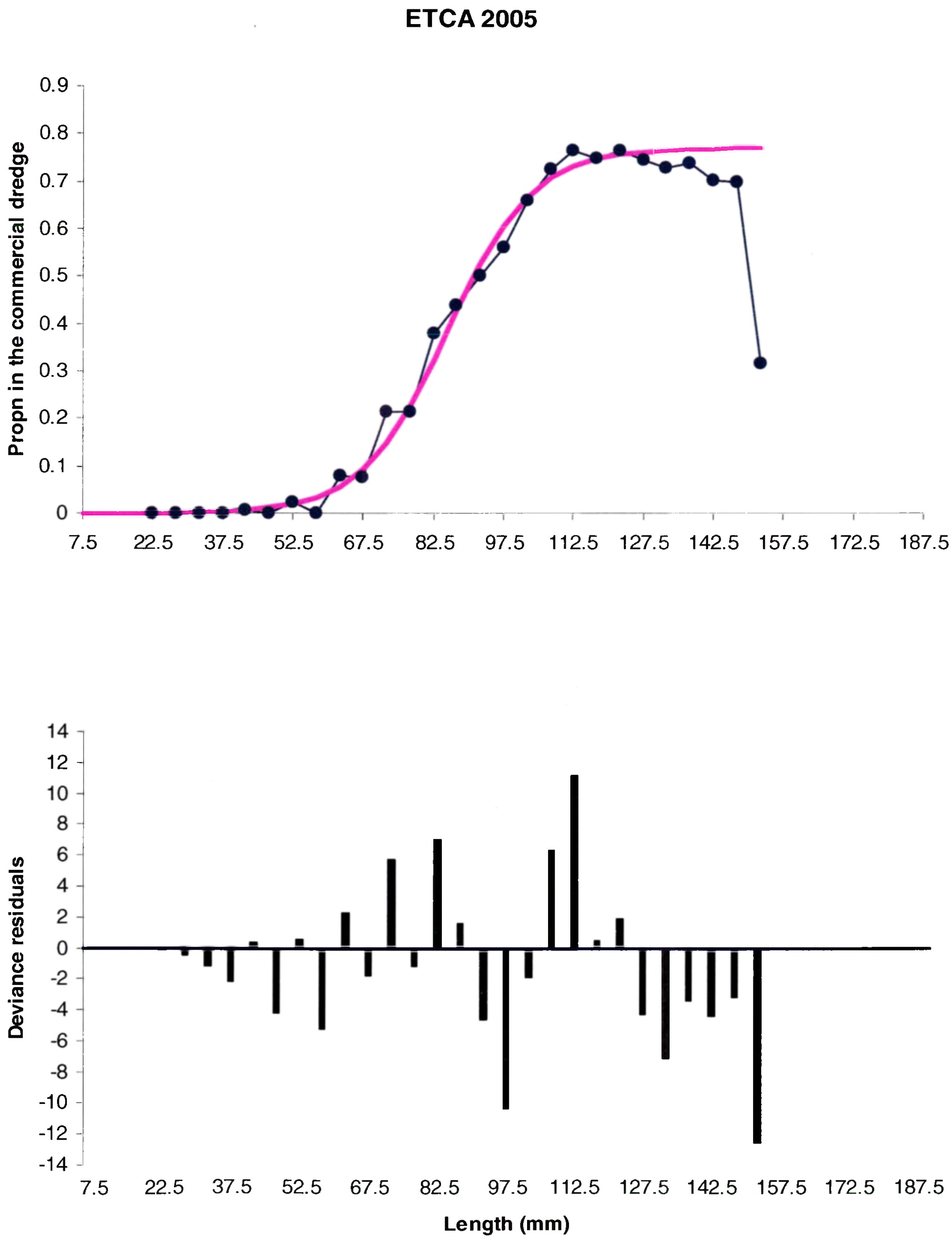
Figure 6 **Logistic SELECT curves fitted to the proportion of the total catch in the commercial gear and deviance residuals for the length classes used in the analyses for a) CA2 2005, b) ETCA 2005, c) ETCA 2006, d) CA2 2005 and ETCA 2005 combined, e) ETCA 2005 and ETCA 2006 combined, and f) CA2 2005, ETCA 2005 and ETCA 2006 combined.**

A)

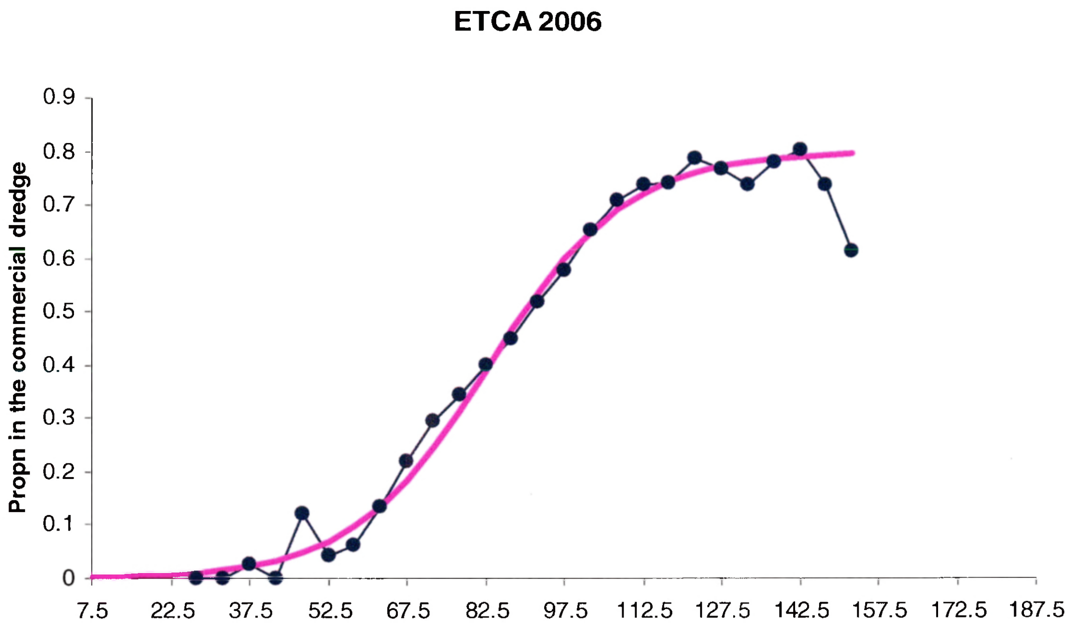


CA2 2005
Propn in the commercial dredge
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7.5
22.5
37.5
52.5
67.5
82.5
97.5
112.5
127.5
142.5
157.5
172.5
187.5
Deviance residuals
6
4
2
0
-2
-4
-6
Length (mm)

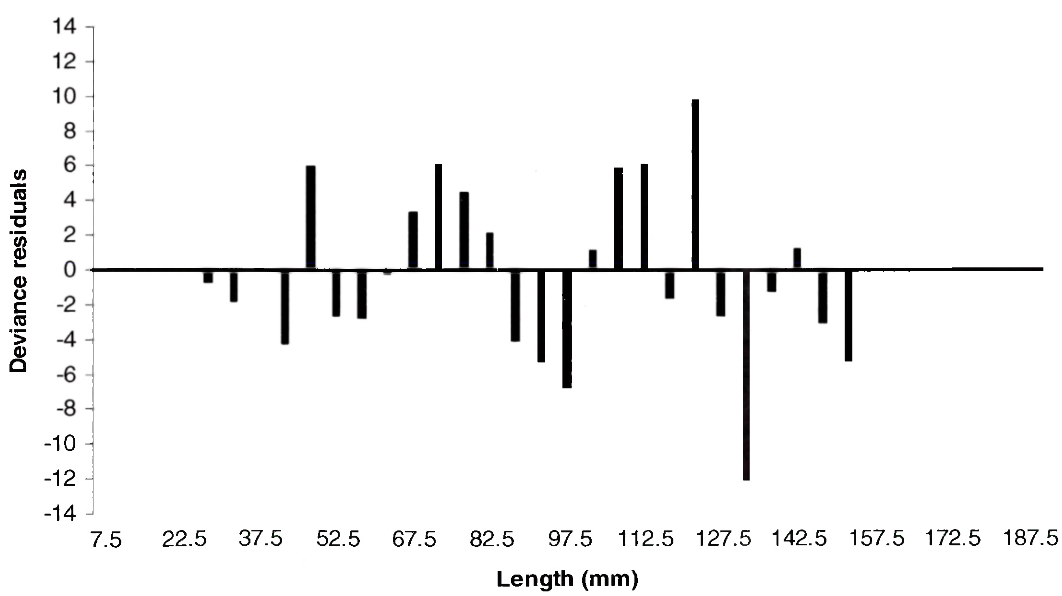
B)


ETCA 2005
Propn in the commercial dredge
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7.5 22.5 37.5 52.5 67.5 82.5 97.5 112.5 127.5 142.5 157.5 172.5 187.5
Deviance residuals
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
7.5 22.5 37.5 52.5 67.5 82.5 97.5 112.5 127.5 142.5 157.5 172.5 187.5
Length (mm)

C)

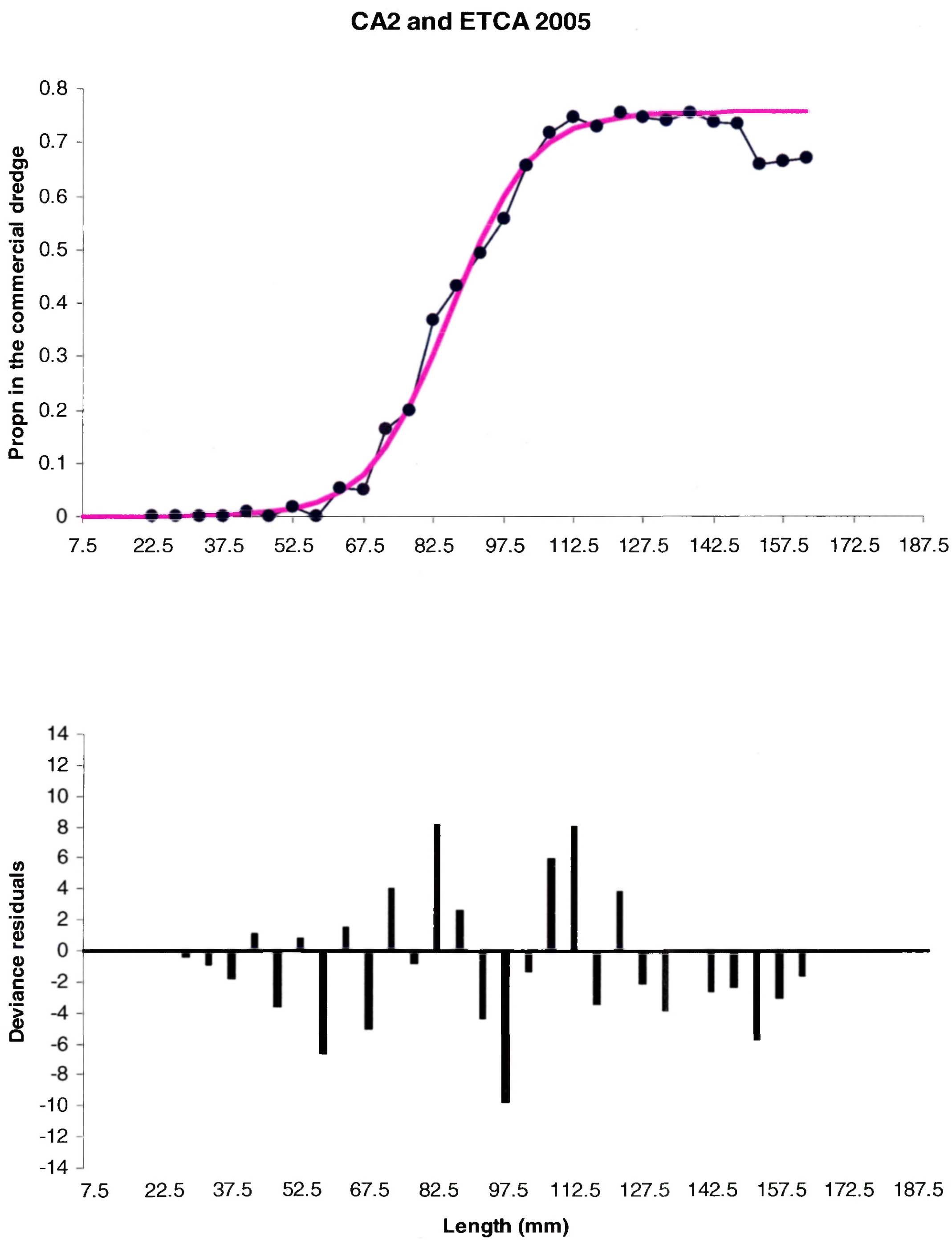


ETCA 2006
Propn in the commercial dredge
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7.5
22.5
37.5
52.5
67.5
82.5
97.5
112.5
127.5
142.5
157.5
172.5
187.5

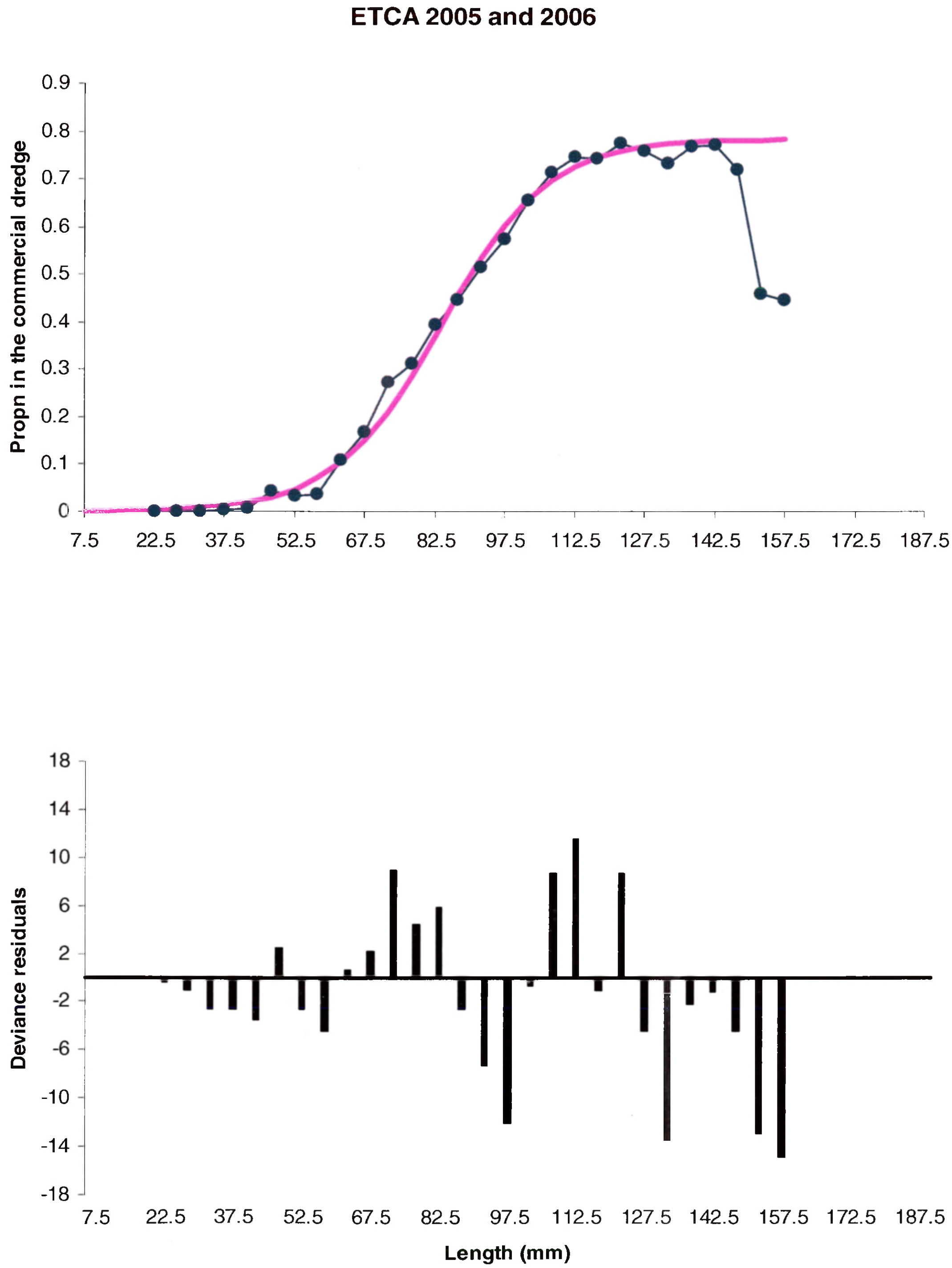


Deviance residuals
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
7.5
22.5
37.5
52.5
67.5
82.5
97.5
112.5
127.5
142.5
157.5
172.5
187.5
Length (mm)

D)


CA2 and ETCA 2005
Propn in the commercial dredge
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7.5
22.5
37.5
52.5
67.5
82.5
97.5
112.5
127.5
142.5
157.5
172.5
187.5
Deviance residuals
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
Length (mm)

E)



ETCA 2005 and 2006
Propn in the commercial dredge
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7.5
22.5
37.5
52.5
67.5
82.5
97.5
112.5
127.5
142.5
157.5
172.5
187.5
Deviance residuals
18
14
10
6
2
-2
-6
-10
-14
-18
Length (mm)

F)

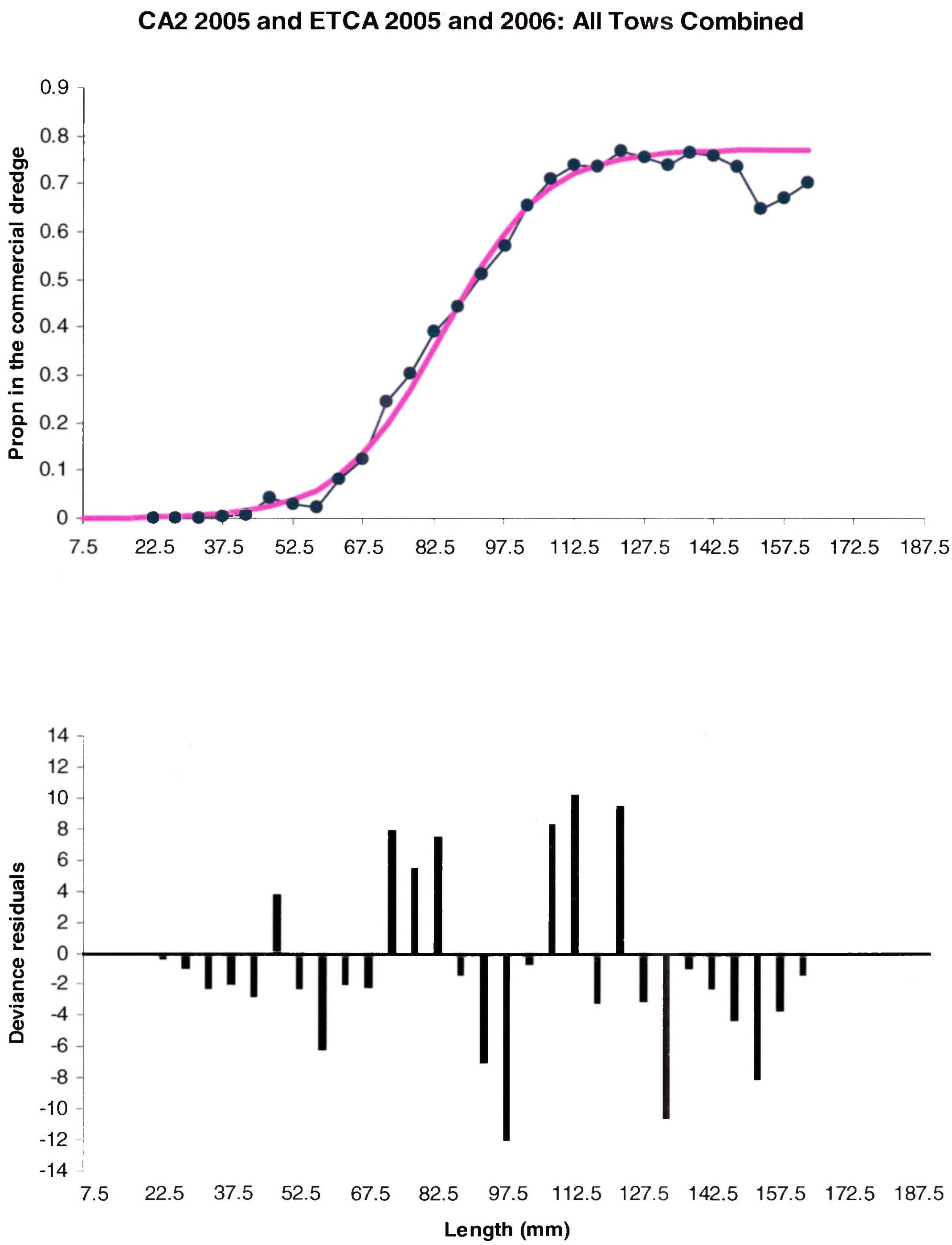

CA2 2005 and ETCA 2005 and 2006: All Tows Combined
Propn in the commercial dredge
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7.5 22.5 37.5 52.5 67.5 82.5 97.5 112.5 127.5 142.5 157.5 172.5 187.5
Deviance residuals
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
7.5 22.5 37.5 52.5 67.5 82.5 97.5 112.5 127.5 142.5 157.5 172.5 187.5
Length (mm)

Figure 7 **Size-selection curves created using the estimated logistic parameters for CA2 2005, ETCA 2005, ETCA 2006, CA2 2005 and ETCA 2005 combined, ETCA 2005 and ETCA 2006 combined, and CA2 2005, ETCA 2005 and ETCA 2006 combined.**

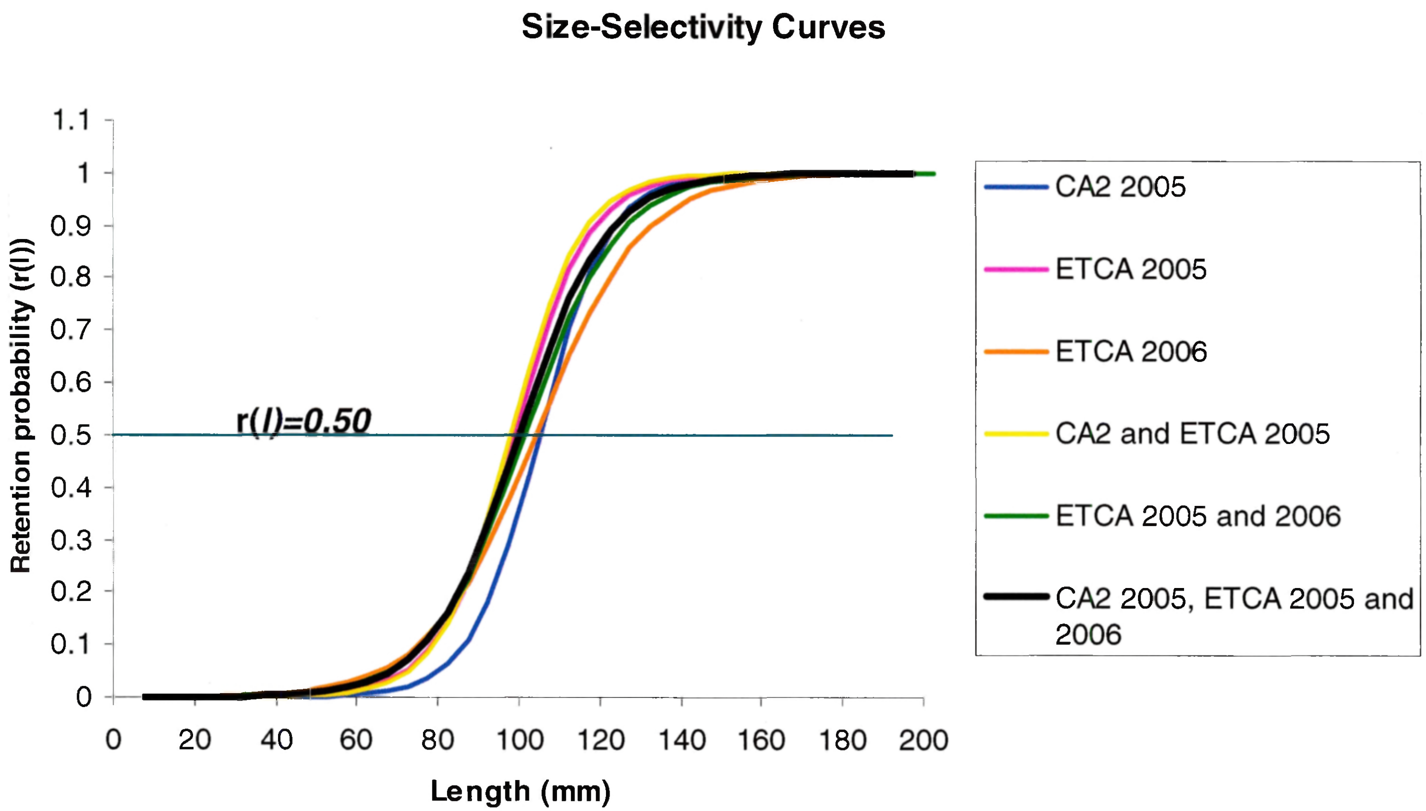
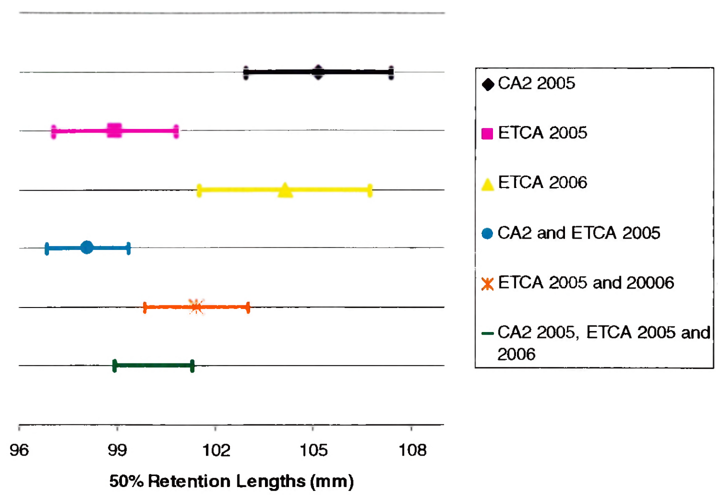

Size-Selectivity Curves
Retention probability (r(l))
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
r(l)=0.50
0
20
40
60
80
100
120
140
160
180
200
Length (mm)
CA2 2005
ETCA 2005
ETCA 2006
CA2 and ETCA 2005
ETCA 2005 and 2006
CA2 2005, ETCA 2005 and 2006

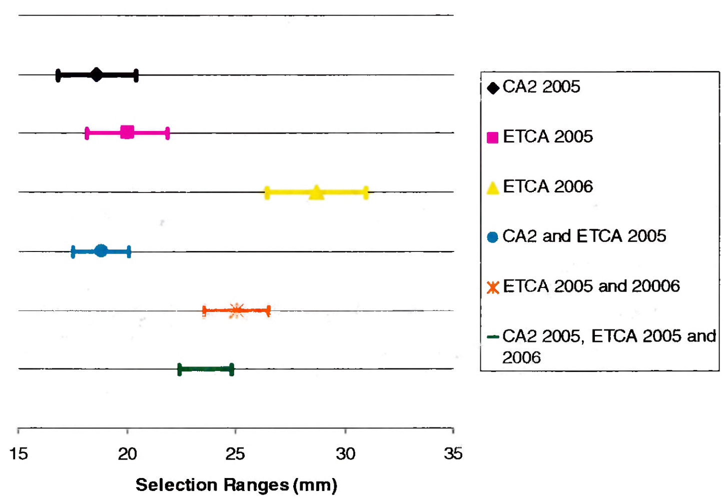
Figure 8 **Estimated a) 50% retention length (l_{50}), b) selection range (SR), and c) split parameter (p_c) values for the different combinations of data with 95% confidence intervals.**

A)



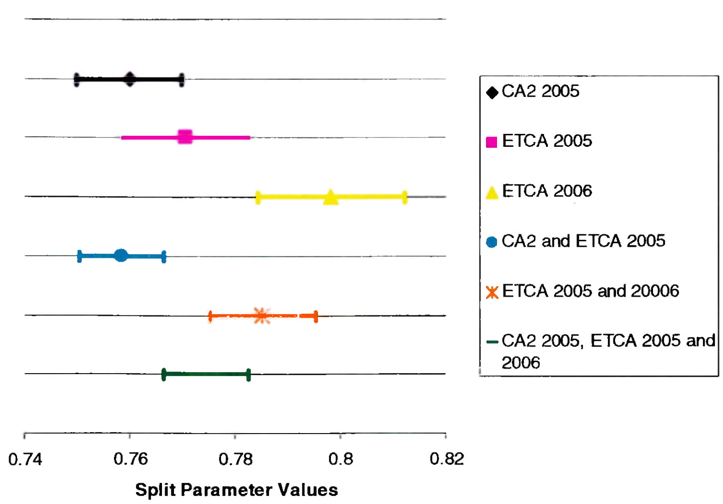
CA2 2005
ETCA 2005
ETCA 2006
CA2 and ETCA 2005
ETCA 2005 and 20006
CA2 2005, ETCA 2005 and 2006
96
99
102
105
108
50% Retention Lengths (mm)

B)



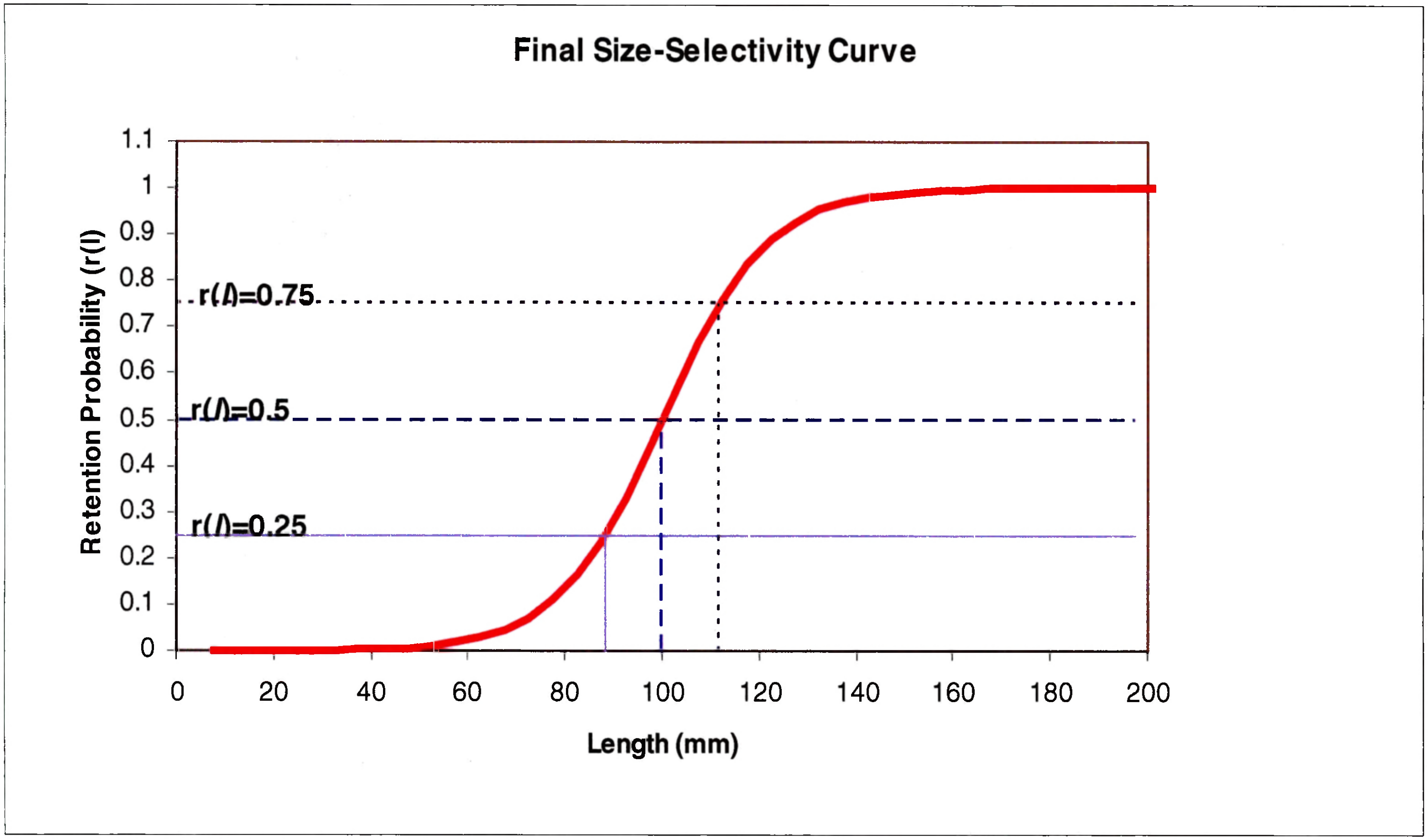
CA2 2005
ETCA 2005
ETCA 2006
CA2 and ETCA 2005
ETCA 2005 and 20006
CA2 2005, ETCA 2005 and 2006
15
20
25
30
35
Selection Ranges (mm)

C)



CA2 2005
ETCA 2005
ETCA 2006
CA2 and ETCA 2005
ETCA 2005 and 20006
CA2 2005, ETCA 2005 and 2006
0.74
0.76
0.78
0.8
0.82
Split Parameter Values

Figure 9 **Logistic selection curve for the New Bedford style dredge which incorporates all valid tows from the three cruises. The lengths at 25%, 50% and 75% probability of retention are shown. The selection range is the difference between the 75% and 25% retention lengths (l_{75}- l_{25}).**



Final Size-Selectivity Curve
Retention Probability (r(l)
Length (mm)
r(l)=0.75
r(l)=0.5
r(l)=0.25
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
0
20
40
60
80
100
120
140
160
180
200

Figure 10 **Von Bertalanffy growth curve (using parameters from Serchuk et al. 1979) showing the age that corresponds to the l_{50} value of 100.1 mm.**

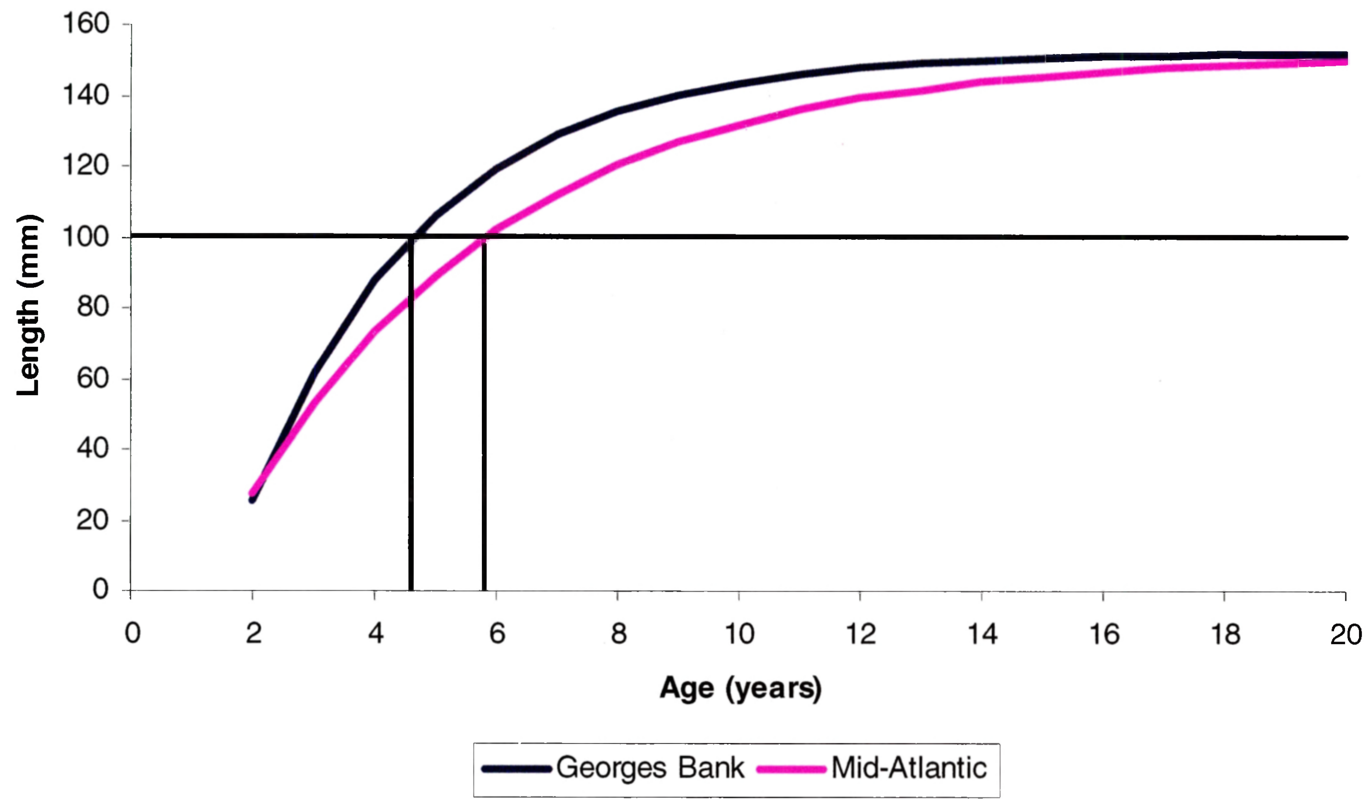
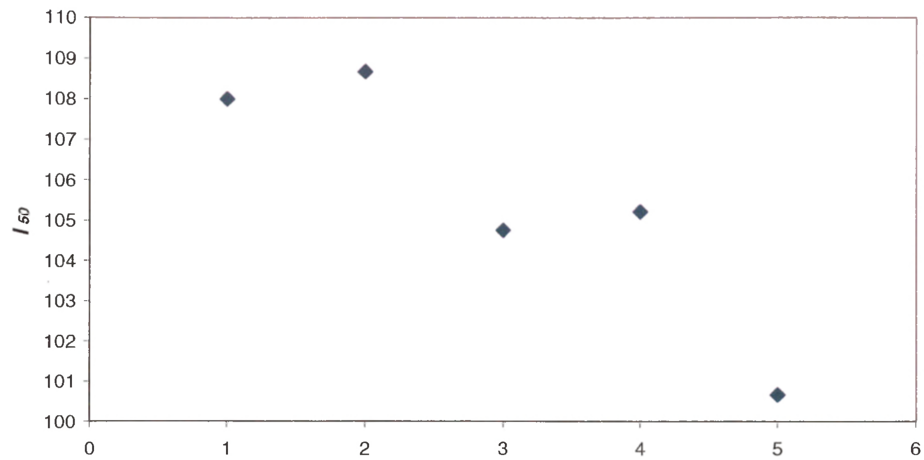

160
140
120
100
80
60
40
20
0
Length (mm)
0
2
4
6
8
10
12
14
16
18
20
Age (years)
Georges Bank
Mid-Atlantic

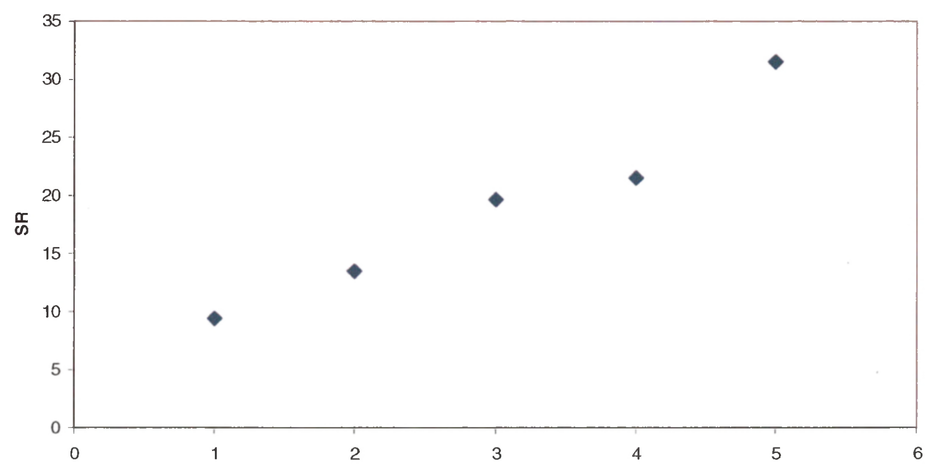
Figure 11 **Estimated a) 50% retention length (l_{50}), b) selection range (SR), and c) split parameter (p_c) values for tows with increasing baskets of scallops in the commercial dredge. The categories are: 1) fewer than three, 2) three to six, 3) six to twelve, 4) twelve to twenty-four, and 5) more than twenty-four baskets of scallops in the commercial dredge.**

A)



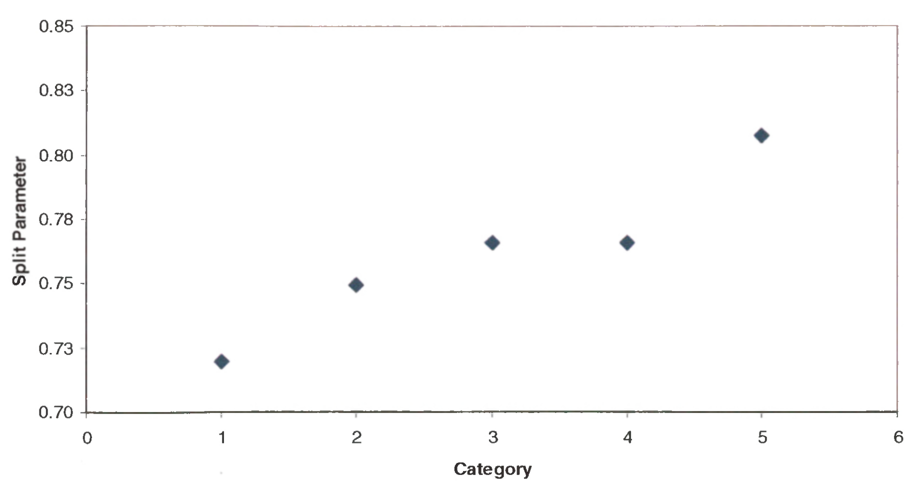
110
109
108
107
106
105
104
103
102
101
100
I_{50}
0
1
2
3
4
5
6

B)



35
30
25
20
15
10
5
0
SR
0
1
2
3
4
5
6

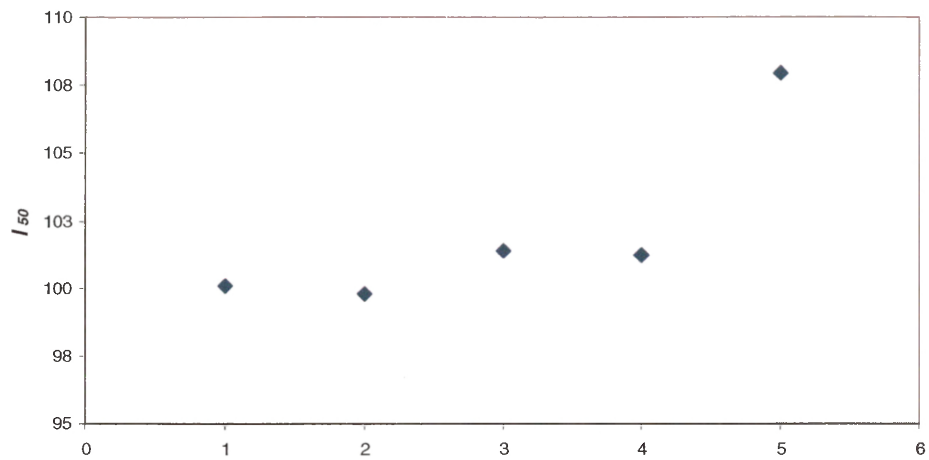
C)



0.85
0.83
0.80
0.78
0.75
0.73
0.70
Split Parameter
0
1
2
3
4
5
6
Category

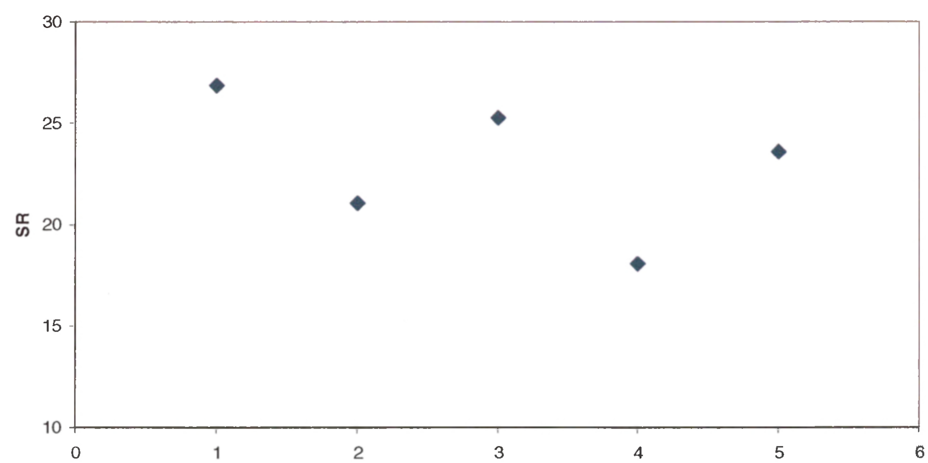
Figure 12 **Estimated a) 50% retention length (l_{50}), b) selection range (SR), and c) split parameter (p_c) values for tows with increasing baskets of trash in the commercial dredge. The categories are: 1) less than 0.25, 2) 0.25 to one, 3) one, 4) one to two, and 5) more than two baskets of trash in the commercial dredge.**

A)



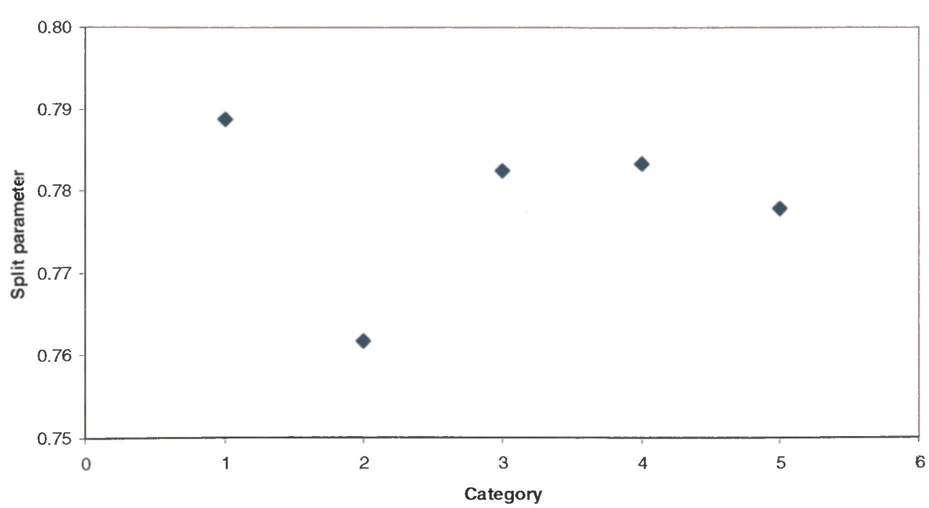
110
108
105
103
100
98
95
I_{50}
0
1
2
3
4
5
6

B)



30
25
20
15
10
SR
0
1
2
3
4
5
6

C)



0.80
0.79
0.78
0.77
0.76
0.75
Split parameter
0
1
2
3
4
5
6
Category

APPENDICES

APPENDIX A

Sea Scallop Biology and Life History

Sea scallops, *Placopecten magellanicus,* are a commercially significant species of the bivalve mollusk super-family Pectinidae. Sea scallops (also called giant, smooth, ocean or Atlantic deep sea scallop) are found along the eastern North American continental shelf, predominantly from the Gulf of St. Lawrence to Cape Hatteras, North Carolina (Waller 1991). The southern limit of sea scallop distribution correlates with the intersection of the Labrador Current with the Gulf Stream (Brand 1991). Sea scallops, a cold water species, are found in shallow water in the north (less than 20m) and in the south are found at depths exceeding 55 m (Bourne 1964). Geographical distribution is a function of water depth, food availability, barriers that limit larval dispersal, salinity, water temperature, substrate type and the presence of competitors and predators (Bourne 1964, Brand 1991). Sea scallops are filter feeders, subsisting on phytoplankton and perhaps some organic detritus (Posgay 1979).

Sea scallops are gonochoristic, although hermaphroditism does occur (Naidu 1970), and fertilization takes place externally in the water column (Posgay 1979). The oldest recorded age for a sea scallop is 29 years old, and the largest scallop was measured at 8.3-inches (211 mm) with an adductor muscle weight of 0.51 lb (231 g) (Naidu 1991). Natural mortality (M) of sea scallops is assumed to be 0.1 y^{-1} for scallops with shell heights greater than 40mm based on Merrill and Posgay's study (1964). Natural predators of scallops include, but are not limited to, cod (*Gadus callarias),* American plaice (*Hippoglossoides platessoides*), wolf fish (*Anarhichas lupus*) and starfish (*Asterias vulgaris* and *Crossaster papposus*). Other causes of natural mortality include water temperature and salinity changes, the flushing of basins and parasites (Medcof and Bourne 1964).

A unique feature to the bivalve family Pectinidae is that their escape response is to swim rather than to close their valves tightly, burrow or summersault. Scallops are able to swim by jet propulsion that occurs by repeated expulsion of water, resulting from the adduction of their shells (Wilkens 1991). Sea scallops, in particular, are adept swimmers. This is attributed primarily to their valve morphology (Stanley 1970). It has been found that the swimming behavior of sea scallops changes with age, primarily that larger scallops are not as active (Caddy 1973, Manuel and Dadswell 1991). Swimming is a mechanism that enables the scallops to move to optimal habitat and avoid predation (Wilkens 1991). Scallops can use their motion-detecting eyes to sense natural predators (Beninger and Le Pennec 1991) and potentially detect the presence of fishing gear (Caddy 1968). Their eyes are located at the tip of a short stalk that extends outward from the middle fold of the mantle, which lines the circumference of the shell. Eyes are found on both the lower and upper valves; however, they are predominantly on the latter. Each eye has a cornea, lens, double retina and a tapetum (Beninger and Le Pennec 1991). The quantity of eyes varies by animal and species and their eyes continue to multiply as the scallop grows and are able regenerate within 40 days of being lost (Wilkens 1991).

APPENDIX B

The Commercial Sea Scallop Fishery

Sea scallops are harvested principally for their adductor muscle, which is commonly removed at sea. Scallops have two adductor muscles; one is the phasic adductor which is the primary muscle for human consumption. It is usually cross-striated and is associated with "fast, repetitive opening and closing of the valves (Chantler 1991)." The smaller, smooth, tonic adductor muscle, which is not as desirable for eating, lacks cross-striations and is used by the scallop to keep its shells closed for long periods of time and is association with slower contractions (Chantler 1991). The adductor muscle has been harvested by U.S. sea scallopers for well over 100 years. The fishery originated in 1884 near Mt. Desert Island, Maine, where scallops were harvested with oyster dredges (Smith 1891). The growth of the fishery is associated with improvements in vessel capabilities and with the development of offshore scallop dredges which allowed scallopers to fish for longer periods of time and further offshore. Landings made a dramatic increase during the mid-1940s and have continued to rise with more dramatic increases occurring in the early 1960s, the late 1970s, the early 1990s and the early 2000s. Alternatively, there was a significant decrease in landings from the late 1960s to the mid-1970s (Van Voorhees 2005).

The commercial fishery extends from Virginia Capes to Port au Port Bay, Newfoundland, though the majority of U.S. sea scallop landings are from Georges Bank, the Mid-Atlantic, Southern New England and the Gulf of Maine (Naidu 1991). The strong currents in Georges Bank create favorable conditions for these benthic filter feeders; however, at very high rates of flow feeding and growth may be inhibited (Brand 1991).

Total effort allowed in the U.S. sea scallop fishery was determined by Amendment #4 to the Sea Scallop Fishery Management Plan. Under this amendment, a moratorium on scallop permits was issued and days at sea (DAS) restrictions were instituted. DAS were (and are) allocated to vessels possessing limited access permits, which were distributed to vessels based on historical fishing practices. Within the limited access permits there are three categories (full-time, part-time and occasional) which correspond to the allotted DAS. In addition, general category permits are made available to vessels that are not eligible for limited access. Vessels with general category permits are limited to a twenty-four hour fishing period and have a meat weight limit (NEFMC 1993). In recent years there has been an increase in landings from vessels with open access general category permits. In 2004, the U.S. sea scallop fishery consisted of about 300 vessels with limited access permits and about 2,800 with general category permits (NEFMC 2005).

Based on biomass estimates from the 2003 NMFS scallop survey, scallops are above the target biomass level (B_{MAX} = 5.6 kg/tow); however, fishing mortality estimates indicate that overfishing is occurring since this value exceeds the maximum fishing threshold (F_{MAX}=0.24) (NEFSC 2004).

APPENDIX C

History of Sea Scallop Management

In accordance with the requirements of the Magnusun-Stevens Act in 1982, the Atlantic Sea Scallop Fishery Management Plan (SSFMP) was implemented creating a foundation for sea scallop management. Fishery Management Plans are developed by regional Fishery Management Councils and are implemented by NMFS. The main objectives of the SSFMP are to restore the adult stock abundance and age distribution, increase the yield-per-recruit, evaluate research, development and enforcement costs and minimize the adverse environmental impacts on scallops. This management plan established a maximum meat count regulation at 40 meats per pound (reduced to 30 the subsequent year) and a minimum shell height standard beginning at 3.25-inches and increasing to 3.5- inches one year later (NEFMC 1982). In 1994, when Amendment #4 to the SSFMP was implemented, the management strategy for sea scallops switched from meat count regulation to effort control, including a minimum ring size (3.5-inches), crew limitations (9 man crew size) and incrementally increasing restrictions on days-at-sea (DAS). In addition, this amendment limited entry into the fishery (NEFMC 1993).

In order to adhere to the new standards set forth by the Sustainable Fisheries Act in 1996, Amendment #7 was created two years later, establishing goals to rebuild the sea scallop population within ten years, end overfishing and achieve and maintain harvest at the optimum yield. This amendment increased the DAS limitations, adjusted the overfishing definition and introduced measures for rotational area closures. Under this plan the Virginia Beach Closed Area and the Hudson Canyon South Closed Area were established to protect juveniles and to increase yield-per-recruit (NEFMC 1998). The most recent amendment (Amendment #10) was implemented in 2004. This was created to deal with issues concerning the rotational closed area management system as well as to address DAS allocation and set new gear requirements. In order to maximize scallop yield and decrease impact on essential fish habitat, more stringent regulations were put in place for rotational closed area management. Under this amendment, the Elephant Trunk Closed Area was established in 2004 and scheduled to reopen in 2007. In addition, in order to improve selectivity, the minimum ring size was increased from 3.5-inches (89 mm) to 4-inches (102 mm) and twine top mesh size was increased from 8-inches (20 cm) to 10-inches (25 cm) in order to reduce groundfish bycatch (NEFMC 2003).

In order to monitor the health of the U.S. sea scallop resource the Northeast Fisheries Science Center has been conducting a sea scallop research survey since 1960. Between 1960 and 1968 the primary objective of the survey was to quantify life history parameters in the Georges Bank region; however, surveys conducted in 1975 and then annually since 1977 have focused on evaluating relative abundance, age composition and recruitment throughout Georges Bank and the Mid-Atlantic regions (Serchuk et al. 1979). Since 1977, survey stations have been assigned using a stratified random sampling design based on latitude and depth and stations are allocated in proportion to total stratum area. From 1975 to 1978, the surveys were conducted using a 10-foot (3.05 m) wide scallop dredge with a 2-inch (5.1 cm) ring bag, towed for 15 minutes at 3.5 knots with a 3:1 wire scope. Beginning in 1979 the dredge width was reduced to 8-feet (2.44 m) and a 1.5-inch (3.8 cm) polypropylene mesh liner was attached to the inside the dredge bag. The introduction of the liner was in response to the belief that this addition would increase retention of pre-recruit (< 70 mm shell height) scallops (Serchuk and Smolowitz 1980).

APPENDIX D

Previous Studies Evaluating Scallop Dredge Design

In order to examine the effects of changing the gear configuration of the commercial sea scallop dredge, several gear comparison studies have been conducted. Previous studies have focused predominantly on the effect of increasing the internal ring diameter (ring size) on dredge efficiency and selectivity. One such study was conducted by Bourne (1965) to assess the differences in the catch of scallop dredges configured with 3 and 4-inch rings. The intention of the study was to see if, by increasing the ring size more 5-year olds would be allowed to reach age six. Bourne found that the difference in catches was small, that the 4-inch ring caught 90% as many 5- year olds as the 3-inch ring. However, the 4-inch ring caught more "markets" (scallops 100 mm and larger), fewer discards (scallops under 100 mm) and less trash, which allowed for a reduction in sorting and culling time and an increase in time to shuck scallops.

Decades later, under the management of the Sea Scallop Fishery Management Plan (SSFMP), increases in the ring size of the commercial gear were mandated in order to control the size-selection of commercial catches. Amendment #4 to the SSFMP mandated a minimum ring size of 3-inches (76 mm) in 1994, increasing to 3.25-inches (83 mm) in 1995 and to 3.5-inches (89 mm) in 1996 (NEFMC 1993).

Most recently, under Amendment #10 to the SSFMP the ring size was set at 4-inches (102 mm) (NEFMC 2003). Coinciding with this progressive increase in ring size, studies have been conducted to understand how these changes affect the performance of the scallop dredge. A study comparing the efficiency and size selectivity of the 3 and 3.25- inch rings was conducted by DuPaul and Kirkley (1994) and of the 3.25 and 3.5- inch rings by Brust et al. (1995). These two studies showed that with increased ring size there is a reduction in catch of the smaller scallops. However, both studies highlight the fact that ring size is not the only factor affecting selectivity of the catch. Similarly, in a study evaluating the selectivity of a 3-inch ring scallop dredge, Caddy concluded that a major part of selection occurs at the inter-ring spaces, implying the need to evaluate the number of links used between rings in addition to internal ring diameter (1972). It was also found that the quantity and placement of chafing gear can affect the selection process (Parsons and Davidson 2004).

A more recent study done by Goff evaluated the performance of the 3.5 vs. 4-inch rings (2002). His results concurred with the findings of previous studies, i.e., that the larger ring size allows a higher percentage of smaller animals to escape. He also concluded (analogous to the study done by Bourne (1965)) that the 4-inch ring caught more "optimal" sized scallops and less trash. In addition, Goff found that the 4-inch ring caught less bycatch of certain species of finfish and that, by using the 4-inch ring, the dredge is more quickly filled with optimal sized scallops. This potentially allows for a shorter tow time, which reduces the impact on the sea floor and on scallops in the dredge path (Goff 2002).

Additionally, ring size has been evaluated for the inshore scallop fishery. A study comparing 3.5 and 4-inch rings on the inshore scallop dredge in the Gulf of Maine concluded that use of the 4-inch ring resulted in a 10% loss of 3.75-inch (2003-2004 legal shell height) scallops and 3% loss of 4-inch (2005 legal shell height) scallops as well as a 25.5% loss of sub-legal scallops when using the 4-inch rings. The researchers also noted that location had a significant effect on scallop catch (Patryn and Holland 2005).

APPENDIX E

Nantucket Lightship Closed Area 2005 Cruise

In order to combine the tows from two or more different cruises for the analysis it was imperative that the gears be the same throughout. Gear configuration was consistent for the Closed Area II (CA2) cruise in 2005 and for the cruises in the Elephant Trunk Closed Area (ETCA) in 2005 and 2006. The dredges used during the cruise in the Nantucket Lightship Closed Area (NLCA), however, were not equivalent. To begin with, the hanging ratio and the size of the twine top on the survey dredge used in the NLCA were different from those used on the other cruises. The hanging ratio changed since, while the number of rings along the frame of the dredge remained the same for all cruises, the size of the twine top was 25 x 17 meshes for the NLCA cruise and was 40 x 15 meshes for the others. Additionally, there was a reduced surface area, and hence a tighter fit, in the NLCA survey dredge twine top because the dimensions 25x17 equate to a total of 425 meshes where a twine top with 40x15 has 600. Furthermore, the commercial dredge in the NLCA differed in that it had a shorter twine top and a longer sweep chain. Therefore, analysis for the data from the NLCA cruise is presented separately and is not included in the final results.

The catch-at-length data from the NLCA cruise (Figure A) was analyzed in the same manner as the other cruises. The estimated parameters for the NLCA cruise yielded a 50% retention length of 101.6 mm, a selection range of 17.63 mm and a split parameter value of 0.76. Standard errors for the estimated parameters were multiplied by the square root of REP because the data were overdispersed. Results from the NLCA are comparable to the results from the other cruises (Table A, Figure B). The split parameter values are similar and there is less than a two millimeter difference between the 50% retention lengths for the NLCA cruise and the other cruises combined. However, the selection ranges differ in that the curve for the NLCA cruise is steeper, indicating that fewer small and more large scallops will be retained. As assessment of these parameters with confidence intervals reveals that there is no significant difference between the two 50% retention lengths and split parameters, but that there is between the selection ranges (Figure C). Regardless, the similarity of the results for the NLCA cruise and for the other cruises combined indicates that he selection curve generated for this study is robust to changes in gear configuration. Additionally, the length frequency distribution in the NLCA is different from the other closed areas. This implies that the selection curve is also robust to differences in length frequency distribution.

Table A **Estimated parameters from the logistic SELECT analyses on catch-at-length data for all length classes with at least 20 scallops in one of the dredges for the NLCA 2005 cruise and for the CA2 2005, ETCA 2005 and 2006 cruises combined. Listed are the lengths used in the analyses and the starting values to estimate the parameters in both R and Excel. The estimated values (left column) for logistic parameters *a* and *b*, as well as the 50% retention length (l_{50}), the selection range (SR= l_{75} -l_{25}) and the relative efficiency split parameter (p_c) are given. The number of tows (No. Tows) used for each analysis, log likelihood (L) and the replication estimate of between-haul variation (REP) are specified as well as the standard errors (right column), which have been multiplied by the square root of REP.**

	NLCA 2005		CA2 2005, ETCA 2005 & 2006	
Lengths	42.5-172.5		22.5-162.5	
Start values	(-12, 0.12, 0.8)		(-12, 0.12, 0.8)	
a	-12.6700		-9.32	
b	0.12		0.09	
p_c	0.76	0.005	0.77	0.004
l_{50} (mm)	101.63	1.42	100.11	0.60
SR (mm)	17.63	1.85	23.61	0.59
L	-50672		-311035	
REP	8.01		7.98	
No. Tows	35		1052	

Figure A **Catch-at-length data combined for all valid tows for the Nantucket Lightship Closed Area 2005 cruise. A length of "7.5" represents the length class 5-10 mm. The values presented here have been multiplied by an expansion factor equal to the number of baskets of scallops caught divided by the number measured.**

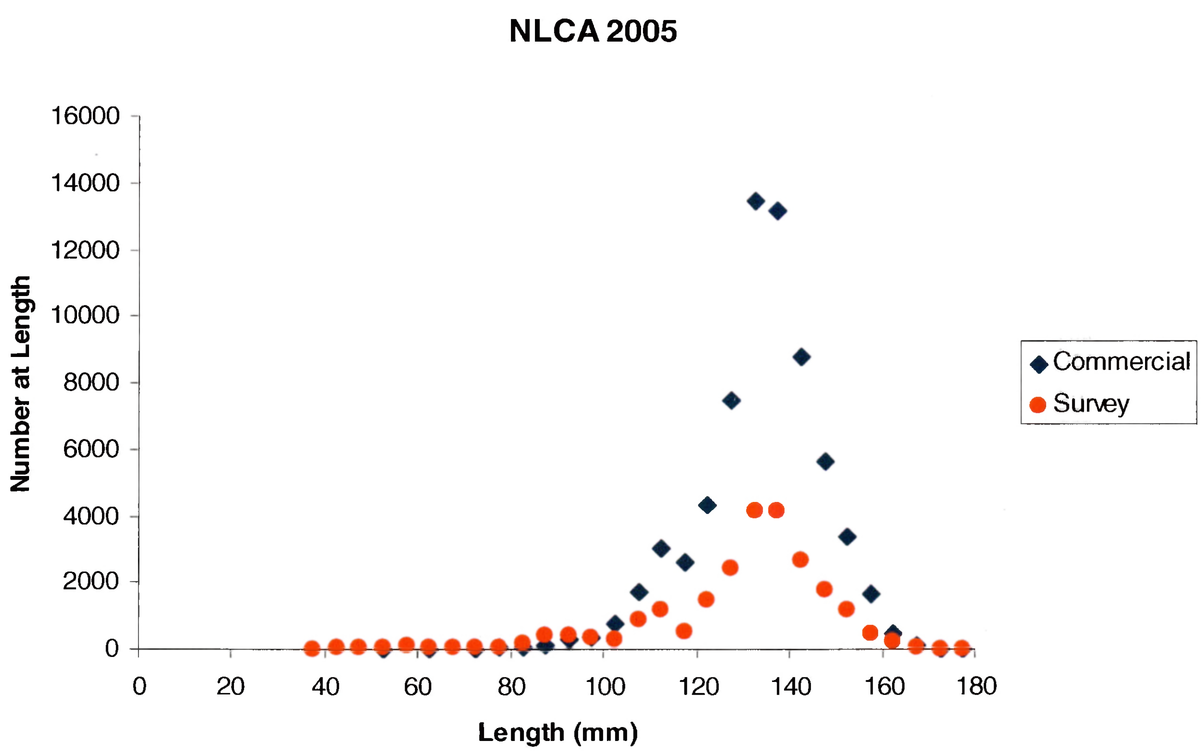


Figure B **Logistic selection curve for the NLCA 2005 cruise and the curve for the CA2 2005, ETCA 2005 and ETCA 2006 cruises combined ("Final Curve").**

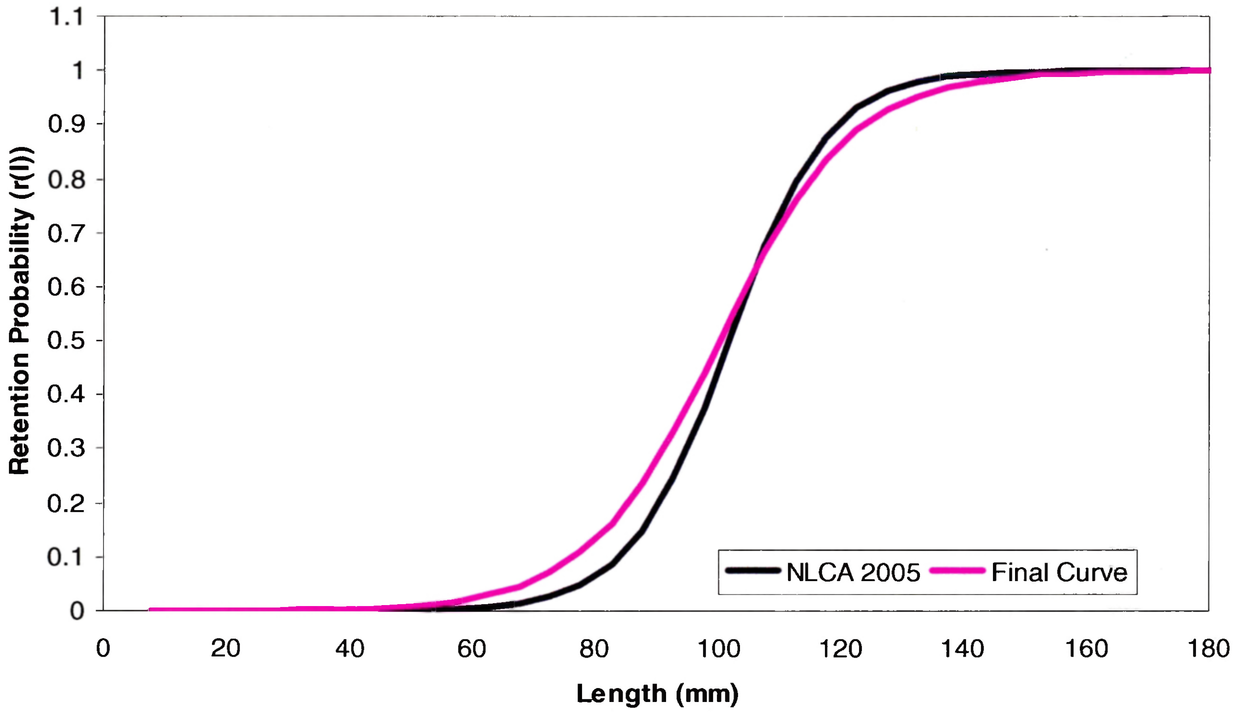
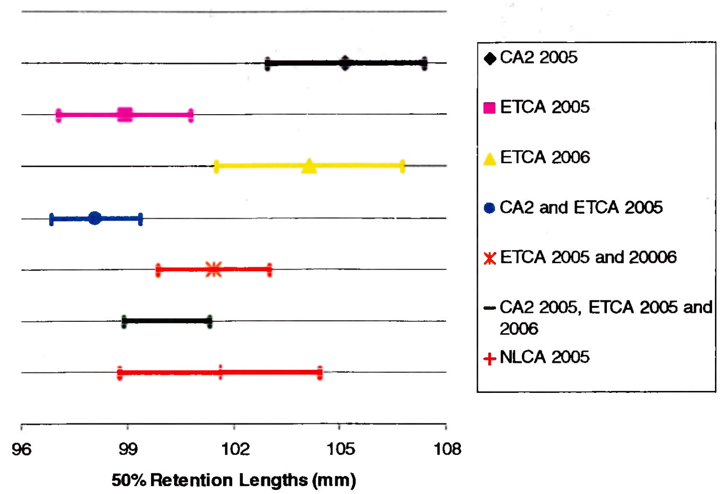
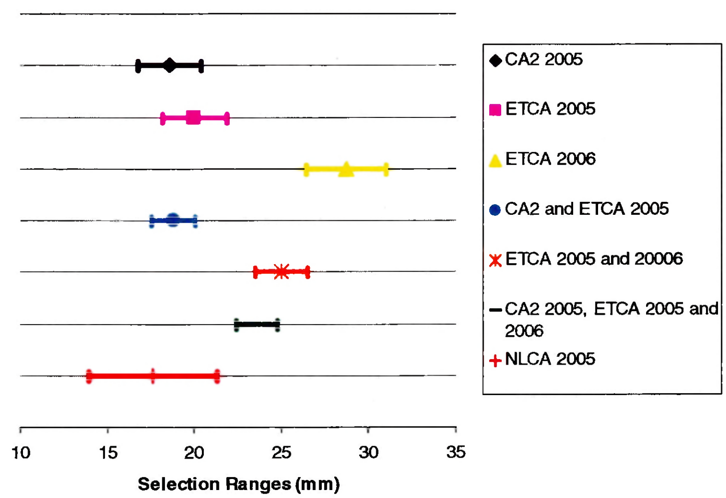


Figure C **Estimated a) 50% retention length (l_{50}), b) selection range (SR), and c) split parameter (p_c) values for the different combinations of data (including the Nantucket Lightship Closed Area 2005) with 95% confidence intervals.**

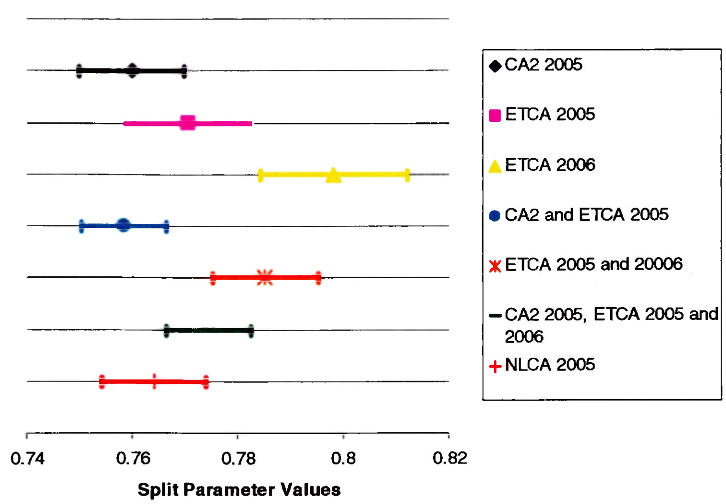
A)


CA2 2005
ETCA 2005
ETCA 2006
CA2 and ETCA 2005
ETCA 2005 and 20006
CA2 2005, ETCA 2005 and 2006
NLCA 2005
96
99
102
105
108
50% Retention Lengths (mm)

B)


CA2 2005
ETCA 2005
ETCA 2006
CA2 and ETCA 2005
ETCA 2005 and 20006
CA2 2005, ETCA 2005 and 2006
NLCA 2005
10
15
20
25
30
35
Selection Ranges (mm)

C)


CA2 2005
ETCA 2005
ETCA 2006
CA2 and ETCA 2005
ETCA 2005 and 20006
CA2 2005, ETCA 2005 and 2006
NLCA 2005
0.74
0.76
0.78
0.8
0.82
Split Parameter Values

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