#4

April 7, 2005 (RM)

Re: Completion Report for Grant No. NA16FD2293, 01-NER-013
Title: "Effects of Codend Mesh Size on the Multispecies Yield and Spawning Stock Biomass of the Western Georges Bank Trawl Fishery"
Period Covered: 05/01/02 – 10/31/04

Rosemary White
The Research Office
University of Rhode Island
70 Lower College Road
Kingston, Rhode Island 02881

Dear Ms. White:

This is to advise you that we have reviewed the report for the project referenced above and conclude that a satisfactory level of project performance has been demonstrated. Accordingly, the report has been approved.

Sincerely,

Harold C. Mears

Harold C. Mears, Director
State, Federal & Constituent
Programs Office

cc: Joseph DeAlteris

NH

February 23, 2005

Re: Final Report for Grant No. NA16FD2293, 01-NER-013
Title: "Effects of Codend Mesh Size on the Multispecies Yield and Spawning Stock Biomass in the Western Georges Bank Trawl Fisheries"
Period Covered: 05/01/02 – 10/31/04

Ms. Rosemary White
University of Rhode Island
The Research Office
70 Lower College Road
Kingston, Rhode Island 02881

Dear Ms. White:

We have completed our review of the Final Report for the University of Rhode Island's Saltonstall-Kennedy (SK) Grant (NOAA award number NA16FD2293), titled "Effects of Increasing Mesh Size in the Multispecies Fisheries in New England Waters: Applied Research". Unfortunately, the report contained many errors and we believe it would be improper to disseminate this information to the public in its current form, even though we agree this information is very important for fishery managers. We request that the investigators provide a revised report, before we distribute it.

Specifically, we are looking for further information and/or clarification on the following:

- In the Statement of Work the investigators stated "we propose to initially target Atlantic cod, haddock, and winter flounder on Georges Bank, but we will collect data on all species covered under the Multispecies FMP." However, during this project the investigators targeted winter flounder, yellowtail flounder, Atlantic cod, and pollock. Why was haddock not targeted?
- There is considerable information in the figures and tables and this makes it difficult to review, and it would be preferable if these could be enlarged.
- Page 1. The last sentence on mesh sizes needs clarification.
- Page 12. In the second sentence, the statement about winter flounder "For all codend mesh sizes, the L50 s are greater for square-shaped codend meshes" contradicts both what other researchers have found and also what the investigators have stated in Table

3 on page 19. We recommend a statistician review this information and provide the corrections for the report.

- Page 12. Under the Atlantic cod heading, the first sentence says winter flounder and Table 3, whereas it should read Atlantic cod and Table 4.
- Page 13. Under the Yellowtail flounder heading, the first sentence should read Table 5, not Table 4.
- Page 13. The second paragraph claims that the "... highest YPR result is attained ... at approximately F=0.4..." However, Table 5 shows that the highest YPR is at F=0.6. Which is correct?
- Page 14. Under Multispecies analysis, the 2nd sentence of the 2nd paragraph refers to the control codend mesh size as "33.03 cm (13 in). The actual mesh size of the control codend is 7.6 cm (3.0 in).
- Page 14. The last sentence of the 3rd paragraph reads " ... peak YPR values at much higher fishing mortalities." Should this be "fishing effort"?
- Page 15. According to figures 9 and 10 on pages 36 and 37, the results are reversed in the 1st sentence of the 3rd paragraph. It should state that the minimum legal size for cod is ABOVE L_{50} for 6.5 in diamond mesh and BELOW L_{50} for the 6.5 in square mesh codend.
- Page 23. The caption for Table 7 is incorrect. The control codend mesh size should be 7.6 cm (3.0 in).
- Page 59. The caption for Figure 32 should include not only yellowtail flounder but also winter flounder and cod.

Final Reports are widely disseminated to our constituents with an interest in the topic. Accordingly, we request a final report by March 10, 2005. I trust that these review comments will be viewed constructively. If you have any questions, please contact Rich Maney of my staff at (978) 281-9265.

Sincerely,

Kenneth Beal

Harold C. Mears, Director
State, Federal and Constituent
Programs Office

cc: Joseph DeAlteris

EFFECTS OF CODEND MESH SIZE ON THE MULTISPECIES YIELD AND SPAWNING STOCK BIOMASS IN THE WESTERN GEORGES BANK TRAWL FISHERIES

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Revised July 2006

Completion for an NMFS S-K Project

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ABSTRACT

Codend size selection is used as a method to reduce fishing mortality of juvenile fish. This allows the fish to grow and reproduce increasing the yields and spawning stock biomasses respectively. Gradual increases in the minimum regulated trawl mesh sizes have occurred in New England since the early 1980's and ground fish stocks have been rebuilding. At present, a 16.5 cm (6.5 in) diamond shape and a 16.5 cm (6.5 in) square shape are the regulated minimum mesh characteristics for New England's groundfish trawl codends.

Mesh size selection studies were conducted on winter flounder (*Pseudopleuronectes americanus*), yellowtail flounder (*Limanda ferruginea*), Atlantic cod (*Gadus morhua*), and pollock (*Pollachius virens*) using nominal codend mesh sizes of 16.5 cm (6.5 in), 17.8 cm (7.0 in), and 20.3 cm (8.0 in) square and diamond shapes. The results have been incorporated into single species yield per recruit models, and a multispecies yield per recruit model was developed using relative recruitment multipliers (RRMs) based on small mesh trawl catches obtained during the selectivity study. The results of these analyses show that the multispecies yield per recruit is maximized for the 17.8 cm (7.0 in) diamond –shaped codend mesh size. Further, for the existing 16.5 cm (6.5 in) codend minimum mesh sizes, the minimum legal fish size for winter flounder should be minimally increased from 30.5 cm (12 in) to 35.6 cm (14 in) and increased for yellowtail flounder from 33.02 cm (13 in) to 35.6 cm (14 in) in order to circumvent minimum mesh size regulations.

INTRODUCTION

Statement of the problem

Increasing the mesh size of fishing gear has proven to be a valuable method of reducing growth and recruitment overfishing, thus optimizing yield and maximizing the spawning stock biomass. One relatively simple method of potentially improving the yield in the New England groundfish fishery is by further increasing the minimum codend mesh sizes and shapes required under the Northeast Multispecies Fishery Management Plan (FMP) (50 CFR § 648.80(a)(3), 2003). There are presently limited data available on mesh size selectivity at and above the 16.5 cm (6.5 in) square and diamond-shaped codend minimum mesh sizes that are required in the multispecies FMP.

Background

The groundfish fishery of New England harvests from a multispecies complex where the fishing gear selects for a wide range of target species and by-catch. The reduction of the catch of non-target species and target species less then the minimum regulated fish size is important to both the fishing industry and the fish resources. Furthermore, in order to maximize the sustainable yield, the overall fish stocks must be allowed to approach their greatest population biomass before being captured by the trawl gear. Fishery management has progressed these goals by regulating the catch and by modifying the legal trawl gear.

One method of reducing fishing mortality of juvenile fish is by increasing the legal minimum mesh sizes and shapes on the codend section of the trawl net. Major declines in catch and the estimated stock abundance during the 1980s and 1990s led to the increase of codend mesh sizes to allow the stocks to replenish. The current codend mesh sizes of the 16.5 cm (6.5 in) square and diamond-shaped designs were implemented in direct response to the needed reduction of growth and recruitment overfishing so as to improve the stock yield and increase the spawning stock biomass.

Objectives

The purpose of this thesis project is to compare the selectivity of the existing regulated codend mesh sizes and shapes under the Northeast Multispecies FMP with larger experimental codend mesh sizes, and then determine the potential effects that an increase in mesh size may have on the yield of the trawl fishery and the spawning stock biomass of the resource.

The specific objectives for this study were:

1. Develop species-specific fish size selection curves for a stretched 16.5 cm (6.5 in), 17.8 cm (7.0 in), and 20.3 cm (8.0 in) square and diamond-shaped codend mesh sizes for winter flounder (*Pseudopleuronectes americanus*), yellowtail flounder (*Limanda*

ferruginea), Atlantic cod (*Gadus morhua*), and pollock (*Pollachius virens*) based on field investigations and estimate standard errors to those curves.
2: Develop yield per recruit (YPR) and spawning stock biomass per recruit (SSBPR) models for each target species with respect to the various codend mesh sizes based on the derived selection curves.
3: Conduct multispecies yield per recruit (YPR) and spawning stock biomass per recruit (SSBPR) analyses so as to determine the optimum codend mesh sizes that will maximize biological yield in the New England groundfish fishery.

LITERATURE REVIEW

Trawl Gear Characteristics and Fish Behavior

The codend selection process results in a different length-frequency distribution in the catch from what the trawl net actually encounters (Pope et al., 1975). A logistic model is typically used to describe size selectivity of trawl fishing gear where the probability of capture is dependent on the length of a fish entering a codend with a particular mesh size and shape. Selection curves are defined by the curves' steepness and the L_{50}, the fish length at which 50% of a particular species is retained in the codend after entering. The characteristics of a particular codend mesh can be further described by its selection factor (SF), the ratio of the L_{50} to the stretched mesh length. Assuming that the SF is constant for a range of fish lengths, a series of selection curves for each species can be developed to characterize the L_{50}s for a range of mesh sizes based on a single SF.

Inconsistent SF values with changing codend mesh sizes of a particular mesh shape for Northwest Atlantic demersal groundfish species is often observed contrary to the expected stable SF of each mesh shape (DeAlteris and Grogan, 1997). The deviation from the expected consistent SF values may be due to morphological changes of a fish species' length to girth ratio with age (Pope et al., 1975). This creates difficulties in simply predicting the effects of changing a mesh size without adequate data.

Diamond or square-shaped mesh codends are used dependant upon the mesh's selection characteristics for the particular species being targeted. As the diamond-shaped mesh codend becomes loaded, it begins to take on a bulbous shape in the water. The meshes ahead of the bulb stretch to create a longer length aperture and a smaller width aperture allowing a better opportunity for escapement of flat fishes, such as the winter flounder (DeAlteris, et al., 1999). Square-shaped mesh codends remain cylindrical as the codend becomes loaded. The square-shaped meshes retain their original shape and thus, provide a better opportunity for the escapement of round fishes like Atlantic cod (Simpson, 1988; Walsh, et al., 1992). With round fish, higher L_{50}s and SFs are more likely obtained in square-shaped mesh codends than in the diamond-shaped mesh codends (Cooper and Hickey, 1989). An analysis of Southern New England yellowtail flounder using 15.2 cm (6.0 in) diamond, 16.5 cm

(6.5 in) square, 16.5 cm (6.5 in) diamond, and 17.8 cm (7.0 in) square-shaped codend mesh sizes concluded that the diamond-shaped codend meshes yielded higher L_{50}s than the square-shaped codend mesh and that an increase in size of either shape showed no significant difference in the catch (Skrobe, et al., 2003).

Tow duration has little effect on the mean length composition of trawl catches (Godø, et al., 1990). Short tows had very similar results as long tows for the cod, haddock, and American plaice fisheries.

The codend catch analysis size selection process occurs in the codend and there is no significant difference of the catch size due to the mesh sizes in the body of the trawl (Testaverde, et al., 1990).

Some of the experimental trawl methods used to obtain selection curves include the alternate haul method, paired trawls, and the covered codend method. The alternate haul method best exemplifies the conditions experienced by the fishing community, although it must rely on using one experimental codend at a time tested in adjacent trawls against a small-mesh control codend. This method requires a great deal of time to obtain adequate data from multiple tows. Paired trawls are simultaneously performed by two vessels, side-by-side, to compare the catch of a control codend and an experimental codend (DeAlteris, 1998). This requires a great deal of effort and coordination between the two vessels although the time spent towing is much less than that of the alternate haul method. The covered codend method involves a small-mesh control codend surrounding an experimental codend so as to retain the fish length classes that escape from the experimental codend. "Masking" can occur in a covered codend method as the cover may deters fish that would normally exit the experimental codend causing a biased result, resulting in a lower L_{50} and SF than would be obtained by the alternate haul method (Pope et al., 1975). Based on remote controlled underwater camera surveillance of eleven covered codend trawls, masking was reported when the cover lost its full upright state and dragged down into the codend inhibiting further escapement of fish within the codend (Halliday, et al., 1999; Lux, 1968). Paired trawls using double rig beam trawling or twin beam trawling reported lower L_{50}s and SFs than the covered codend method (Fonteyne, 1991).

Analytical Procedures

Trawl selectivity data can be analyzed using linear and nonlinear approaches. In the logit procedure, the proportion of a fish species retained is calculated by taking a ratio of the experimental codend catch frequency to the control codend catch frequency for each length class (Pope et al., 1975). Unfortunately, this method is problematic when the proportion retained exceeds unity in the likely case of larger length classes where the experimental codend catch is found to be greater than the control codend catch. Pope et al. (1975) suggest dividing the total number of fish caught above the effective selection range of the experimental codend by that caught in the small mesh codend. The same logic can be applied towards the smaller length classes (Simpson, 1989). In the nonlinear method, the steepness and L_{50} of the predicted selection curves are driven by the values obtained through minimizing the sums of the squares for the difference between observed and expected probabilities of retention. Alternatively, the nonlinear SELECT method can be applied whereby a selection curve is fitted along with a split parameter p which represents the expected proportion of the total number of fish entering the experimental codend that enters the experimental and control codends (Cadigan and Millar, 1991). The SELECT method often results in the best estimates of the L_{50} and SF when the sample sizes are very small since it relies on the sum of two groups of tows.

Changes in the selectivity of the fishing gear or legal minimum size limits for the fish stocks may not always cause a great shift in the catch and stock biomasses, although significant changes in the age distributions will most likely occur (Ricker, 1975). The maximization of a catch biomass through the control of fishing mortality and the age of entry into the fishery can be obtained through the use of a yield per recruit (YPR) analysis assuming a steady-state stock structure (King, 1995). It is also possible to assess the impact of selectivity changes on short-term yield if sufficient data are available concerning the size structure of the fish caught even in unfavorable conditions (Gulland, 1983).

The New England ground fisheries are not exclusive to single species. That is, gear selection characteristics harvest from a multispecies fish complex. A multispecies YPR analysis can be utilized to better define the fishery rather than the traditional single species YPR analyses that are usually conducted to characterize the groundfish fishery (Murawski, 1982). Results from the multispecies analysis can then be broken down into its species components by determining the biological characteristics and catchability coefficients (q), the coefficient of proportionality between fishing effort and fishing mortality, for each respective species. Murawski provides two models addressing the distinctions of either a single operational fishery or that of several interacting fisheries for Atlantic cod, yellowtail flounder, winter flounder, and haddock data. The current and future importance of each species' contribution towards the total yield is a function of the selection process. Shifts in the harvest gear selectivity can cause profound changes within each target species' age class structures, and the economics of the fishery.

METHODS AND MATERIALS

Vessel Specifications for the F/V Morue

The F/V Morue, a 96-foot hard bottom groundfish commercial trawler home-ported in New Bedford, MA, was used for this study. The vessel had three drums for the storage and operation of the nets and codends and a crane to facilitate hauling procedures. The F/V Morue supported a crew of five and three scientists.

Gear Descriptions

All fishing gear was designed to emulate the actual conditions used in the fishing industry and specifically by the F/V Morue. The codends were constructed of knotted, braided, single or double twine polyethylene webbing. Trawl gear characteristics included a 39 m (128 ft) length sweep with 81.3 cm (32 inch) rock hoppers at the center and 61 cm (24 inches) in the wings. The headrope was 31.7 m (104 ft) long with 80 floats. Legs and backstraps were 9.1 m (30 ft) and 11 m (36 ft) long respectively. The doors were 1000 kg and 4.2 m^2 oval-shaped, and the trawl warp was 25.4 mm (1 in).

Field Work

The research was conducted from the commercial fishing vessel, the F/V Morue in the Great South Channel, Georges Bank of New England over three five-day voyages. Using the alternate tow method, six experimental codends, consisting of nominal 16.5 cm (6.5 in), 17.8 cm (7.0 in), and 20.3 cm (8.0 in) square and diamond-shaped stretched mesh sizes, were compared with the 7.6 cm (3.0 in) stretched mesh size diamond-shaped control codend (Pope et al., 1975).

Ten consecutive meshes from each codend were chosen haphazardly and measured at the beginning and middle of each of the three voyages to monitor for changes in the actual stretched mesh sizes over time. Measurements were taken along the run of the twine using a standard ruler with each aperture stretched to its maximum length. The resulting actual mesh sizes were averaged over the entire study with respect to each expected mesh shape and size. The various mesh sizes are referred to by their nominal mesh sizes and not the actual mesh sizes although the actual mesh sizes are utilized in all related calculations.

The alternate tow method followed a staggered format for the experimental codends beginning with trawl set one as 16.5 cm (6.5 in) square, 16.5 cm (6.5 in) diamond, 17.8 cm (7.0 in) square, 17.8 cm (7.0 in) diamond, 20.3 cm (8.0 in) square, and 20.3 cm (8.0 in) diamond-shaped mesh codends (Table 1). In trawl set two, the 16.5 cm (6.5 in) square-shaped mesh size codend was moved to the last tow. This pattern repeated with the first mesh size of the current trawl set becoming the last mesh of the following trawl set. The staggered formation allowed all the mesh sizes to be utilized throughout varied times of the day. The 7.6 cm (3.0 in) control mesh size codend was used as the second, fifth, and eighth trawl in each trawl set. This allowed each experimental codend trawl to be compared later against an adjacent control codend trawl.

Tow duration, distance traveled, total codend catch weight, and the coordinates at the beginning, middle, and end of each trawl were recorded. Distance traveled was approximately 4.8 km (3 miles) in one direction and 4.8 km (3 miles) in the approximate opposite direction although not directly over the same path. The total tow duration back and forth approximated 2 hours after which the codend was brought back aboard and the next codend was immediately deployed. Tows were performed as close to the previous tow area as possible although not directly overlapping it, in order to reduce the inherent variability that may exist due to a change in location. This minimized possible deviations in confidence of the comparative analysis between the control and experimental tows.

The fish retained in the codend were emptied onto the deck after each tow was completed. Target fish were sorted by species and then haphazardly placed into baskets. Total basket counts for each species were recorded. Total length measurements to the next largest centimeter were then recorded for target fish using a fish measuring board. The total fish length is defined as the distance from the snout to the furthest end of the sagittally compressed caudal rays.

A sub-sample of the target fish species was collected in tows where the total target species catch could not be measured in the available time, limited by the next tow's 2 hour duration. A species representative sub-sample was taken as a fraction of the total baskets collected for that particular species. The sub-sample was then adjusted to account for the unmeasured baskets.

Analysis

Data was compiled using Microsoft Excel. Cumulative length frequency distributions for each experimental codend was generated and compared with adjacent cumulative control tows with respect to target species.

The catch data for each tow was adjusted to account for deviations from the desired, standardized 6-mile trawl distance. The true distance traveled was multiplicatively applied to the catch data as a proportion of the standard distance. A further adjustment to the length-frequency catch data for each tow was applied to account for sub-samples of the true catch representing each of the target species. Measured baskets of fish species' were scaled up to represent the total basket counts for those same species.

The slope and the length class at which 50% of the fish are retained in the codend, referred to as the L_{50}, define the logistic selection curve. The L_{50} is given by:

$$L_{50} = \alpha/\beta;$$

where α and β are the empirical coefficients derived from the regression line.

The predicted logistic curve that defines the selection characteristics of the codends is described as such:

$$P = 1/(1+e^{-(\alpha+\beta\cdot L)});$$

where L is the fish length and P is the probability of retention for each species with respect to the particular experimental codends (DeAlteris, 1998). Values for P were calculated by dividing the total numbers of the species caught with the experimental codend by the compared control codends. Linearizing the prior equation gives:

$$\ln(P/(1-P)) = \alpha+\beta\cdot L;$$

Estimates of α and β were determined from a linear regression of the Y value ($\ln(P/(1-P))$) as a function of the length classes.

A ratio unit of comparison of the L_{50} over the stretched mesh length, referred to as the selection factor (SF) for each experimental codend's selection curve with respect to each target species, was determined via the following equation:

$$SF = L_{50}/\text{stretched mesh length}.$$

Estimations for the SELECT method utilize a nonlinear technique to obtain values for α and β by maximizing the log likelihood (LL) of the predicted phi (Φ_{pred}) curve defined by the following equation:

$$\Phi_{pred} = (p\cdot e^{\alpha+\beta\cdot L})/(1-p+e^{\alpha+\beta\cdot L});$$

where split parameter p represents the expected proportion of the total number of fish that enter the experimental codend relative to the sum of the fish that enter the control and experimental codends (Cook et al., 1996; Millar and Fryer, 1999). The value for p was assumed 0.5 for this study under the assumption that the relative fishing power is equal for both the experimental and control nets. Therefore, Φ_{pred} can take on a range from 0 to 0.5.

The log likelihood (LL) is defined by the following equation:

$$LL = n_{l,exp}\cdot\ln(\Phi_{pred})+n_{l,control}\cdot\ln(1-\Phi_{pred});$$

where $n_{l,exp}$ is the number of fish at length L retained in the experimental codend and $n_{l,control}$ is the number of fish at length L retained in the control codend.

The actual characteristics of the selection curve are then obtained in the same manner as above for the logit method.

The following equation was used to test for deviance residual for length class L (D_L):

$$D_L = \text{sign}(\Phi_{obs}-\Phi_{pred})\{2(n_{1,exp}+n_{1,control})(\Phi_{obs}\cdot\ln(\Phi_{obs}/\Phi_{pred})+(1-\Phi_{obs})\cdot\ln((1-\Phi_{obs})/(1-\Phi_{pred})))\}^{1/2};$$

where Φ_{obs} is the proportion of experimental to total length L fish and sign(Φ_{obs}–Φ_{pred}) = 1 if x>0 and –1 if x<0. The model deviance (D) is the summation of the deviance residuals for all length classes. Both the model deviance and deviance residuals have approximate X^2 distributions when the model is correct and sample sizes are sufficient. A failure to fit the X^2 distribution may indicate a violation of the assumption that all fish behave independently with respect to the fish entering into the two codends and their ability to escape the experimental codend. Measures of the goodness of fit (GOF) are obtained by taking the summation of the squared deviance residuals over all length classes.

Estimated standard errors for parameters α and β are obtained using a Fisher Matrix (Lloyd and Lipow, 1962). Standard errors for the L_{50} and SR are derived from the variances and covariances of α and β (Lehmann, 1983). Confidence intervals were obtained at 95% significance.

The standard errors may be further modified by the existence of between-haul variation in replicate hauls, which are analyzed as if they were a single haul (Millar, 1993). The following equation tests whether the data follows a X^2 distribution:

$$Q = \sum_{l} \sum_{h} \frac{\left(n_{l1}^{h} - n_{l+}^{h} y_l\right)^2}{n_{l+}^{h} y_l \left(1 - y_l\right)}$$

where Q has an approximate X^2 distribution with degrees of freedom (d.o.f.), l is the number of fish in the experimental codend at length L, l+ is the experimental to control ratio of length L fish, h is the haul, and y_l is the proportion of experimental to total length L fish. If Q is less then or equal to the critical value, then the data follows the normal X^2 distribution. If Q is greater than the critical value, then the standard errors must be multiplied by the square root of the replication estimation of dispersion (REP) defined as such:

$$REP = Q/d.o.f.$$

Yield per recruit (YPR) models were estimated for each target species for various levels of fishing mortality and size retention using the following equation:

$$Y_t = [P \cdot F/(P \cdot F_t + M_t)] \cdot (N_{t-1} - N_t) \cdot W_t;$$

where Y_t is the yield at each time step, F is the fishing mortality, M is the natural mortality, N is the numbers of fish at times t and t-1, and W_t is the weight of fish at time t (DeAlteris and Riedel, 1996).

Normalizing the total yield by the number of recruits in a cohort gives the yield per recruit (YPR) value. For all species, the assumed natural mortality was considered equal to 0.2 (DeAlteris and Grogan, 1997). The following continuous model was used to determine the fish species' relative population death rate:

$$N_t = N_0 e^{-tM}$$

where N_t is the number of fish at time t, N_0 is the initial fish population, and M is the natural mortality. Time increments of 1/10th of a year for 20 years for each species were used for this study.

Values for the intrinsic rate of growth and maximum lengths and weights of the fish species with respect to changes in fish length and weight over time were obtained from DeAlteris and Grogan (1997) and applied to the following continuous growth model at time increments of 1/10 of a year:

$$L_t = L_\infty \cdot (1-e^{-K \cdot t});$$

where L_t is the length at time t, L_∞ is the maximum fish length, and K is the intrinsic rate of growth.

The relationship between length and weight is defined by the following equation:

$$W_t = a \cdot L_t^{b};$$

where a and b are the intrinsic values for each species.

The spawning stock biomass per recruit (SSBPR) models were estimated for each target species for various levels of fishing mortality and size retention using the following equation:

$$SSB_t = (N_t \cdot W_t \cdot p_t);$$

where the SSB_t is the spawning stock biomass at each time step, N and W are the numbers and weights at time t respectively, and the p_t is the estimated percent fish mature at time t and is given via the following equation:

$$p_t = (1+e^{-\alpha 1 \cdot (t-\beta 1)})^{-1};$$

where $\alpha 1$ and $\beta 1$ are the intrinsic maturity parameters for each species. Values for $\alpha 1$ and $\beta 1$ were obtained from DeAlteris and Grogan (1997).

The total YPR and SSBPR is estimated using relative recruitment multipliers (RRM) in order to standardize the recruitment variations for the multispecies fishery. The RRM is simply defined as a scaler for individual species based on the absolute abundance data or the relative indices of the catch data. For this study, the species numbers are scaled as proportions from the most abundant species caught, which is the winter flounder. The fishing mortality (F) is adjusted for the relative catchability of each species, which produces the fishing effort (f) and is given as such:

$$F = q \cdot f;$$

where q is the catchability coefficients for each species. Values for q for the Georges Bank trawl fishery for winter flounder, Atlantic cod, and yellowtail flounder are 0.000047, 0.000029, and 0.000056 respectively (Kinani,1997).

For the purpose of this study, the individual species and multispecies yield per recruit (YPR) analyses and the spawning stock biomass per recruit (SSBPR) analyses are based off of the parameters obtained from the SELECT method selection curves since standard errors are applied to the selection curve results.

RESULTS

Overview

Thirteen paired trawl sets were conducted for the 16.5 cm (6.5 in) square, 16.5 cm (6.5 in) diamond, 17.8 cm (7.0 in) square, 17.8 cm (7.0 in) diamond, and 20.3 cm (8.0 in) square-shaped experimental mesh codends and 12 paired trawl sets were conducted for the 20.3 cm (8.0 in) diamond-shaped experimental mesh codend for the entire study. The general staggered order of tow sets designed for this study is shown in Table 1.

The mesh sizes and shapes of 16.5 cm (6.5 in), 17.8 cm (7.0 in), and 20.3 cm (8.0 in) square and diamond and the 7.6 cm (3.0 in) control mesh are referred to by their nominal mesh types in the text. The actual mean mesh sizes for each experimental codend were used in all calculations and are reported in Table 2.

Selection curves were obtained for winter flounder, yellowtail flounder, Atlantic cod, and pollock using the 16.5 cm (6.5 in), 17.8 cm (7.0 in), and 20.3 cm (8.0 in) square and diamond-shaped codend mesh sizes. All selection curves were generated from the comparative length-frequency distributions for the experimental and control tows with respect to each species and experimental mesh size and shape. The SELECT method selection curves more often resulted in a lower residual sum of the squares. These latter type selection curves, in turn, were used to develop YPR and SSBPR curves.

Winter flounder

The results of the logit and SELECT method selection curve analysis for winter flounder are shown in Table 3 and Figures 1-6. The standard error for the 20.3 cm (8.0 in) diamond-shaped codend mesh is larger than the other standard errors given but still within 10% of the associated L_{50}. All SF values for square-shaped codend meshes are within 0.3 of each other. All SF values for diamond-shaped codend meshes are within 0.4 of each other. No significant difference exists between the L_{50}s for the 16.5 cm (6.5 in) and 17.8 cm (7.0 in) codend meshes due to mesh size. The 20.3 cm (8.0 in) codend meshes were significantly different from other mesh sizes. In all cases, a significant difference exists between the L_{50}s for the codend meshes due to mesh shape. For all codend mesh sizes, the L_{50}s are greater for diamond-shaped codend meshes.

The results of the YPR curves for winter flounder show relatively little differences over all mesh sizes and shapes before a fishing mortality of approximately 0.4 with the exception of the 20.3 cm (8.0 in) diamond-shaped codend mesh which diverges early and is inconsistent with the rest of the analysis (Figure 7). At lower fishing mortalities, the highest YPR is attained by the 17.8 cm (7.0 in) diamond-shaped codend mesh and the 20.3 cm (8.0 in) square-shaped codend mesh at approximately F=0.5. The 20.3 cm (8.0 in) square-shaped codend mesh size reaches the highest YPR value at F=1.0. Both the 16.5 cm (6.5 in) and 17.8 cm (7.0 in) square-shaped codend mesh sizes greatly dip at high fishing mortalities.

The results of the SSBPR curves for winter flounder showed relatively little difference between the 16.5 cm (6.5 in) and 17.8 cm (7.0 in) codend meshes due to mesh size (Figure 8). In all cases, the diamond-shaped codend meshes produced higher values for the SSBPR over its entire range as compared to the square-shaped codend meshes of the same sizes. With the exception of the 20.3 cm (8.0 in) diamond-shaped codend mesh for the reasons given above, the 20.3 cm (8.0 in) square-shaped codend mesh provides the highest SSBPR values.

Atlantic cod

The results of the logit and SELECT method selection curve analysis for winter flounder are shown in Table 4 and Figures 9-14. All SF values for square and diamond-shaped codend meshes are within 0.3 of each other respectfully. A significant difference exists for all L_{50}s with respect to codend mesh sizes and shapes. For all codend mesh sizes, the L_{50}s are greater for square-shaped codend meshes. An increase in the L_{50} occurs with an increase in codend mesh size.

The results of the YPR curves for Atlantic cod show relatively little differences over all mesh sizes and shapes before a fishing mortality of approximately 0.2 (Figure 15). The highest YPR is attained by the 20.3 cm (8.0 in) square-shaped codend meshes at approximately F=0.6. All other YPR curves predict slightly lower maximum values at lower fishing mortalities. In all cases, the square-shaped codend meshes produce a higher YPR than the respected diamond-shaped codend meshes of the same size.

The 20.3 cm (8.0 in) square-shaped codend mesh gives the highest SSBPR for Atlantic cod (Figure 16). The square-shaped codend meshes produced higher values for the SSBPR over its entire range as compared to the diamond-shaped codend meshes of the same lengths. In all cases, the codend meshes produce higher values for the SSBPR with respect to larger mesh sizes for each shape.

Yellowtail flounder

The results of the logit and SELECT method selection curve analysis for yellowtail flounder are shown in Table 5 and Figures 17-22. All SF values for square and diamond-shaped codend meshes are within 0.2 and 0.7 of each other respectively. No significant difference exists for the 16.5 cm (6.5 in) and 17.8 cm (7.0 in) square-shaped codend mesh size L_{50}s. No significant difference exists for the 17.8 cm (7.0 in) and 20.3 cm (8.0 in) diamond-shaped codend mesh size L_{50} values. With the exception of the 17.8 cm (7.0 in) and 20.3 cm (8.0 in) diamond-shaped codend meshes, there is an increase in L_{50} values with respect to mesh size. Also with exception to the 20.3 cm (8.0 in) codend meshes, the diamond-shaped codend meshes result in higher L_{50} values than square-shaped codend meshes.

Within reasonable levels of fishing mortality, the highest YPR result is attained by the 16.5 cm (6.5 in) and 17.8 cm (7.0 in) square-shaped codend meshes at approximately F=1.4 and 1.6 respectfully for yellowtail flounder (Figure 23). All other base YPR curves give their respective maximum YPR values at much higher fishing mortalities. YPR results using the 20.3 cm (8.0 in) square-shaped codend meshes are inconsistent with the rest of the YPR results.

With the exception of the 20.3 cm (8.0 in) square-shaped codend mesh for the reasons given above in the YPR analysis, the 17.8 cm (7.0 in) diamond-shaped codend mesh reports the highest SSBPR for yellowtail flounder; the lowest SSBPR is reported by the 16.5 cm (6.5 in) square-shaped codend mesh size (Figure 24). Also with exception of the 20.3 cm (8.0 in) codend meshes, the diamond-shaped codend meshes produced higher values for the SSBPR as compared to all of the square-shaped codend meshes.

Pollock

The results of the logit and SELECT method selection curve analysis for pollock are shown in Table 6 and Figures 25-30. The standard error for the 17.8 cm (7.0 in) square-shaped and the 20.3 cm (8.0 in) square and diamond-shaped codend meshes are larger than the other standard errors given but still within 10% of the associated L_{50} values. The 20.3 cm (8.0 in) square and diamond-shaped codend meshes could not be adjusted for between-haul variations due to small sample sizes. For this reason, this mesh size will not be discussed in relation to pollock.

SF values for the 16.5 cm (6.5 in) and 17.8 cm (7.0 in) square-shaped codend mesh are within 0.5 of each other (Table 6). SF values for the 16.5 cm (6.5 in) and 17.8 cm (7.0 in) diamond-shaped codend meshes are within 0.8 of each other. A significant difference exists between the L_{50} values for the 16.5 cm (6.5 in) and 17.8 cm (7.0 in) codend meshes due to mesh size. A significant difference exists between the L_{50} values of the 16.5 cm (6.5 in) and 17.8 cm (7.0 in) codend meshes due to mesh shape. For all codend mesh sizes, the L_{50} values are greater for square-shaped codend meshes. For all codend mesh sizes, an increase in the L_{50} value occurs with an increase in codend mesh size.

Since the pollock data resulted in small sample sizes with associated large or incomplete standard error results due to the inability of performing X^2 tests for the 20.3 cm (8.0 in) square and diamond-shaped codend meshes, the pollock data was not used in the single species YPR or SSBPR analyses.

Multispecies analysis

The results of the multispecies YPR and SSBPR analyses are based solely on data obtained from winter flounder, Atlantic cod, and yellowtail flounder for all experimental codends studied. Single species YPR and SSBPR curves were not generated for pollock and were therefore, not included in the multispecies YPR and SSBPR analyses.

Relative recruitment multiplier (RRM) values were obtained for Atlantic cod and yellowtail flounder as total catch proportions of the total winter flounder catch since the winter flounder had the largest catch numbers. The adjusted total catch is defined as the total fish for each species retained within the 7.6 cm (3.0 in) diamond-shaped control codend mesh and adjusted for variations in the standard conditions with respect to time traveled and measured baskets. The RRM values used in the multispecies YPR and SSBPR curves are shown in Table 7.

The results of the multispecies YPR curves are reported as a function of fishing effort (f) and expressed in terms of days (Figure 31 and Table 8). Values for f are rounded to the nearest one thousand. All codend mesh sizes provide very similar results at less than approximately 8,000 days with the exception of the 20.3 cm (8.0 in) diamond-shaped codend mesh which initially produces lower YPR values. The highest YPR values are attained at higher effort levels by the 20.3 cm (8.0 in) square-shaped codend mesh when f values are greater than approximately 8,000 days. All 16.5 cm (6.5 in) and 17.8 cm (7.0 in) codend meshes produce similar and close multispecies YPR trends with the 17.8 cm (7.0 in) diamond-shaped codend mesh performing the best overall.

The results of the multispecies SSBPR curves are reported as percentages of the total biomasses per recruit for winter flounder, Atlantic cod, and yellowtail flounder (Figure 32 and Table 8). With the exception of the 20.3 cm (8.0 in) codend meshes, the highest overall SSBPR levels occur using the 17.8 cm (7.0 in) diamond-shaped codend mesh although these results are similar to the remaining tested codend meshes.

DISCUSSIONS AND CONCLUSIONS

The New England biological groundfish fishery is a multispecies complex. Therefore, changes to the existing trawl mesh characteristics must be considered in regard to all fish species that are part of the complex. For this study, only those species that provided reliable selection curves are considered in the multispecies YPR and SSBPR analyses, which include winter flounder, Atlantic cod, and yellowtail flounder. Pollock results generally consisted of small sample sizes and therefore, were excluded from the multispecies YPR and SSBPR analyses. Furthermore, as the codend mesh sizes increase, they select for a smaller percentage of length classes in the fish populations. In some cases, the larger experimental codend meshes also suffered from small sample sizes and will be discussed on a case-by-case situation.

The series of selection curves generated for winter flounder and yellowtail flounder shows that in all cases, the minimum legal size of these fish at 30.48 cm (12 in) and 33.02 cm (13 in) respectively are way below the calculated L_{50} levels (Figures 1-6 and 17-22). In order to adjust for this difference while not affecting the other fisheries, the minimum legal fish size for those species below the L_{50} levels must be increased closer to the L_{50} levels of the current codend meshes being used. Therefore, according to the results of this study for the regulated minimum codend mesh size of 16.5 cm (6.5 in) square and diamond shapes, the minimum legal fish size for winter flounder and yellowtail flounder should be minimally increased to 35.6 cm (14 in). Additionally, by increasing the minimum legal fish size, the incentive for using small mesh liners in order to retain a higher percentage of legal-sized fish is reduced.

According to the selection curves generated for Atlantic cod, the minimum legal fish size of 55.88 cm (22 in) is above the L_{50} level estimated from the 16.5 cm (6.5 in) diamond-shaped codend mesh and below the L_{50} level estimated from the 16.5 cm (6.5 in) square-shaped codend mesh (Figures 9-14). The selection curve generated from the 17.8 cm (7.0 in) diamond-shaped codend mesh estimated an L_{50} level closest to the current minimum legal fish size over all the mesh sizes and shapes. All other selection curves estimated L_{50} levels higher than that given by the 16.5 cm (6.5 in) diamond-shaped codend mesh. The square-shaped codend meshes give higher L_{50} levels than those given by the diamond-shaped codend meshes of the same sizes. Therefore, it is this author's opinion that the current minimum legal codend mesh size of 16.5 cm (6.5 in) is suitable for this species.

According to the selection curves generated for pollock, the minimum legal fish size of 48.30 cm (19 in) is below the L_{50} levels for all codend mesh sizes and a close fit to the L_{50} level estimated from the 16.5 cm (6.5 in) diamond-shaped codend mesh (Figures 25-30). All other selection curves estimated L_{50} levels higher than that given by the 16.5 cm (6.5 in) diamond-shaped codend mesh. The square-shaped codend meshes give higher L_{50} levels than those given by the diamond-shaped codend meshes of the same sizes. Therefore, it is this author's opinion that the current minimum legal codend mesh size of 16.5 cm (6.5 in) is suitable for this species.

The YPR analyses are based on the selection curves given by the SELECT method rather than the logistic selection curve method due to the presence of standard errors obtained by the SELECT method (Tables 3-6). The curves derived from both methods generally show a strong agreement.

Increases in the current legal mesh sizes will affect the groundfish fishery as a whole. At lower levels of fishing efforts, the multispecies YPR curves derived from the selectivity curves, shows nearly identical results for all codend mesh sizes and shapes with the exception of the 20.3 cm (8.0 in) diamond-shaped codend mesh size (Figure 31). The 17.8 cm (7.0 in) codend meshes provide slightly higher multispecies yields than the 16.5 cm (6.5 in) codend meshes. Therefore, by increasing the current codend mesh sizes from the 16.5 cm (6.5 in) to the 17.8 cm (7.0 in) sizes, the YPR will only decrease a minimal amount while slightly increasing the SSBPR. This additional spawning stock biomass may allow for a greater population growth increasing the potential future YPR.

Results from the 20.3 cm (8.0 in) codend meshes have larger associated standard errors with smaller sample sizes (Tables 3-6). This author feels that although most of the standard errors for the 20.3 cm (8.0 in) codend meshes are within acceptable boundaries, this mesh size does not provide results as strong as the other codend mesh sizes.

Table 1. Repeating staggered tow sets with control tows as the 2nd, 5th, and 8th tow in each set. "D" refers to diamond-shaped meshes and "S" refers to square-shaped meshes.

Set #	Staggered tow sets with control tows								
1	6.5" S	3.0" D	6.5" D	7.0" S	3.0" D	7.0" D	8.0" S	3.0" D	8.0" D
2	6.5" D	3.0" D	7.0" S	7.0" D	3.0" D	8.0" S	8.0" D	3.0" D	6.5" S
3	7.0" S	3.0" D	7.0" D	8.0" S	3.0" D	8.0" D	6.5" S	3.0" D	6.5" D
4	7.0" D	3.0" D	8.0" S	8.0" D	3.0" D	6.5" S	6.5" D	3.0" D	7.0" S
5	8.0" S	3.0" D	8.0" D	6.5" S	3.0" D	6.5" D	7.0" S	3.0" D	7.0" D
6	8.0" D	3.0" D	6.5" S	6.5" D	3.0" D	7.0" S	7".0 D	3.0" D	8.0" S
7	6.5" S	3.0" D	6.5" D	7.0" S	3.0" D	7.0" D	8.0" S	3.0" D	8.0" D

Table 2. Actual measured stretched mesh lengths for codend mesh sizes averaged over six trial dates. Trial dates represent the beginning or middle of each sampling voyage.

	mean mesh lengths (cm)						
date measured	3.0" D	6.5" S	6.5" D	7.0" S	7.0" D	8.0" S	8.0" D
9/6/2002	7.72	16.07	16.80	17.84	17.84	21.81	21.75
9/8/2002	7.46	16.54	16.92	18.13	18.00	21.24	22.10
9/19/2002	8.22	16.29	17.08	17.43	18.70	22.00	22.26
9/22/2002	7.91	15.62	16.19	17.65	18.03	21.78	21.78
10/3/2002	7.87	16.80	16.95	18.35	17.91	21.78	22.45
10/8/2002	7.87	15.46	17.34	17.49	17.59	22.26	22.64
Total Mean:	7.84	16.13	16.88	17.82	18.01	21.81	22.16

Table 3. Summary of logit method and SELECT method selection curves, and the maximum YPR with the corresponding F value and SSBPR for each experimental mesh codend for winter flounder. ML is the actual average mesh length for the nominal experimental codend meshes used to determine the selection factor (SF). Standard errors are given for the SELECT method L_{50}s. Values for the F and SSBPR correspond to the highest YPR value. All SSBPR values are expressed as a percentage of the maximum spawning stock biomass at F=0.

winter flounder

Mesh:	6.5" Square	7.0" Square	8.0" Square	6.5" Diamond	7.0" Diamond	8.0" Diamond
ML (cm):	16.1	17.8	21.8	16.9	18.0	22.2
Logit L_{50} (cm):	37.8	37.7	47.5	42.4	43.3	60.9
Logit SF:	2.3	2.1	2.2	2.5	2.4	2.7
SELECT L_{50} (cm):	38.6	38.1	48.4	43.9	43.8	61.3
SELECT SF:	2.4	2.1	2.2	2.6	2.4	2.8
L_{50} SE:	0.3	0.4	0.7	0.9	0.6	3.0
max YPR (kg):	0.6	0.6	0.7	0.7	0.7	0.7
F at max YPR:	0.5	0.5	1.0	0.6	0.7	2.1
SSBPR at max YPR:	22%	22%	23%	24%	22%	26%

Table 4. Summary of logit method and SELECT method selection curves, and the maximum YPR with the corresponding F value and SSBPR for each experimental mesh codend for Atlantic cod. ML is the actual average mesh length for the nominal experimental codend meshes used to determine the selection factor (SF). Standard errors are given for the SELECT method L_{50}s. Values for the F and SSBPR correspond to the highest YPR value. All SSBPR values are expressed as a percentage of the maximum spawning stock biomass at F=0.

Atlantic cod

Mesh:	6.5" Square	7.0" Square	8.0" Square	6.5" Diamond	7.0" Diamond	8.0" Diamond
ML (cm):	16.1	17.8	21.8	16.9	18.0	22.2
Logit L_{50} (cm):	64.6	67.9	79.7	53.7	60.1	75.2
Logit SF:	4.0	3.8	3.7	3.2	3.3	3.4
SELECT L_{50} (cm):	62.1	69.0	78.4	50.4	58.5	72.7
SELECT SF:	3.9	3.9	3.6	3.0	3.3	3.3
L_{50} SE:	0.8	1.4	1.3	0.9	1.0	1.2
max YPR (kg):	1.3	1.3	1.5	1.2	1.3	1.4
F at max YPR:	0.3	0.4	0.6	0.3	0.3	0.5
SSBPR at max YPR:	30%	28%	30%	23%	28%	27%

Table 5. Summary of logit method and SELECT method selection curves, and the maximum YPR with the corresponding F value and SSBPR for each experimental mesh codend for yellowtail flounder. ML is the actual average mesh length for the nominal experimental codend meshes used to determine the selection factor (SF). Standard errors are given for the SELECT method L_{50}s. Resulting values for the maximum YPR and corresponding F and SSBPR values that were unreasonably large were indicated as not available (na). Values for the F and SSBPR correspond to the highest YPR value. All SSBPR values are expressed as a percentage of the maximum spawning stock biomass at F=0.

yellowtail flounder

Mesh:	6.5" Square	7.0" Square	8.0" Square	6.5" Diamond	7.0" Diamond	8.0" Diamond
ML (cm):	16.1	17.8	21.8	16.9	18.0	22.2
Logit L_{50} (cm):	37.3	39.8	52.5	42.5	52.1	52.1
Logit SF:	2.3	2.2	2.4	2.5	2.9	2.3
SELECT L_{50} (cm):	37.9	38.9	49.1	42.5	50.6	47.4
SELECT SF:	2.4	2.2	2.3	2.5	2.8	2.1
L_{50} SE:	0.5	0.5	1.4	1.0	1.9	1.3
max YPR (kg):	0.3	0.3	na	0.3	0.3	0.3
F at max YPR:	1.4	1.6	na	2.1	5.2	3.7
SSBPR at max YPR:	17%	17%	na	19%	20%	19%

Table 6. Summary of logit method and SELECT method selection curves for each experimental mesh codend for pollock. ML is the actual average mesh length for the nominal experimental codend meshes used to determine the selection factor (SF). Standard errors are given for the SELECT method L_{50}s.

pollock

Mesh:	6.5" Square	7.0" Square	8.0" Square	6.5" Diamond	7.0" Diamond	8.0" Diamond
ML (cm):	16.1	17.8	21.8	16.9	18.0	22.2
Logit L_{50} (cm):	73.1	79.2	110.9	53.3	72.8	109.6
Logit SF:	4.5	4.5	5.1	3.2	4.0	4.9
SELECT L_{50} (cm):	67.6	82.8	86.4	52.4	70.3	73.1
SELECT SF:	4.2	4.7	4.0	3.1	3.9	3.3
L_{50} SE:	1.9	5.7	8.6	1.3	1.7	4.1

Table 7. Adjusted total catch of winter flounder, Atlantic cod, and yellowtail flounder obtained from the 33.02 cm (13 in) diamond-shaped control codend mesh tows. Relative recruitment multiplier (RRM) values are given for each species as a proportion of the winter flounder catch.

	Atlantic cod	winter flounder	yellowtail flounder
Total Catch	8762.06	32210.97	3321.44
RRM Values	0.27	1.00	0.10

Table 8. Summary of the multispecies YPR and SSBPR curves for each experimental mesh codend. ML is the actual average mesh length for the nominal experimental codend meshes. Values for the f and SSBPR correspond to the highest YPR value and are approximated to the nearest thousand for f. All SSBPR values are expressed as a percentage of the maximum spawning stock biomass at f=0.

multispecies

Mesh:	6.5" Square	7.0" Square	8.0" Square	6.5" Diamond	7.0" Diamond	8.0" Diamond
ML (cm):	16.1	17.8	21.8	16.9	18.0	22.2
max YPR (kg):	1.0	1.0	1.1	1.0	1.0	1.1
f at max YPR:	11000	12000	21000	12000	13000	33000
SSBPR at max YPR:	26%	27%	35%	28%	35%	26%

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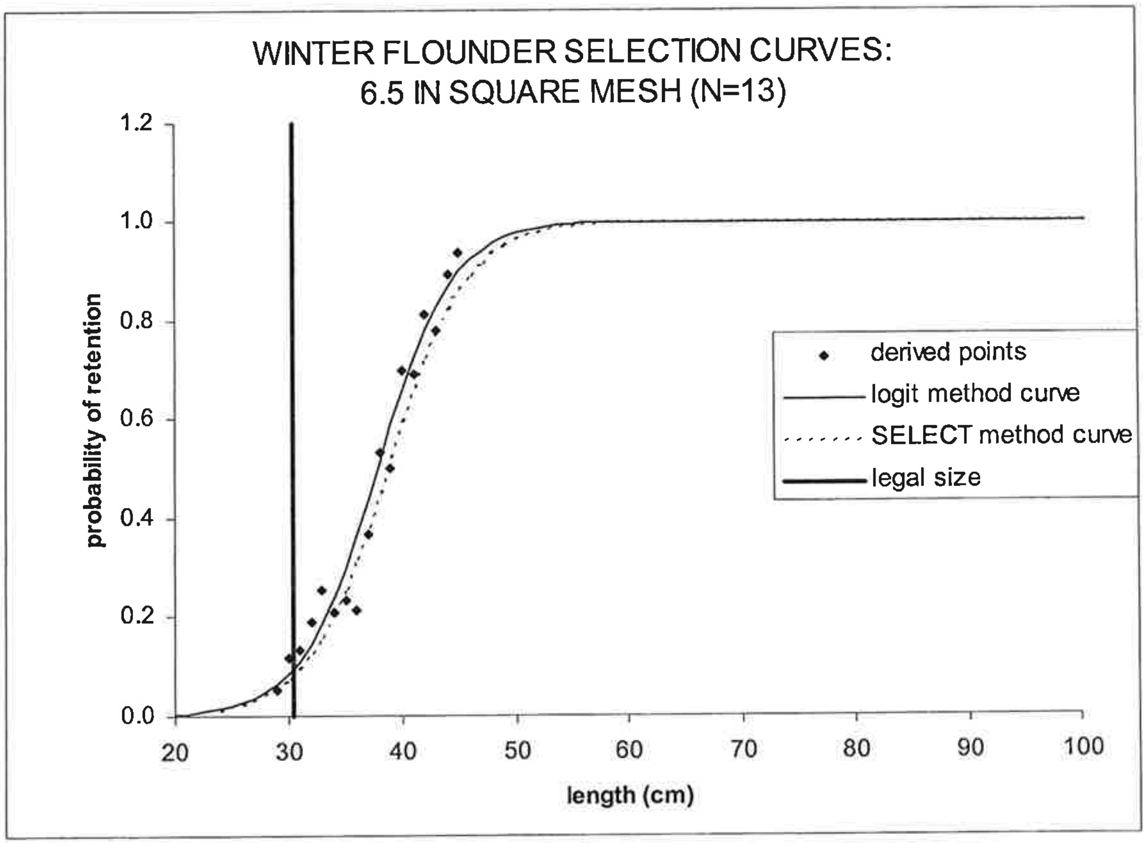

Figure 1. Winter flounder logit and SELECT method selection curves derived from the catch data analysis of 13 paired tows comparing the 16.5 cm (6.5 in) square-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for winter flounder.

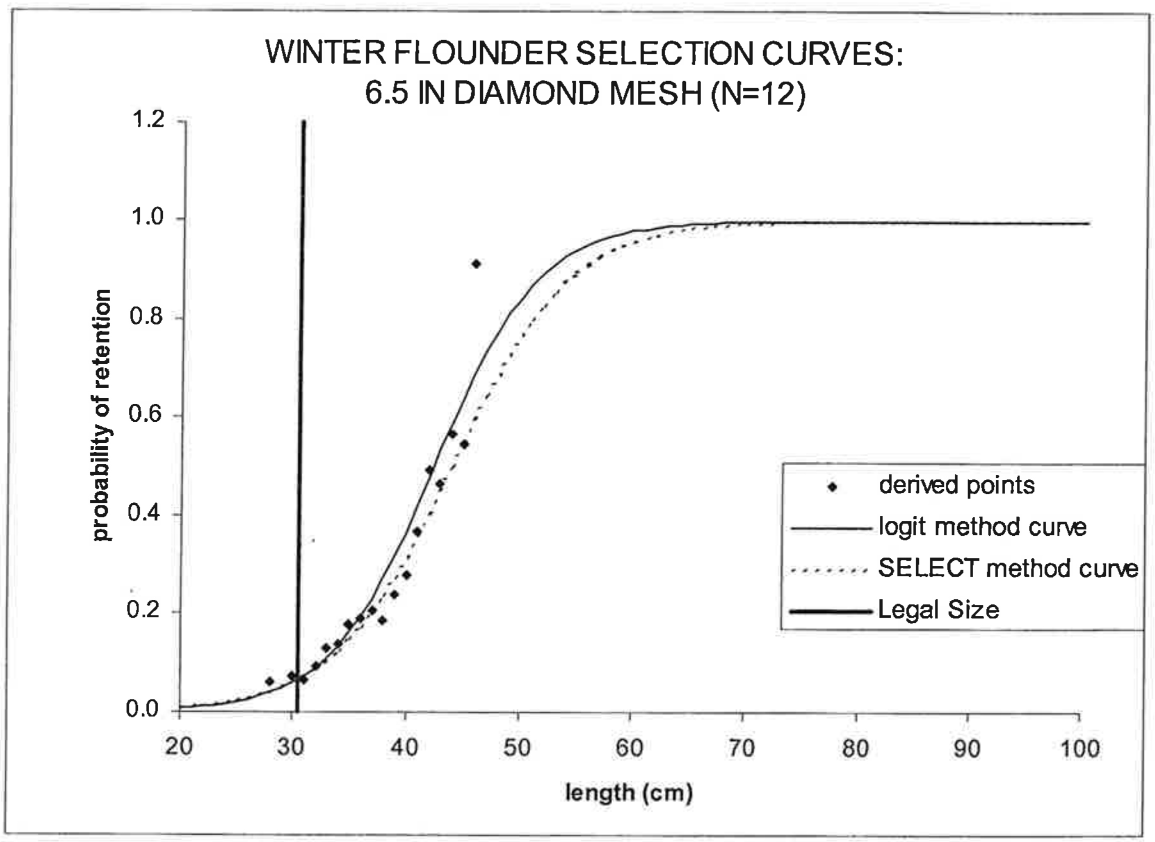

Figure 2. Winter flounder logit and SELECT method selection curves derived from the catch data analysis of 12 paired tows comparing the 16.5 cm (6.5 in) diamond-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for winter flounder.

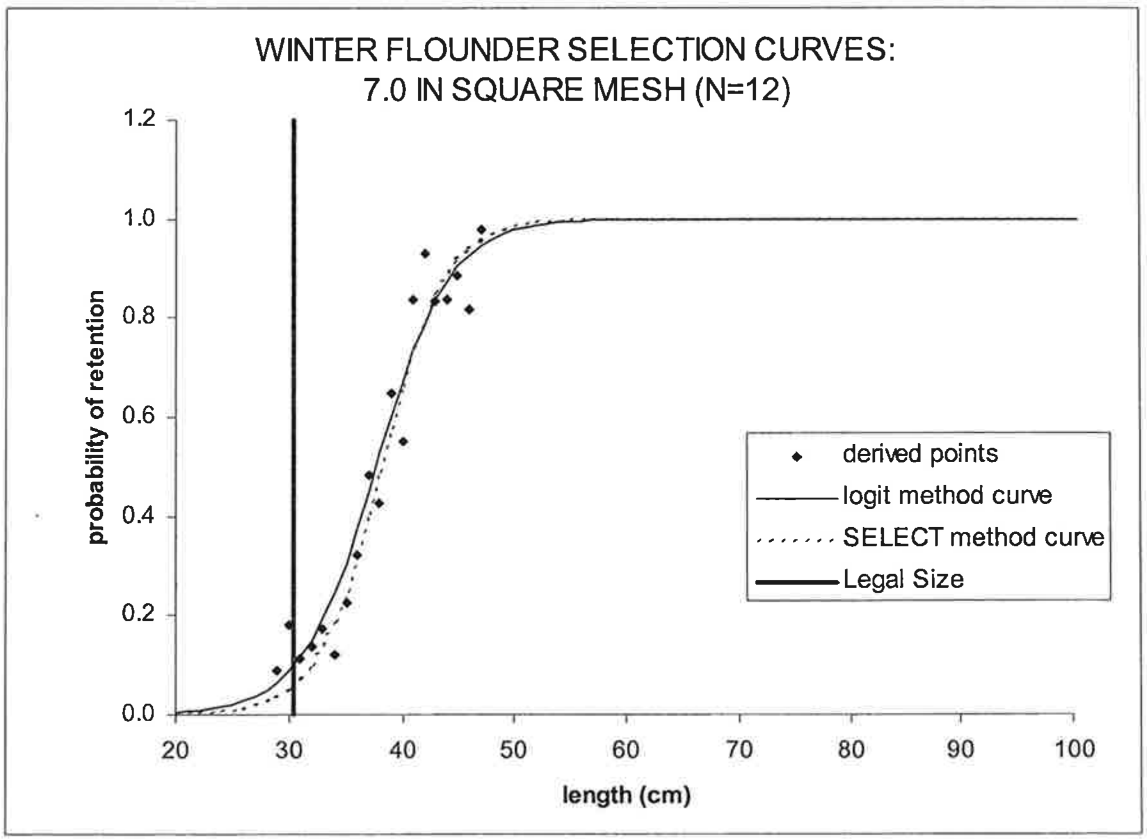

Figure 3. Winter flounder logit and SELECT method selection curves derived from the catch data analysis of 12 paired tows comparing the 17.8 cm (7.0 in) square-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for winter flounder.

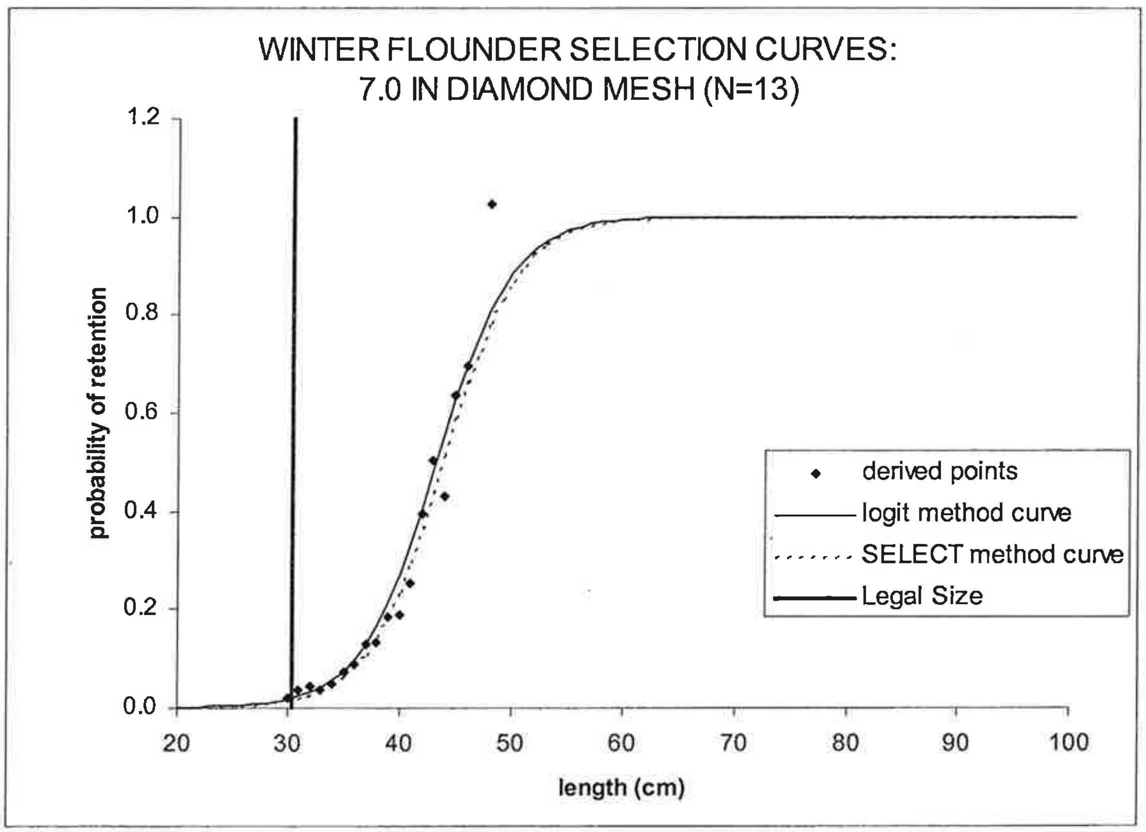

Figure 4. Winter flounder logit and SELECT method selection curves derived from the catch data analysis of 13 paired tows comparing the 17.8 cm (7.0 in) diamond-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for winter flounder.

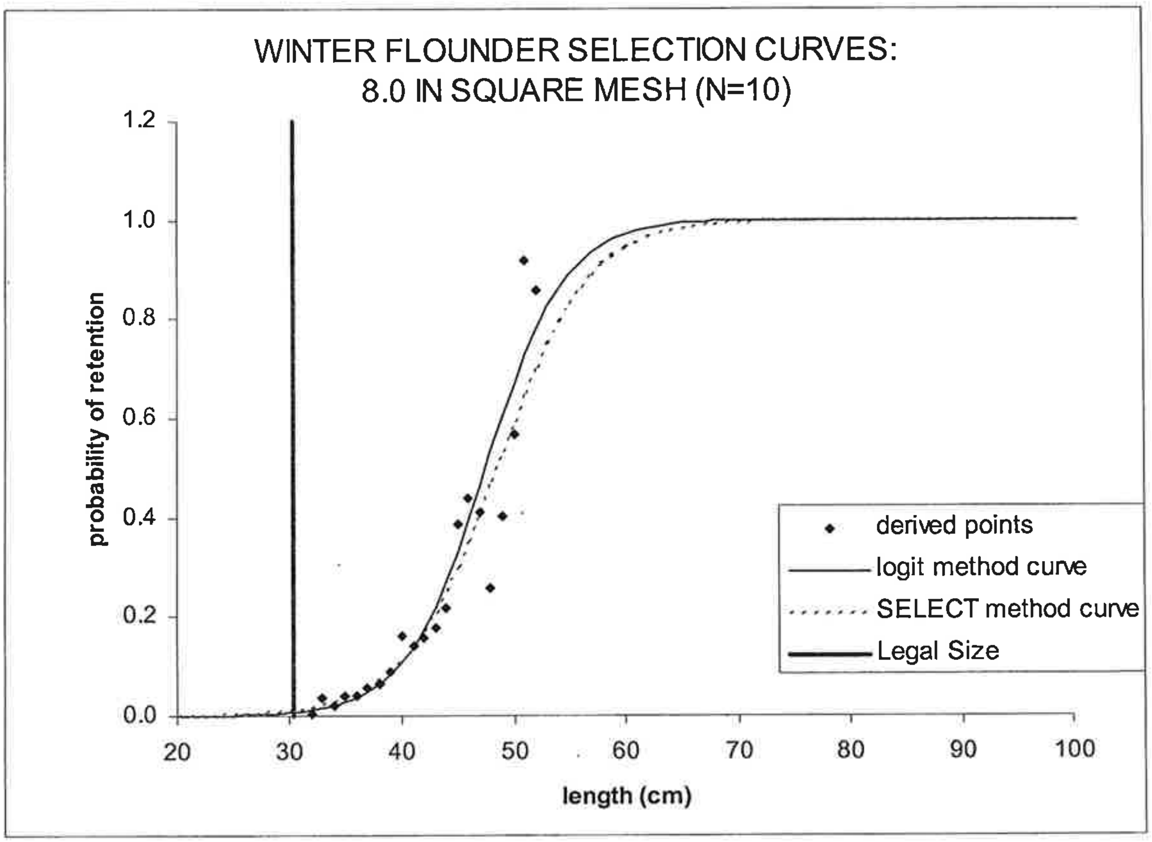

Figure 5. Winter flounder logit and SELECT method selection curves derived from the catch data analysis of 10 paired tows comparing the 20.3 cm (8.0 in) square-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for winter flounder.

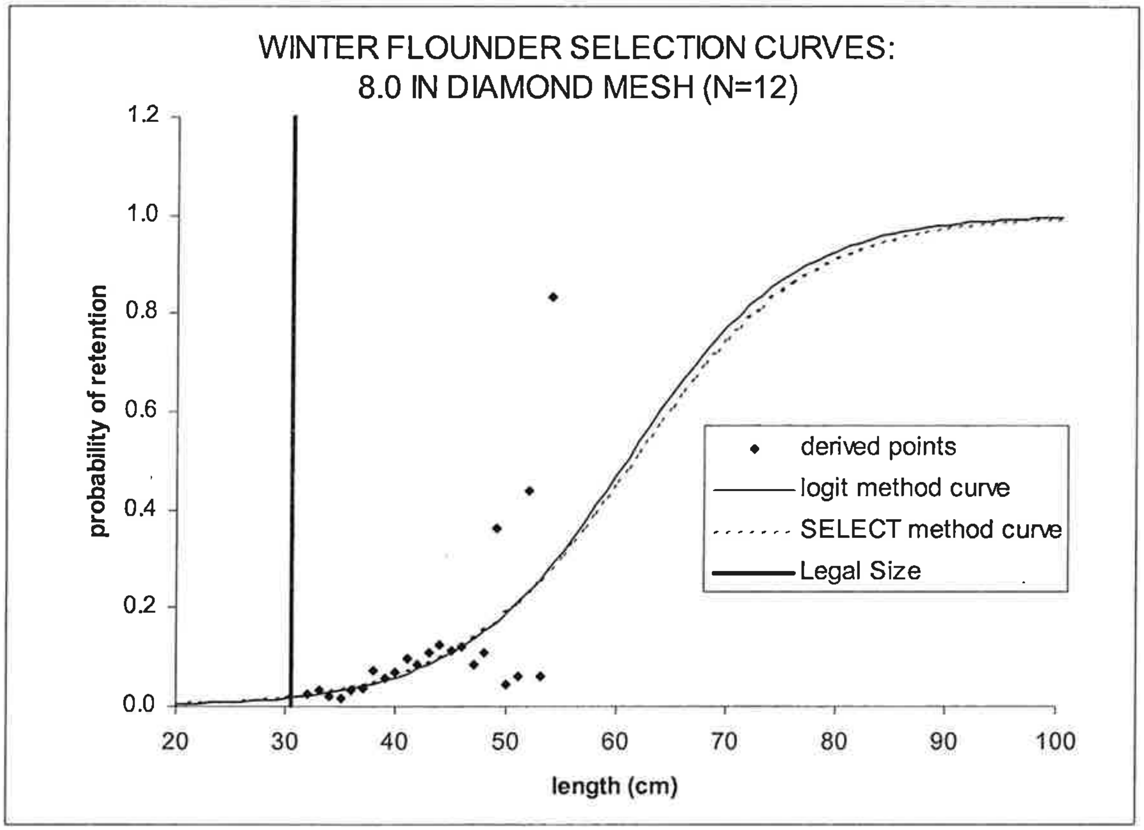

Figure 6. Winter flounder logit and SELECT method selection curves derived from the catch data analysis of 12 paired tows comparing the 20.3 cm (8.0 in) diamond-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for winter flounder.

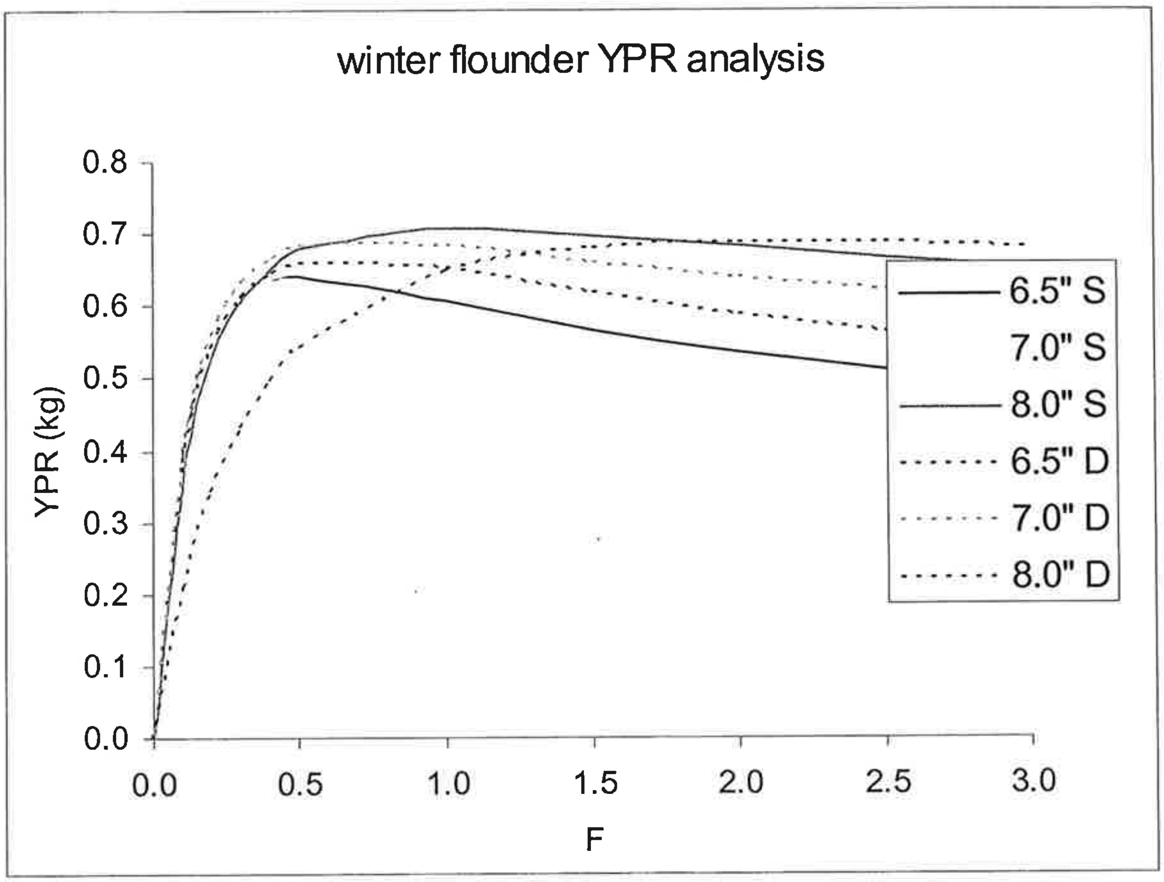

Figure 7. Yield per recruit (YPR) curves for winter flounder derived from the 16.5 cm (6.5 in), 17.8 cm (7.0 in), and 20.3 cm (8.0 in) square and diamond-shaped codend mesh sizes SELECT method selection curves at different levels of fishing mortality (F).

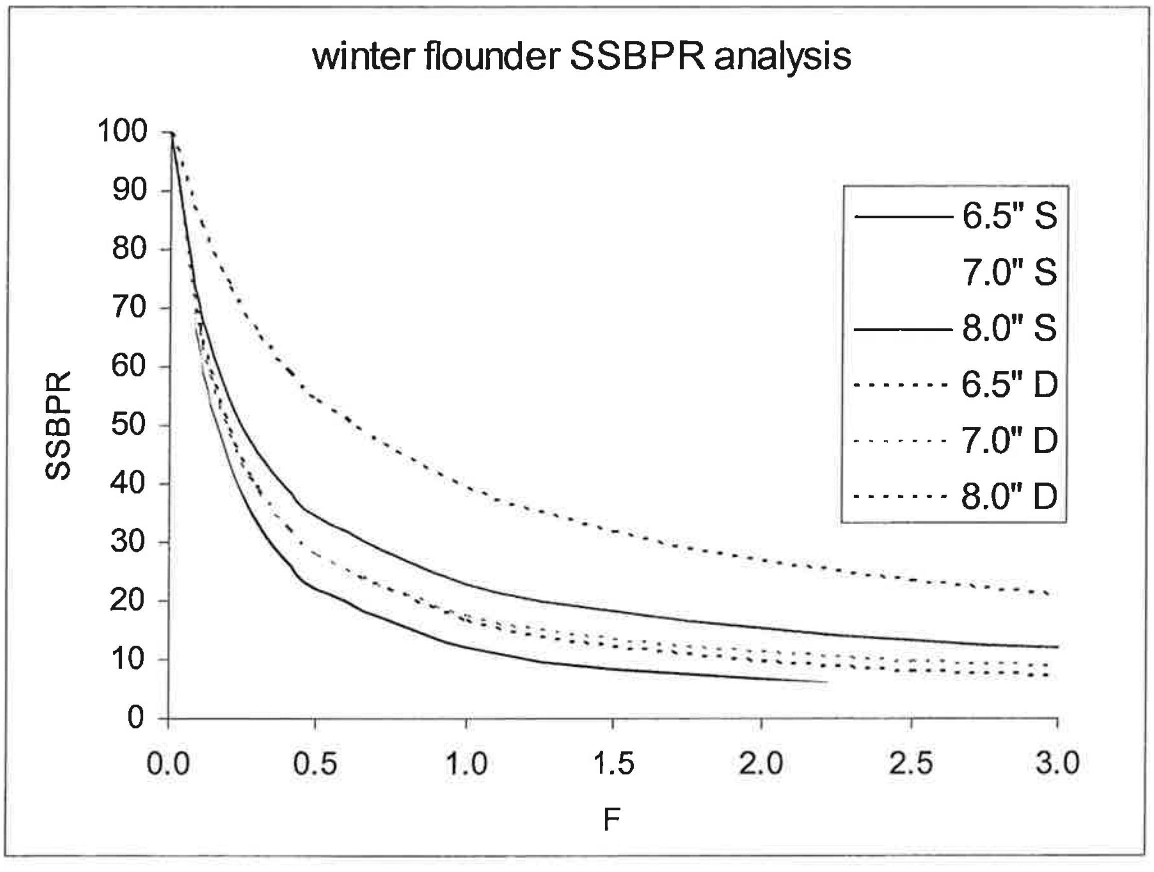

Figure 8. Spawning stock biomass per recruit (SSBPR) curves for winter flounder derived from the 16.5 cm (6.5 in), 17.8 cm (7.0 in), and 20.3 cm (8.0 in) square and diamond-shaped codend mesh sizes SELECT method selection curves at different levels of fishing mortality (F). The SSBPR is expressed as a percentage of the maximum spawning stock biomass at F=0.

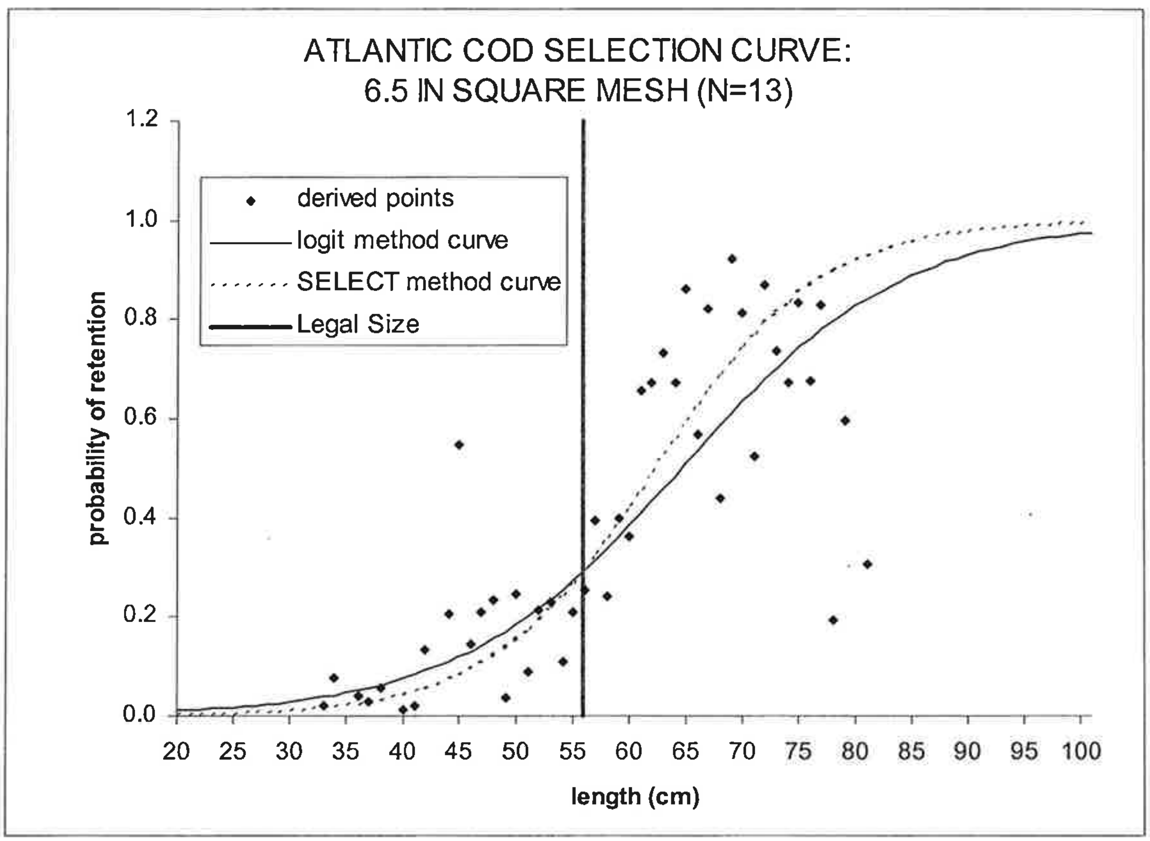

Figure 9. Atlantic cod logit and SELECT method selection curves derived from the catch data analysis of 13 paired tows comparing the 16.5 cm (6.5 in) square-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for Atlantic cod.

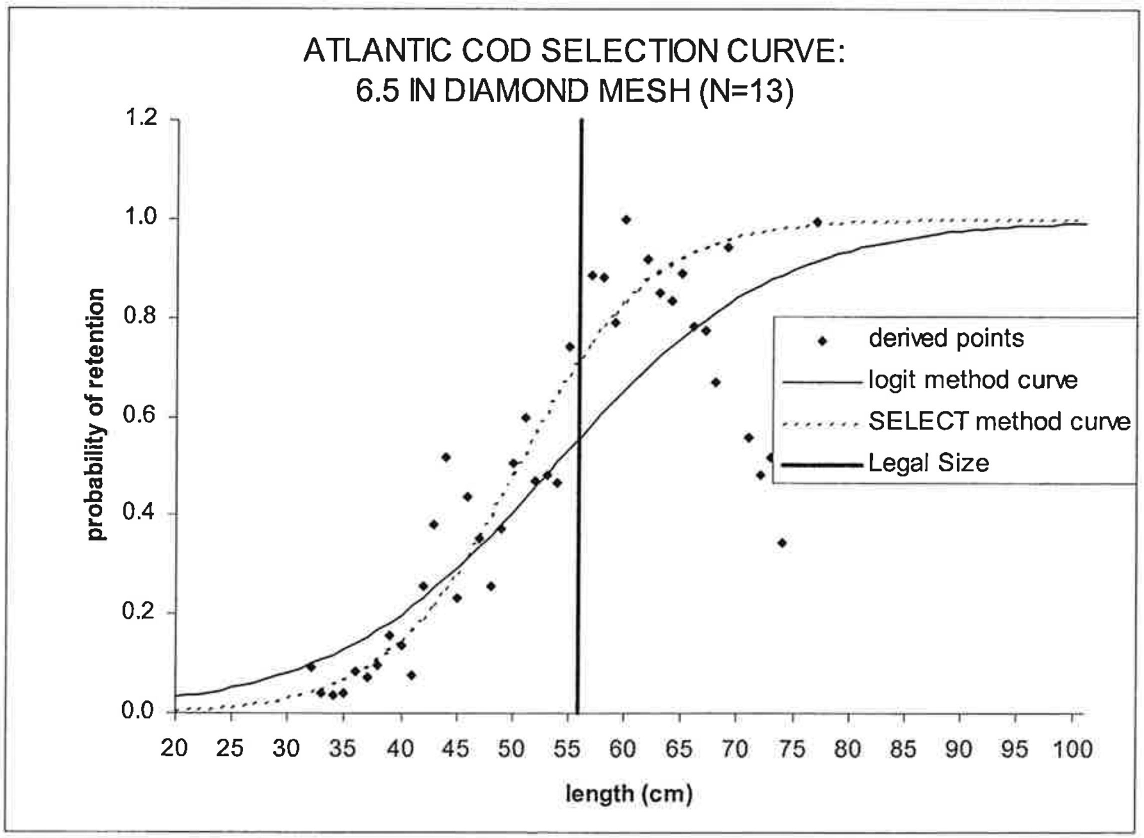

Figure 10. Atlantic cod logit and SELECT method selection curves derived from the catch data analysis of 13 paired tows comparing the 16.5 cm (6.5 in) diamond-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for Atlantic cod.

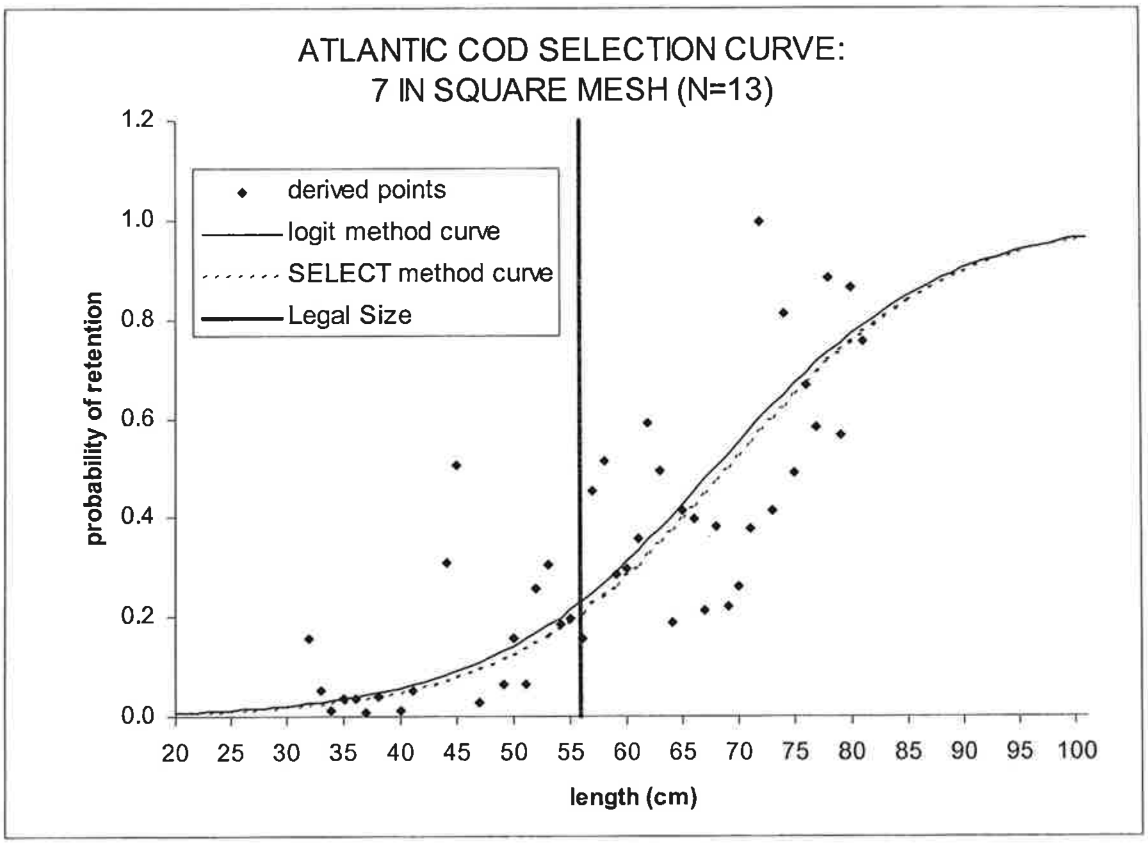

Figure 11. Atlantic cod logit and SELECT method selection curves derived from the catch data analysis of 13 paired tows comparing the 17.8 cm (7.0 in) square-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for Atlantic cod.

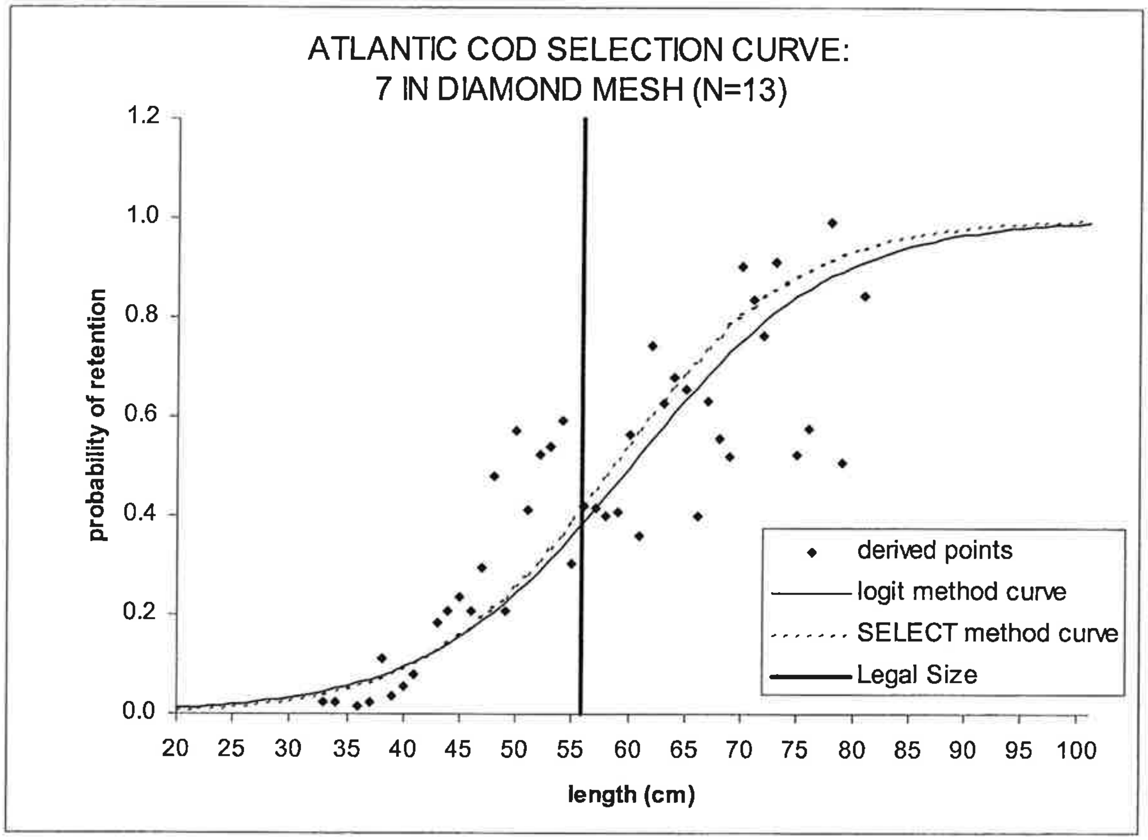

Figure 12. Atlantic cod logit and SELECT method selection curves derived from the catch data analysis of 13 paired tows comparing the 17.8 cm (7.0 in) diamond-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for Atlantic cod.

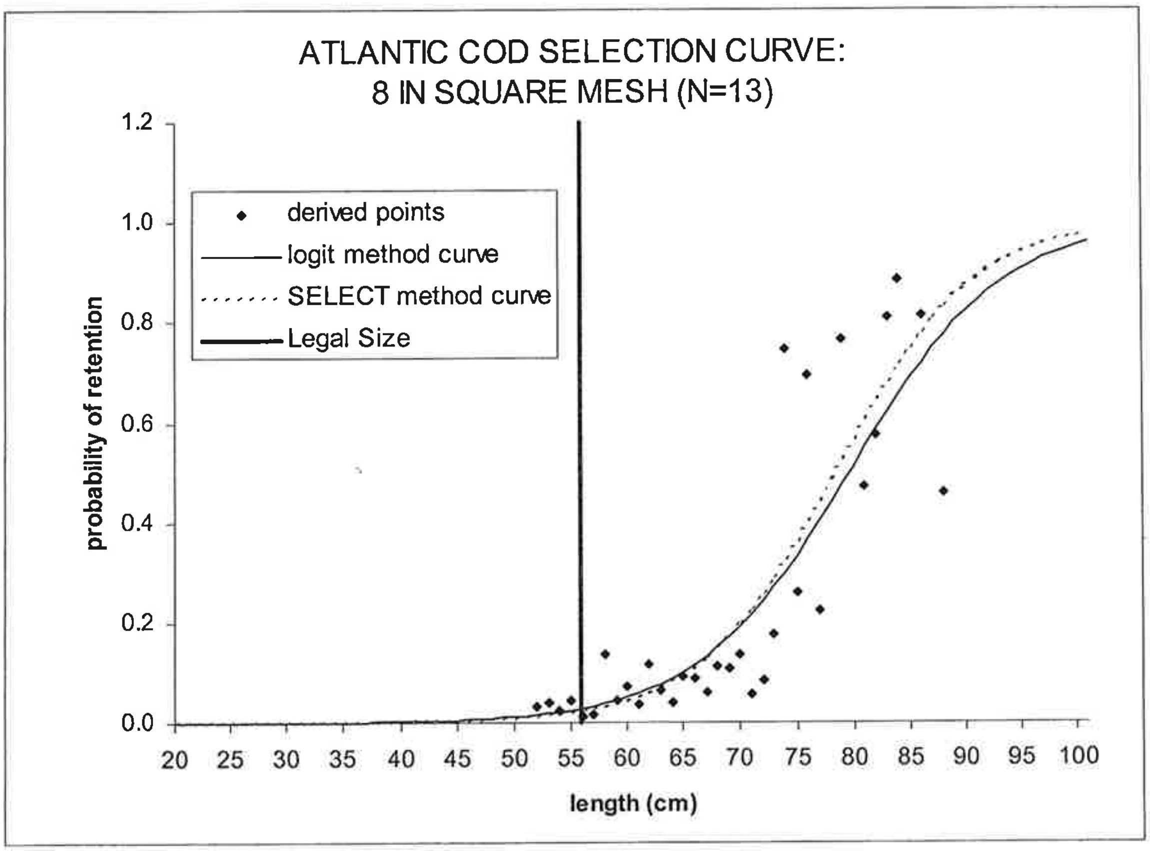

Figure 13. Atlantic cod logit and SELECT method selection curves derived from the catch data analysis of 13 paired tows comparing the 20.3 cm (8.0 in) square-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for Atlantic cod.

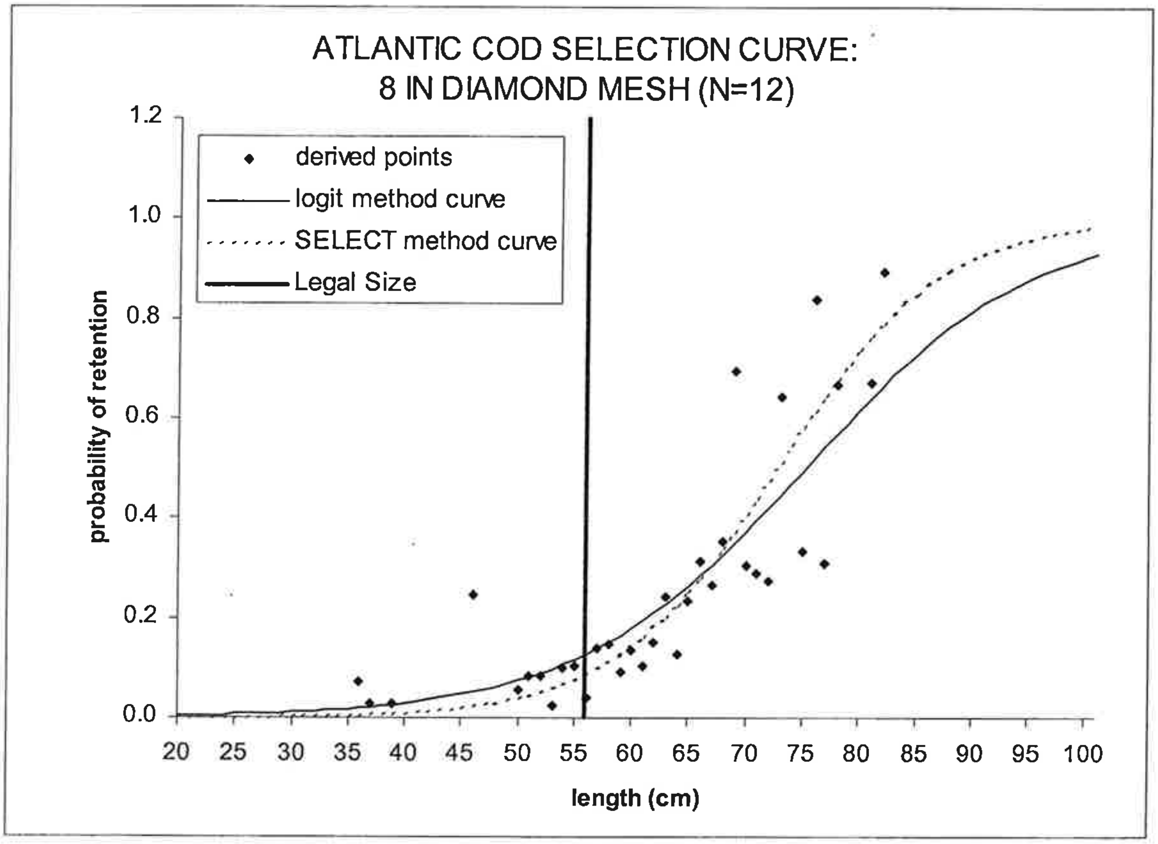

Figure 14. Atlantic cod logit and SELECT method selection curves derived from the catch data analysis of 12 paired tows comparing the 20.3 cm (8.0 in) diamond-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for Atlantic cod.

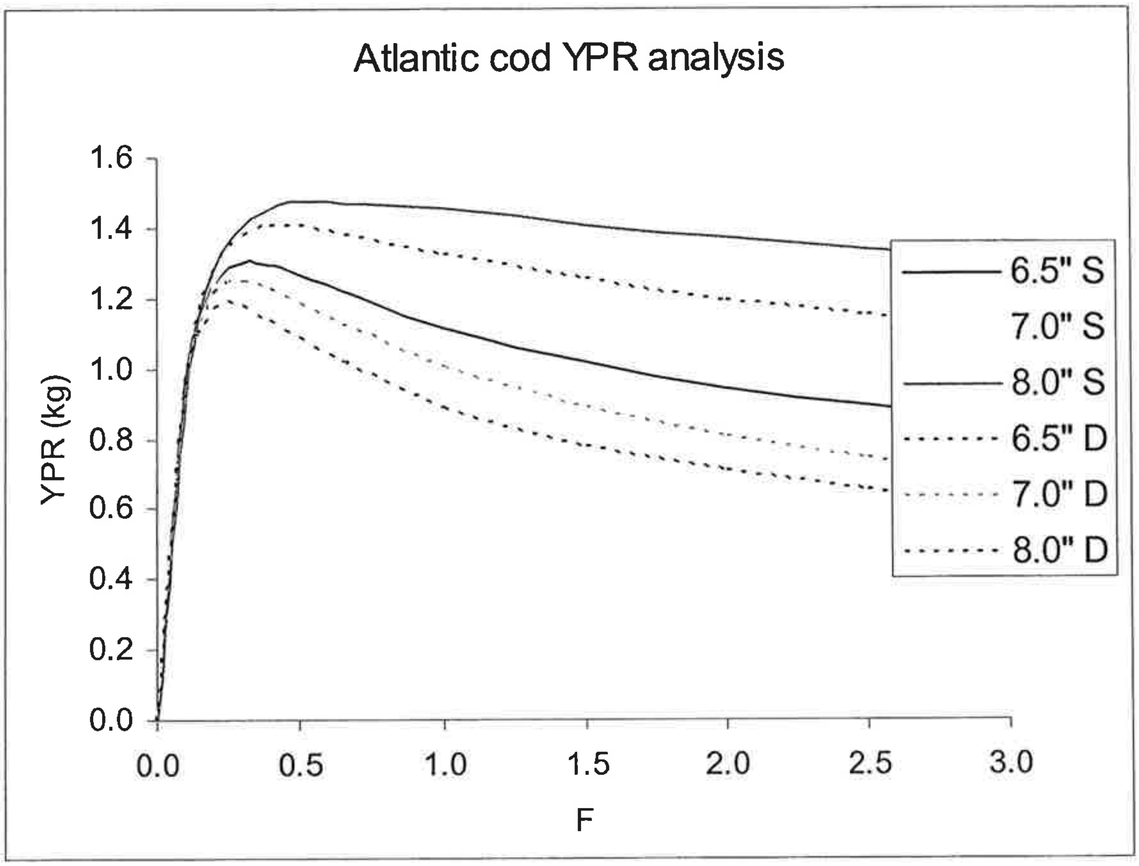

Figure 15. Yield per recruit (YPR) curves for Atlantic cod derived from the 16.5 cm (6.5 in), 17.8 cm (7.0 in), and 20.3 cm (8.0 in) square and diamond-shaped codend mesh sizes SELECT method selection curves at different levels of fishing mortality (F).

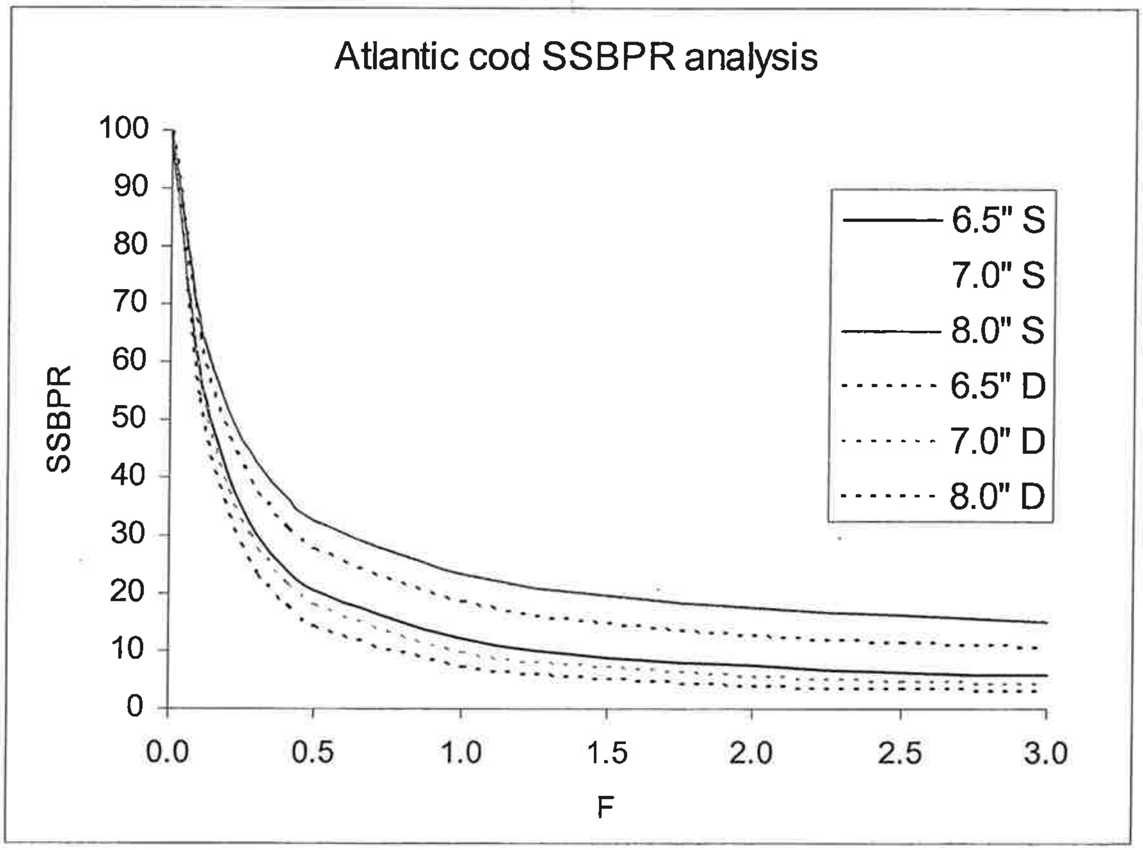

Figure 16. Spawning stock biomass per recruit (SSBPR) curves for Atlantic cod derived from the 16.5 cm (6.5 in), 17.8 cm (7.0 in), and 20.3 cm (8.0 in) square and diamond-shaped codend mesh sizes SELECT method selection curves at different levels of fishing mortality (F). The SSBPR is expressed as a percentage of the maximum spawning stock biomass at F=0.

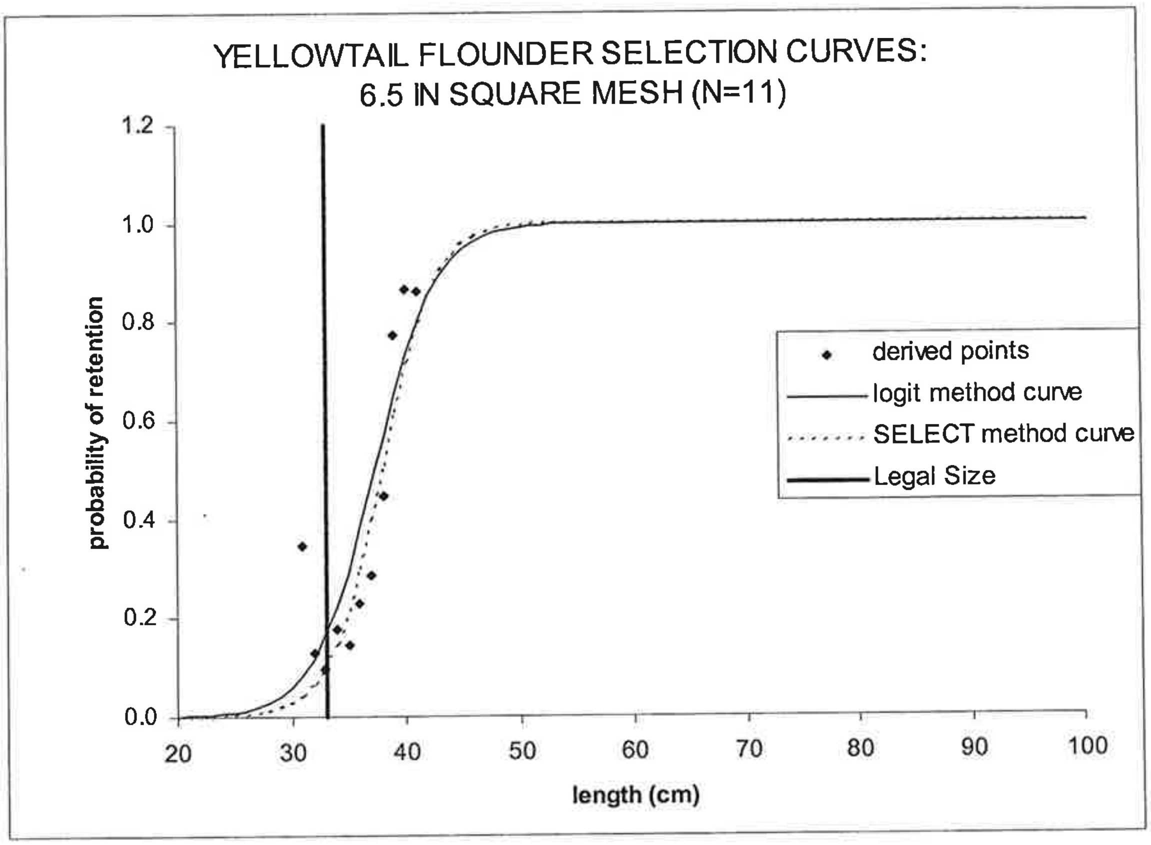

Figure 17. Yellowtail flounder logit and SELECT method selection curves derived from the catch data analysis of 11 paired tows comparing the 16.5 cm (6.5 in) square-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for yellowtail flounder.

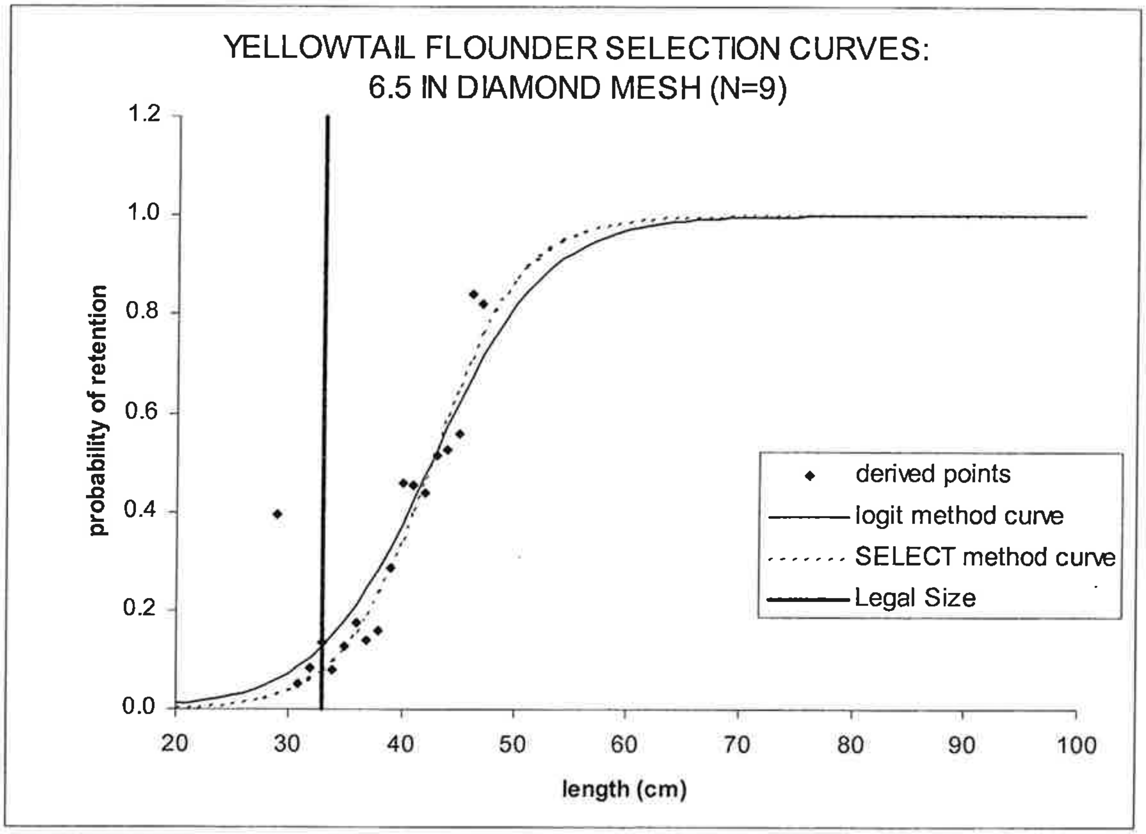

Figure 18. Yellowtail flounder logit and SELECT method selection curves derived from the catch data analysis of 9 paired tows comparing the 16.5 cm (6.5 in) diamond-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for yellowtail flounder.

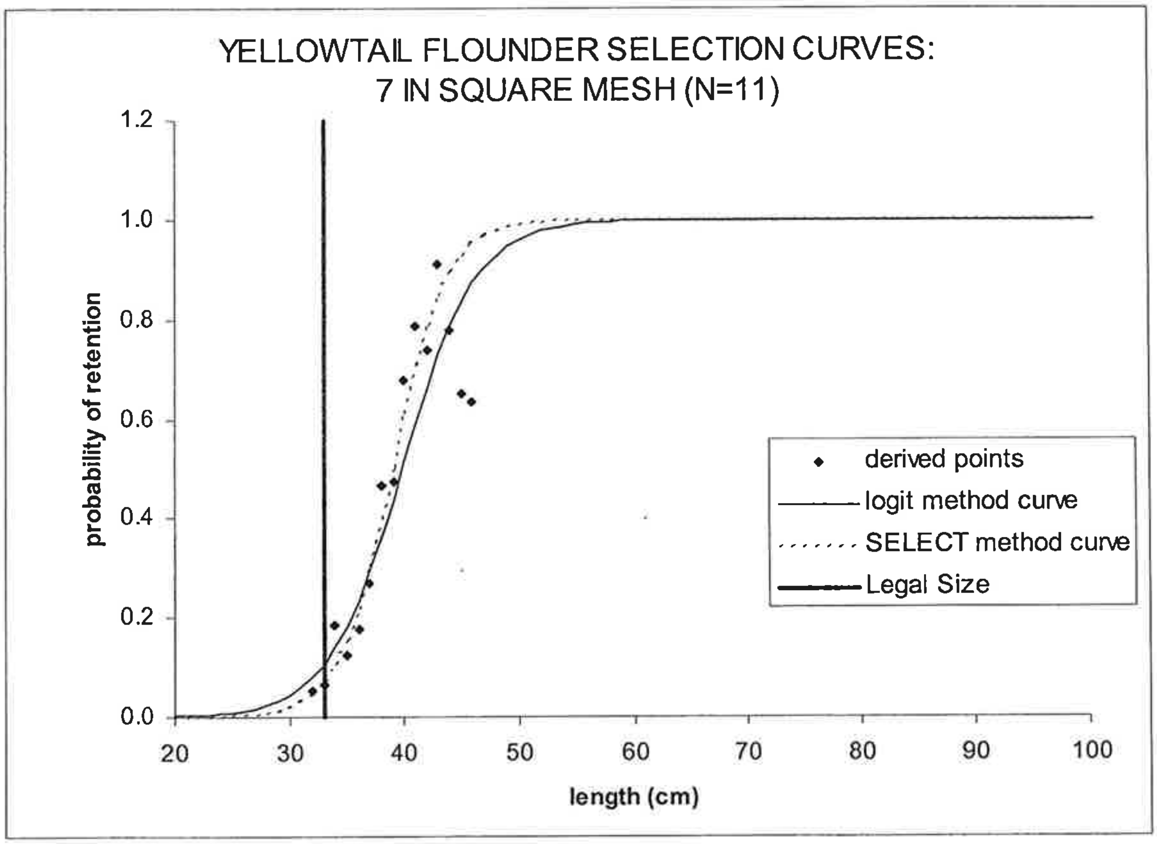

Figure 19. Yellowtail flounder logit and SELECT method selection curves derived from the catch data analysis of 11 paired tows comparing the 17.8 cm (7.0 in) square-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for yellowtail flounder.

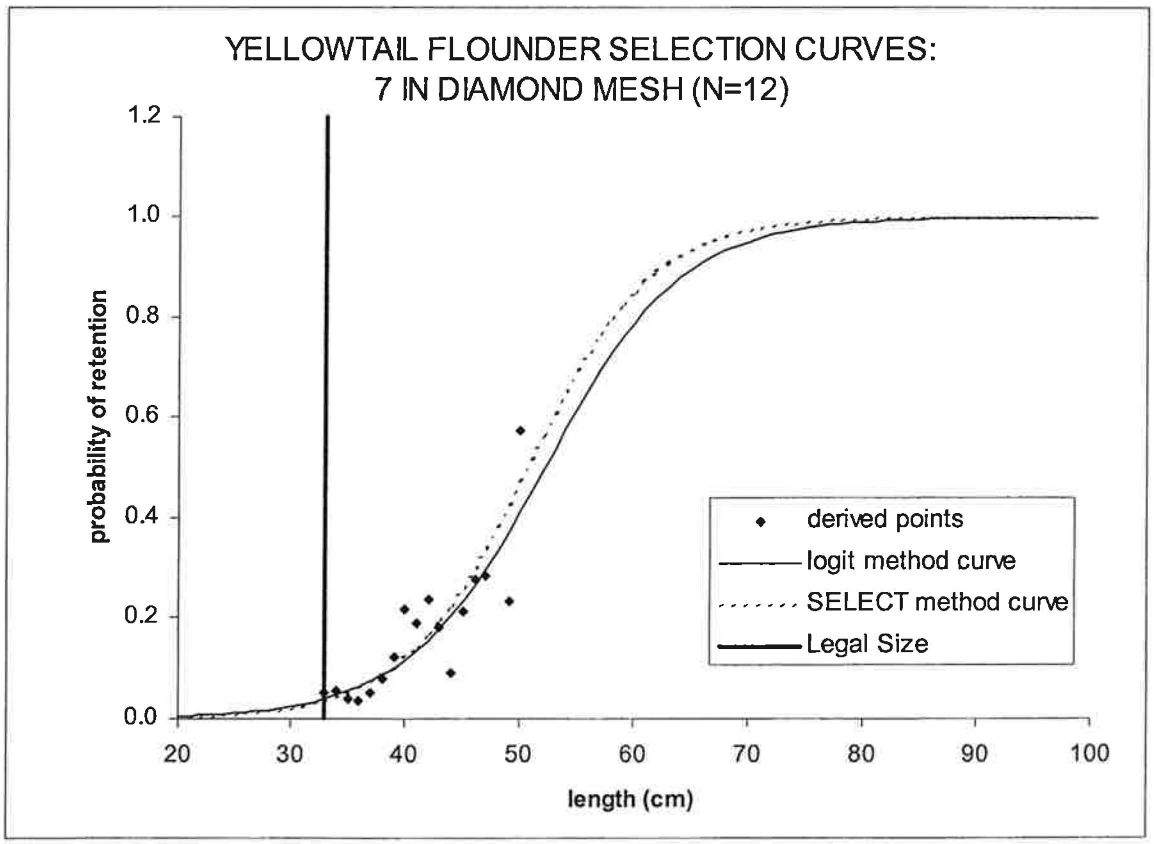

Figure 20. Yellowtail flounder logit and SELECT method selection curves derived from the catch data analysis of 12 paired tows comparing the 17.8 cm (7.0 in) diamond-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for yellowtail flounder.

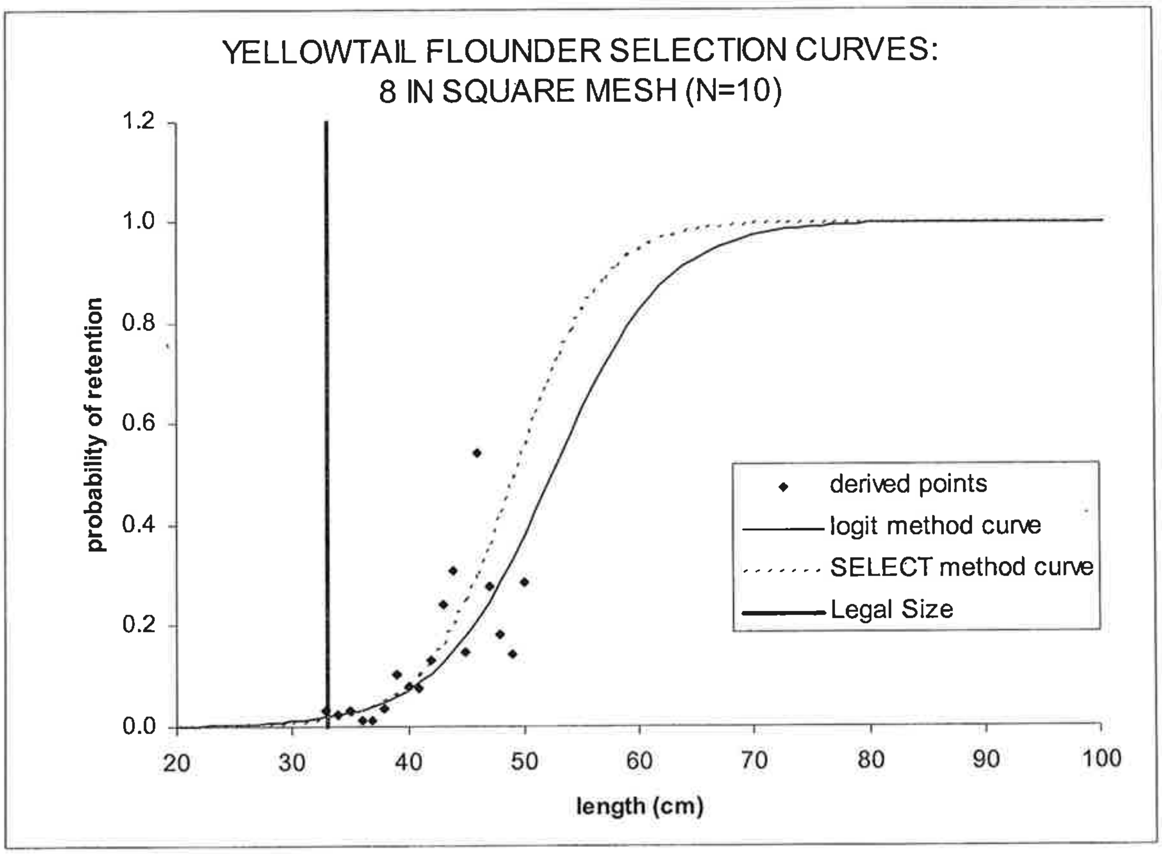

Figure 21. Yellowtail flounder logit and SELECT method selection curves derived from the catch data analysis of 10 paired tows comparing the 20.3 cm (8.0 in) square-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for yellowtail flounder.

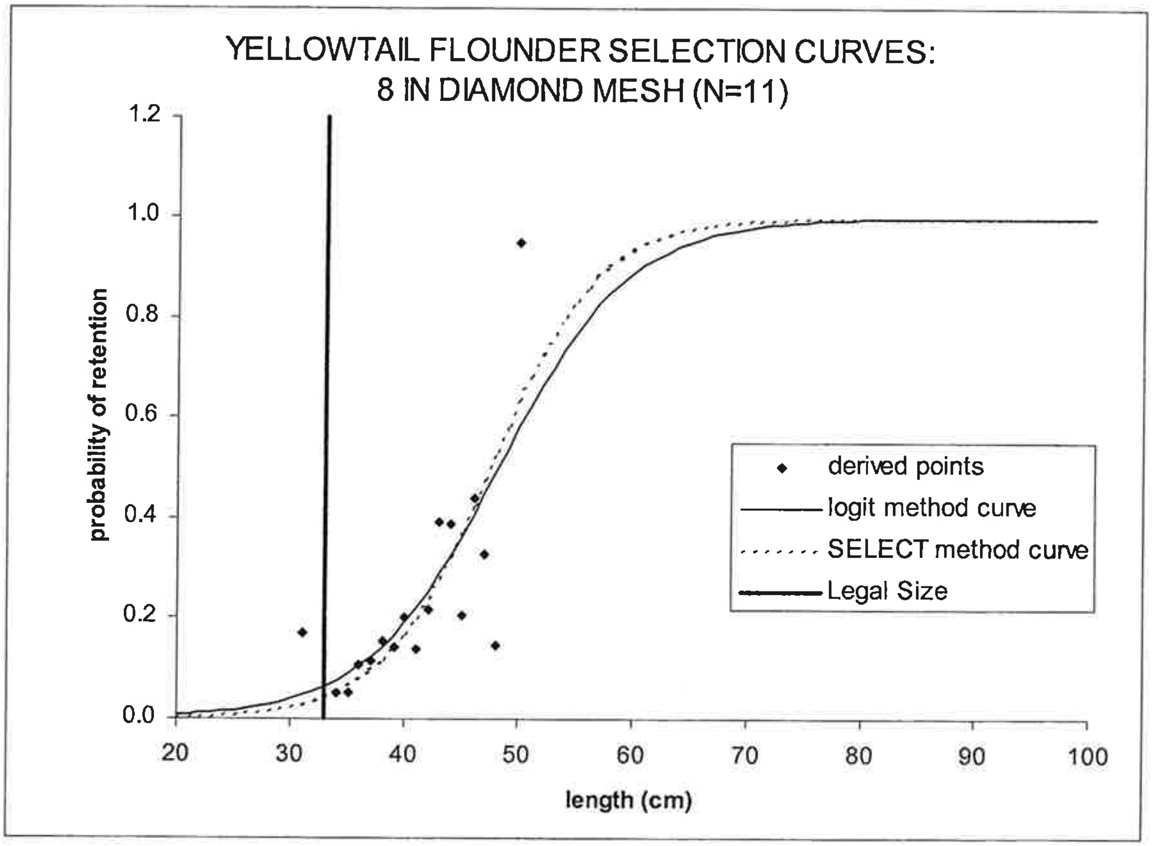

Figure 22. Yellowtail flounder logit and SELECT method selection curves derived from the catch data analysis of 11 paired tows comparing the 20.3 cm (8.0 in) diamond-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for yellowtail flounder.

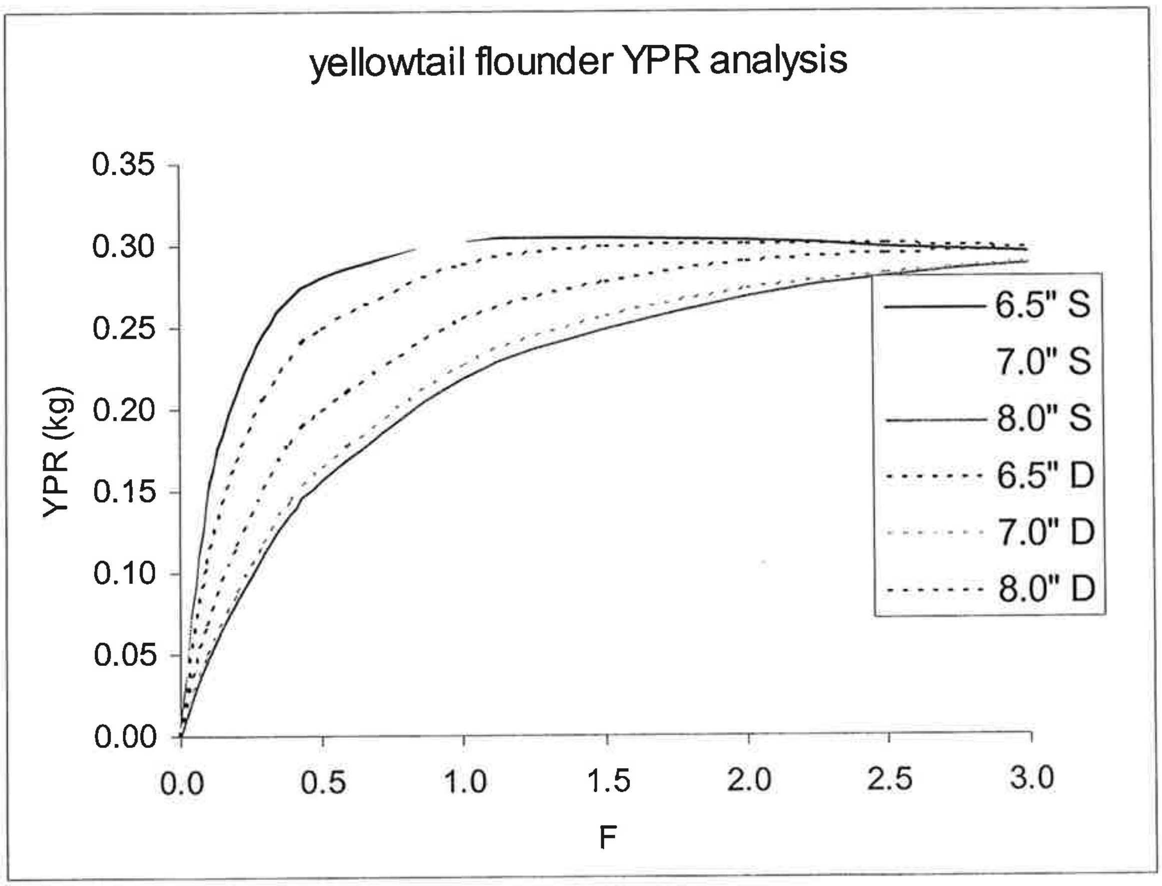

Figure 23. Yield per recruit (YPR) curves for yellowtail flounder derived from the 16.5 cm (6.5 in), 17.8 cm (7.0 in), and 20.3 cm (8.0 in) square and diamond-shaped codend mesh sizes SELECT method selection curves at different levels of fishing mortality (F).

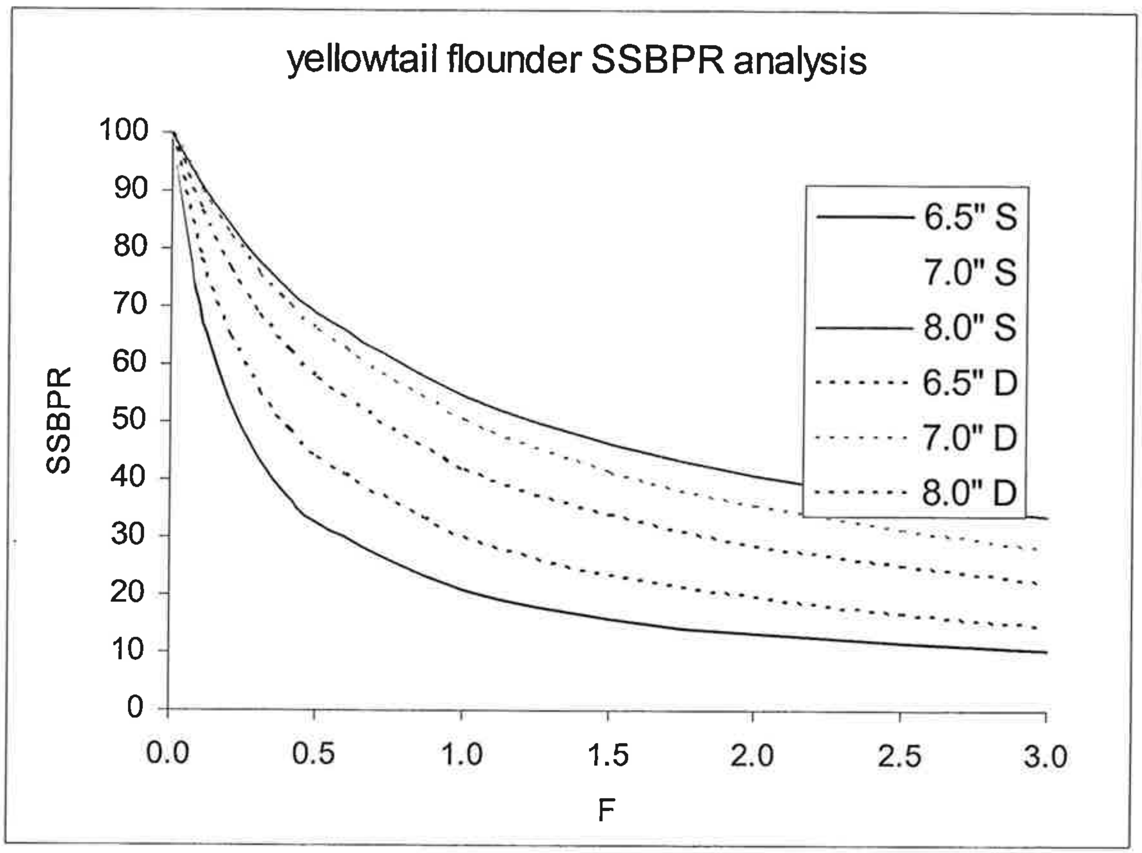

Figure 24. Spawning stock biomass per recruit (SSBPR) curves for yellowtail flounder derived from the 16.5 cm (6.5 in), 17.8 cm (7.0 in), and 20.3 cm (8.0 in) square and diamond-shaped codend mesh sizes SELECT method selection curves at different levels of fishing mortality (F). The SSBPR is expressed as a percentage of the maximum spawning stock biomass at F=0.

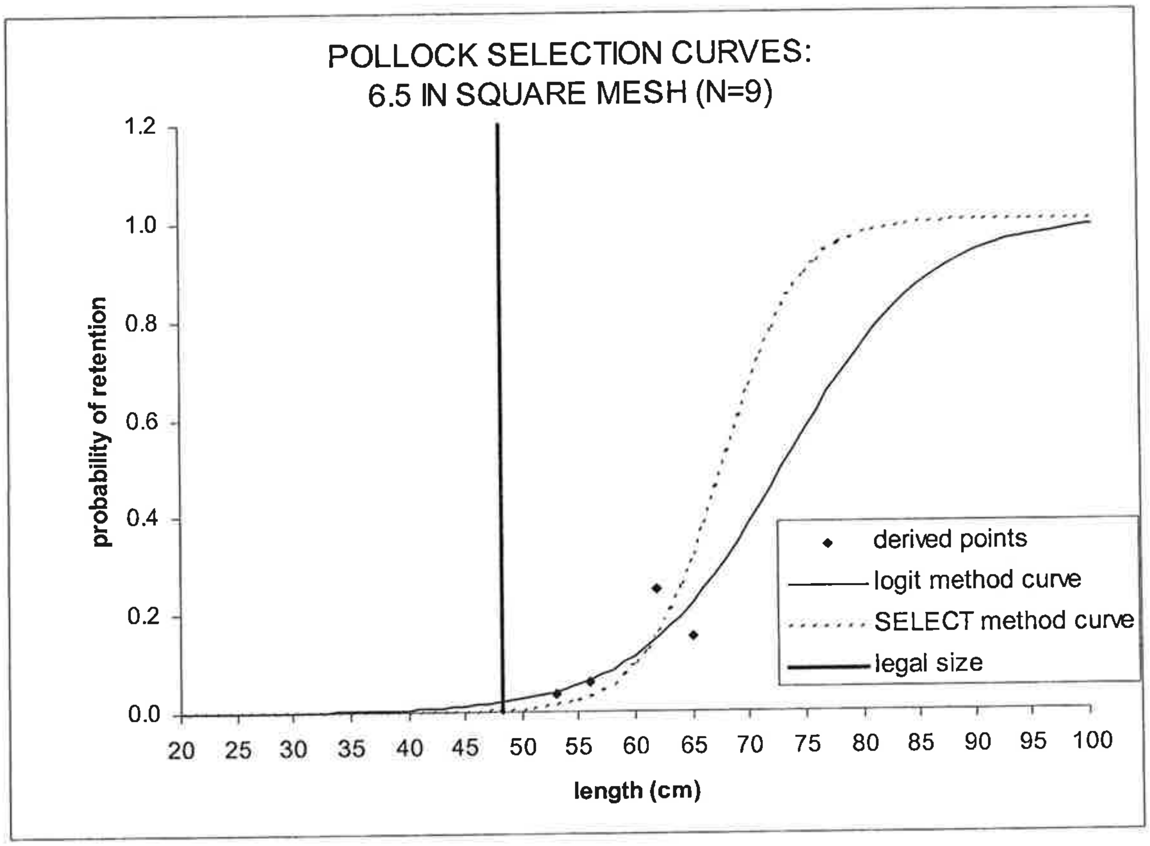

Figure 25. Pollock logit and SELECT method selection curves derived from the catch data analysis of 9 paired tows comparing the 16.5 cm (6.5 in) square-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for pollock.

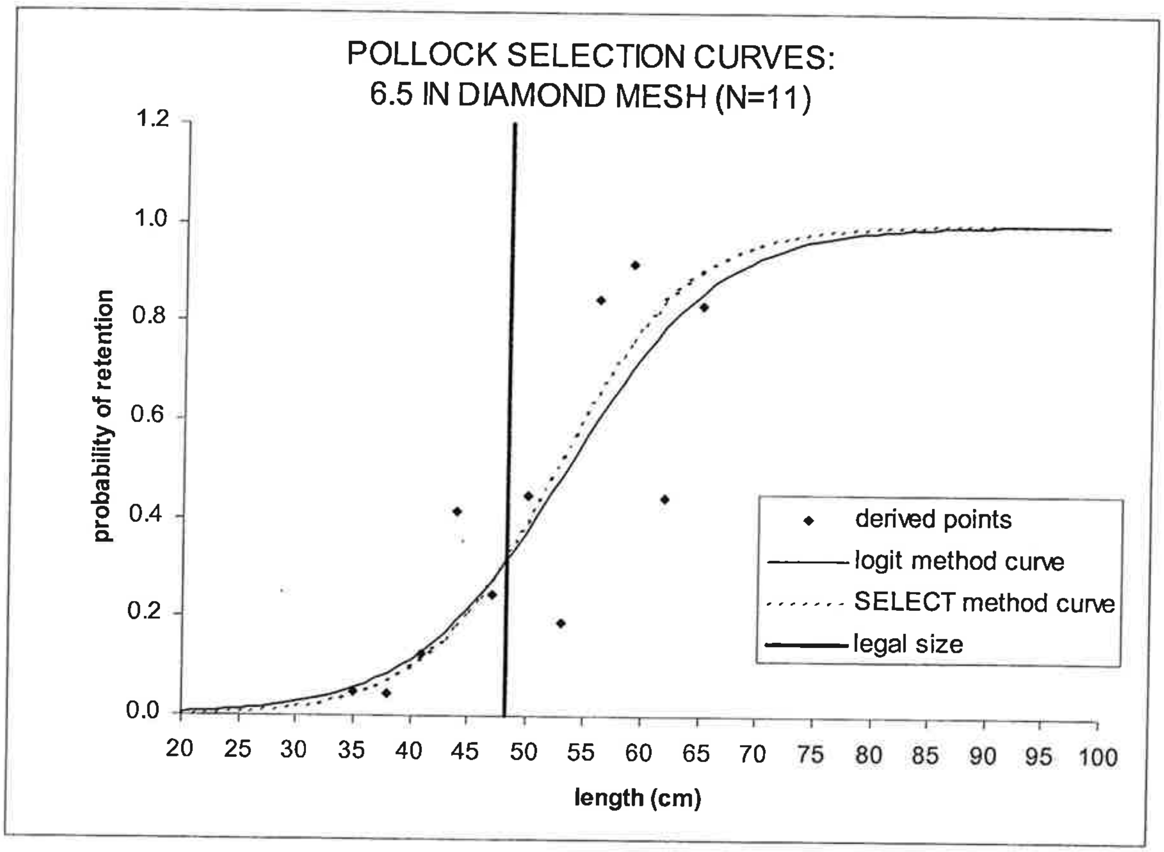

Figure 26. Pollock logit and SELECT method selection curves derived from the catch data analysis of 11 paired tows comparing the 16.5 cm (6.5 in) diamond-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for pollock.

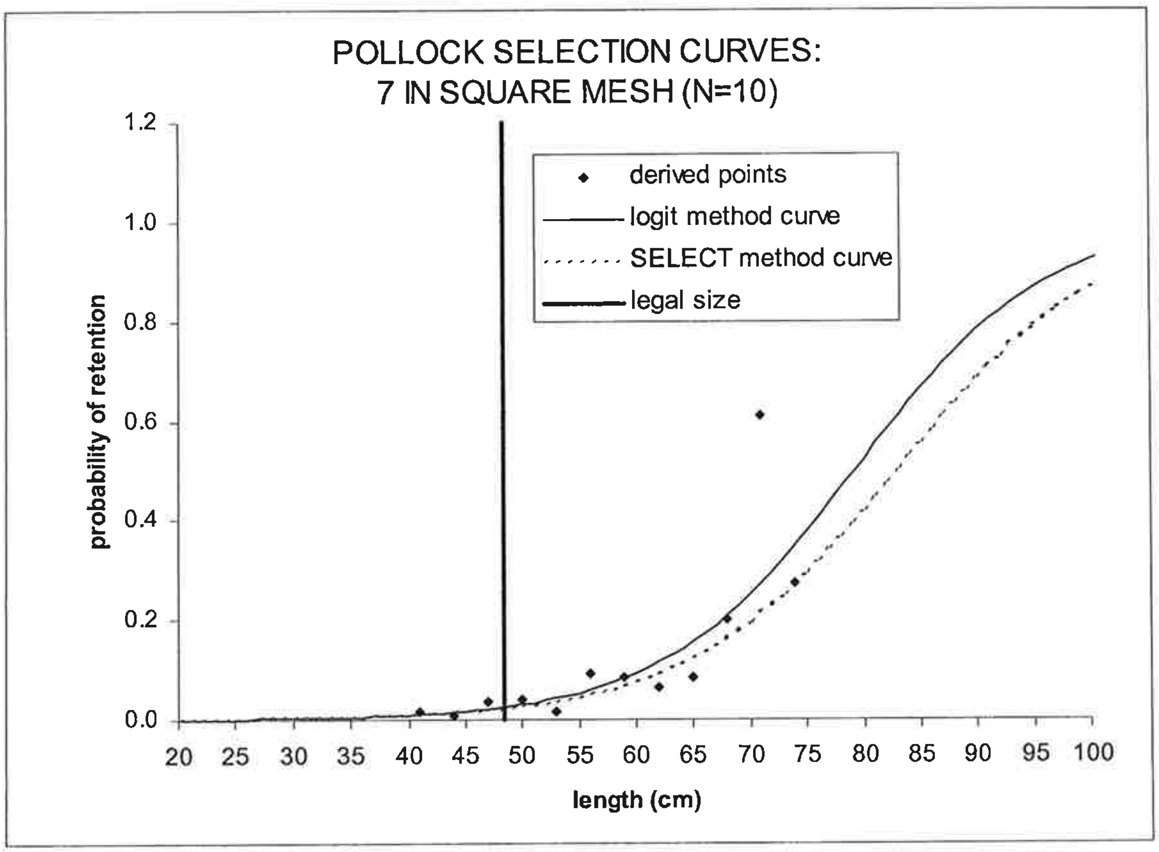

Figure 27. Pollock logit and SELECT method selection curves derived from the catch data analysis of 10 paired tows comparing the 17.8 cm (7.0 in) square-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for pollock.

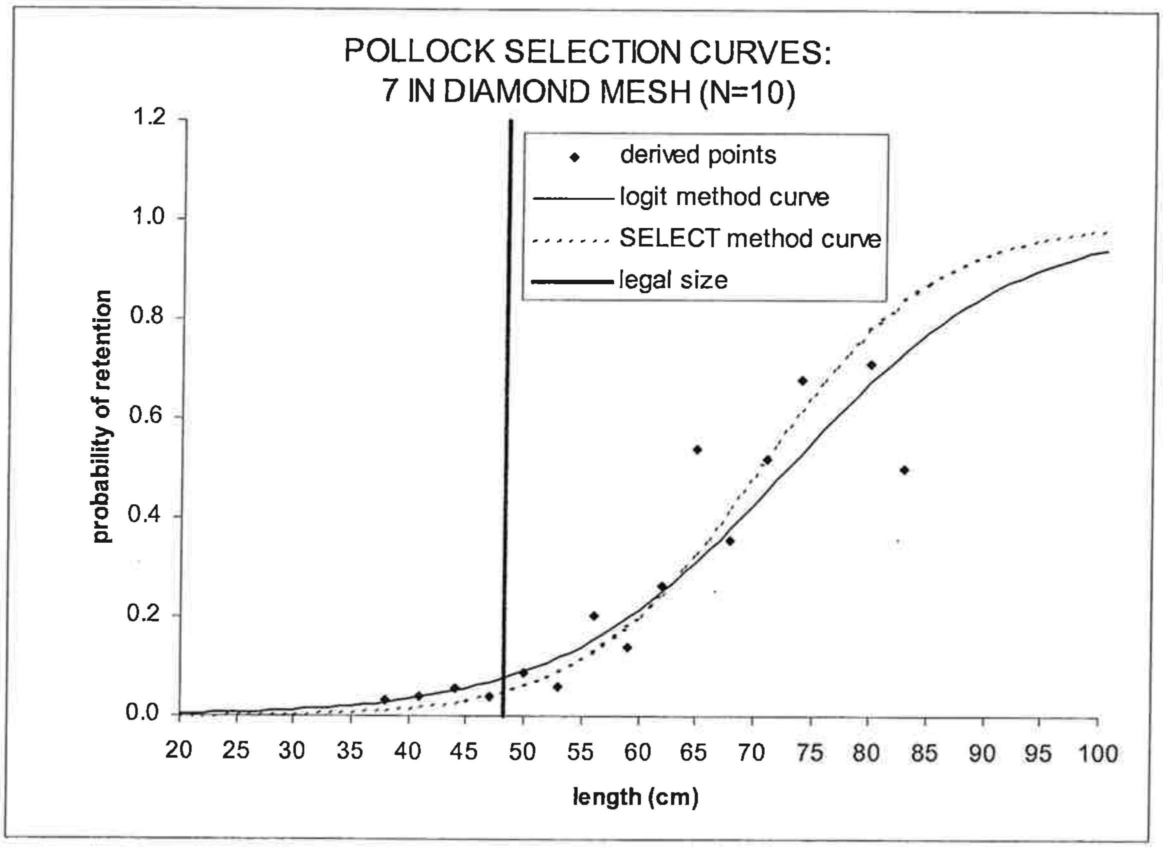

Figure 28. Pollock logit and SELECT method selection curves derived from the catch data analysis of 10 paired tows comparing the 17.8 cm (7.0 in) diamond-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for pollock.

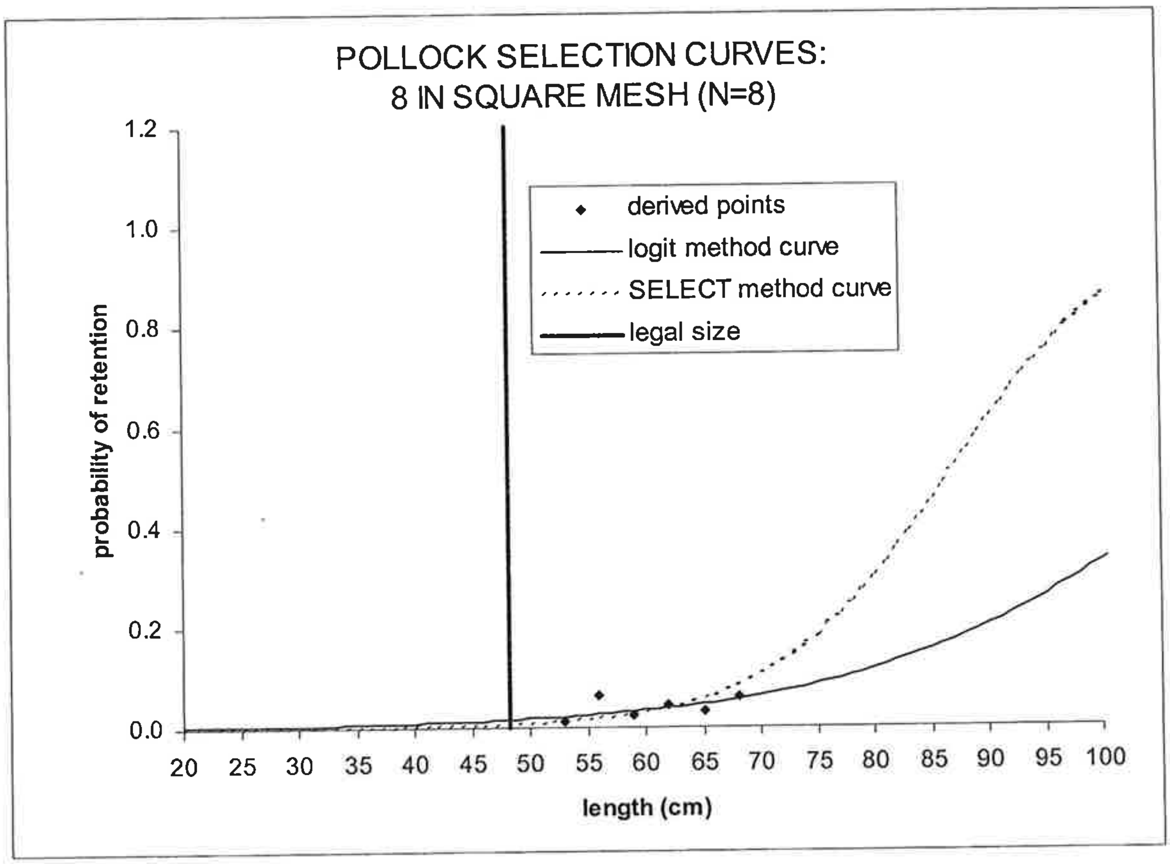

Figure 29. Pollock logit and SELECT method selection curves derived from the catch data analysis of 8 paired tows comparing the 20.3 cm (8.0 in) square-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for pollock.

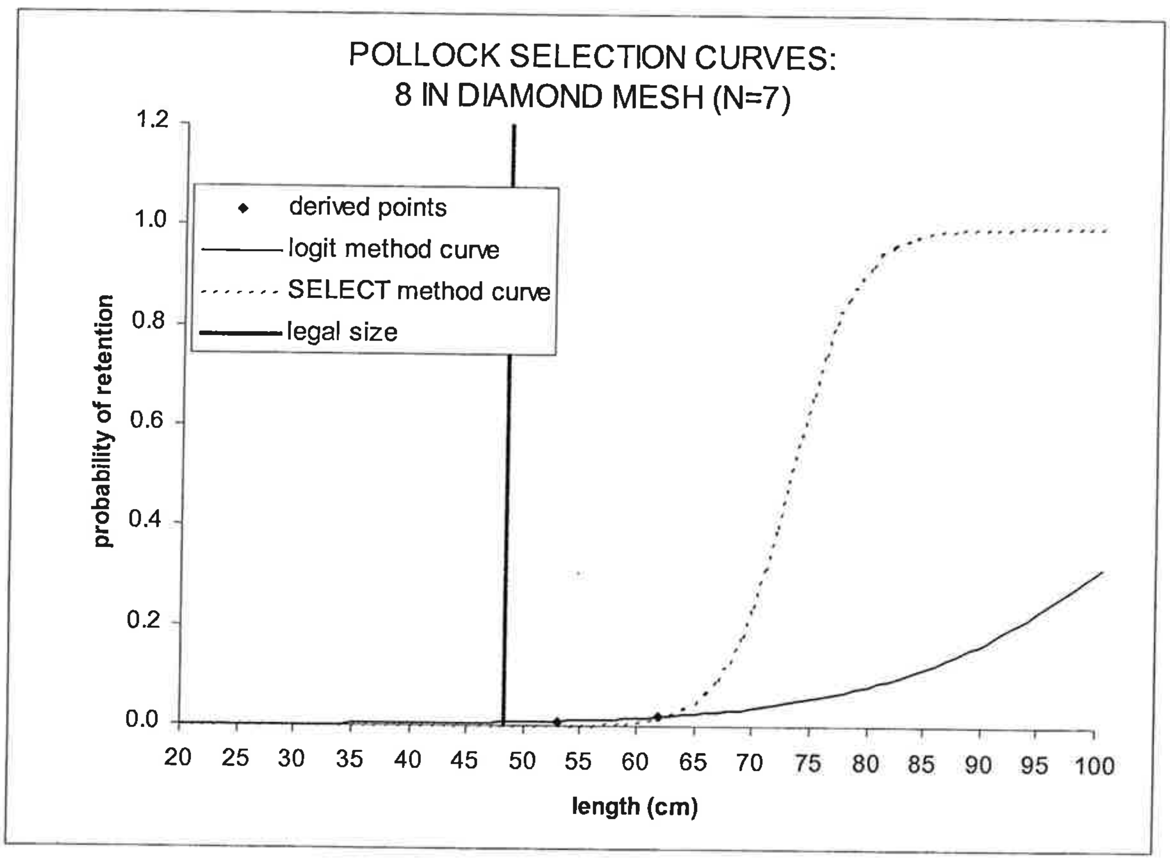

Figure 30. Pollock logit and SELECT method selection curves derived from the catch data analysis of 7 paired tows comparing the 20.3 cm (8.0 in) diamond-shaped mesh experimental codends and the 7.6 cm (3.0 in) diamond-shaped mesh control codend with derived data points. Vertical line shows the minimum legal size for pollock.

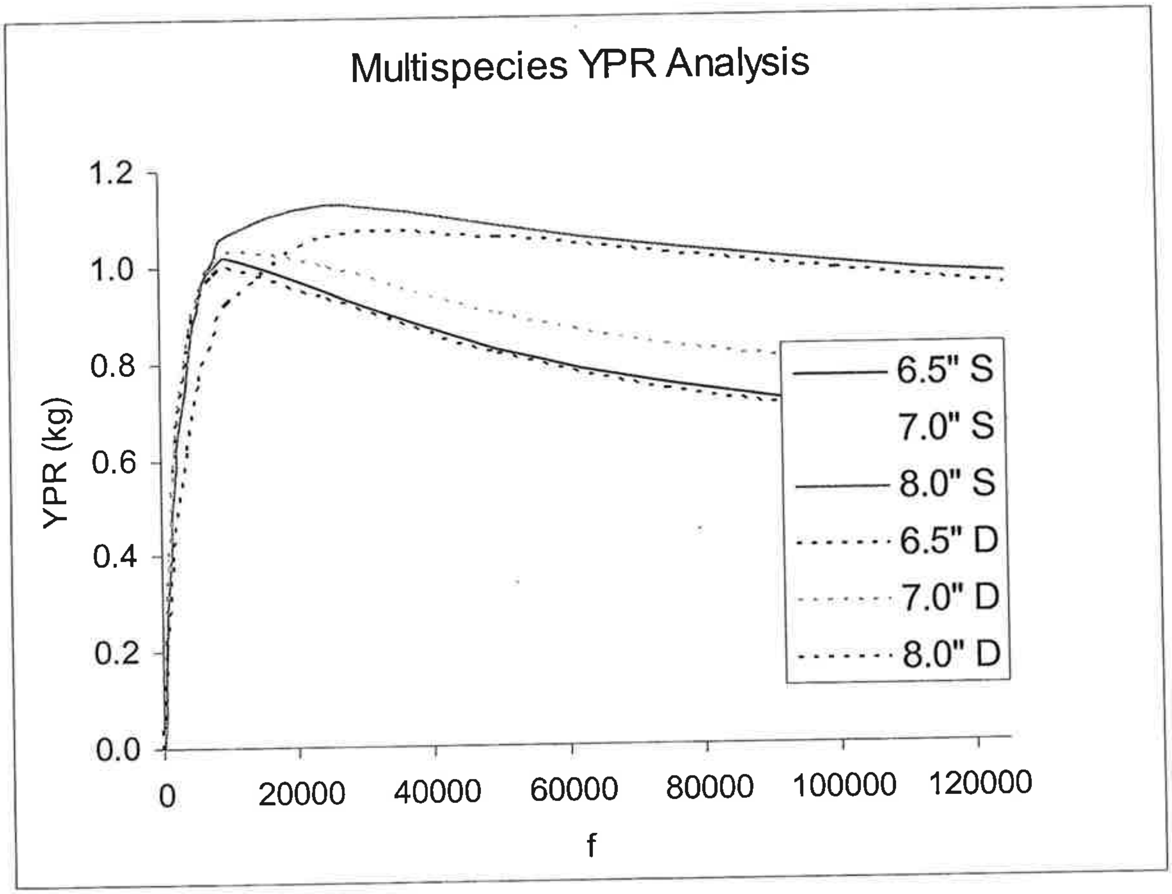

Figure 31. Multispecies yield per recruit (YPR) analysis based on the standardized yields obtained from winter flounder, Atlantic cod, and yellowtail flounder for the 16.5 cm (6.5 in)., 17.8 cm (7.0 in)., and 20.3 cm (8.0 in). square and diamond-shaped codend mesh sizes SELECT method selection curves. The total yield was calculated starting at the approximate age of the legal minimum size for all species. Standardization utilizes a relative recruitment multiplier (RRM) derived from the catch data. All yields are expressed as a function of fishing effort (f). The catchability coefficient (q) for winter flounder is 0.000047. The catchability coefficient (q) for winter flounder is 0.000029. The catchability coefficient (q) for yellowtail flounder is 0.000056.

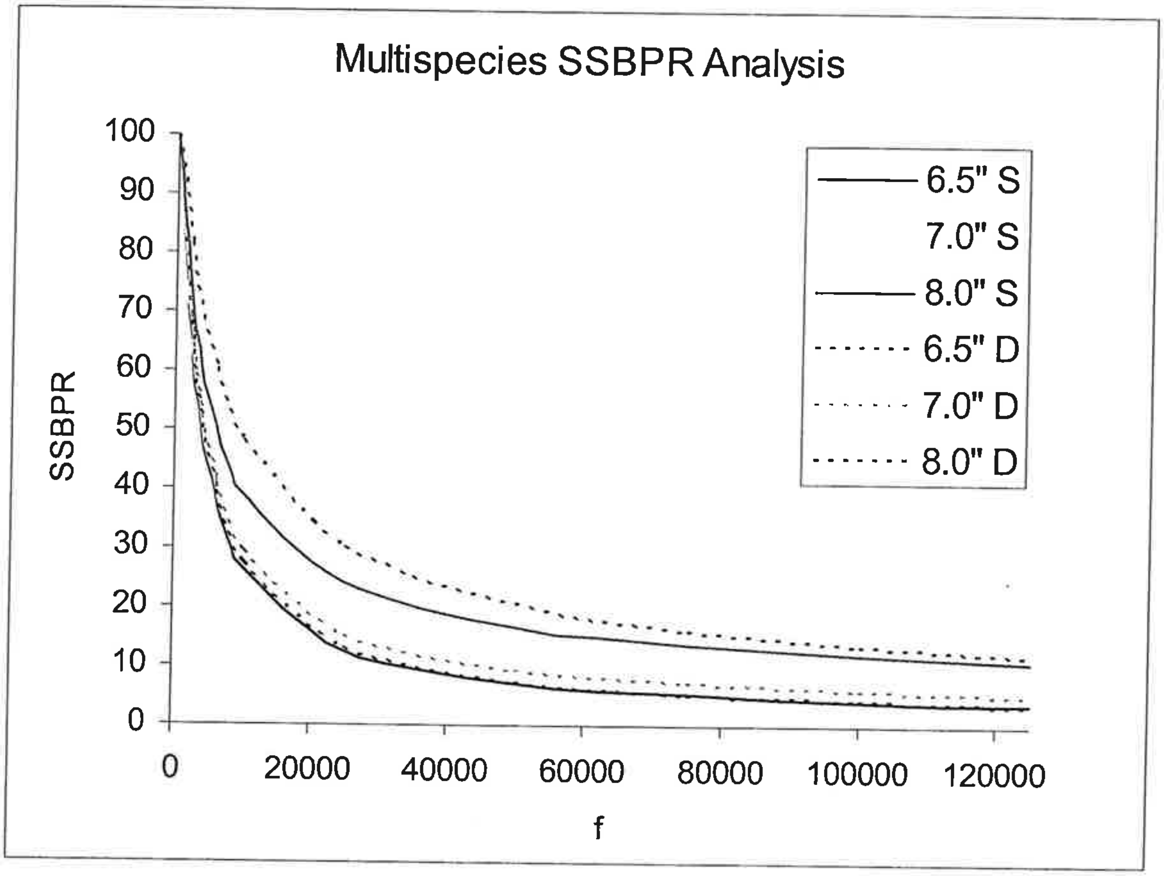

Figure 32. Multispecies spawning stock biomass per recruit (SSBPR) curves for yellowtail flounder derived from the 16.5 cm (6.5 in), 17.8 cm (7.0 in), and 20.3 cm (8.0 in) square and diamond-shaped codend mesh sizes SELECT method selection curves. Standardization utilizes a relative recruitment multiplier (RRM) derived from the catch data. All yields are expressed as a function of fishing effort (f). The catchability coefficient (q) for winter flounder is 0.000047. The catchability coefficient (q) for Atlantic cod is 0.000029. The catchability coefficient (q) for yellowtail flounder is 0.000056. The SSBPR is expressed as a percentage of the maximum spawning stock biomass at f=0.

The scope of work lists three tasks to be accomplished during the period of the grant award:

Task 1: Conduct mesh size selectivity studies aboard a large, commercial fishing vessel that typically harvests groundfish managed in the Gulf of Maine and Georges Bank under the multispecies FMP.

Task 2: Integrate the results of these studies into YPR (yield per recruit) and SSBPR (spawning stock biomass per recruit) models evaluating the effects of incrementally increasing mesh sizes.

Task 3: Conduct an outreach program directed to fishery resource managers and fishermen on the benefits and costs of increasing mesh size based on selectivity data collected within the region on commercial fishing vessels.

The final report states that the objectives of the project were:

Task 1: Develop species-specific fish size selection curves for a stretched 16.5 cm (6.5 in), 17.8 cm (7.0 in), and 20.3 (8.0 in) square and diamond-shaped codend mesh sizes for winter flounder, yellowtail flounder, Atlantic cod, and pollack based on field investigations and estimate standard errors for those curves.

Task 2: Develop YPR and SSBPR models for each target species with respect to the various codend mesh sizes based on the derived selection curves.

Task 3: Conduct a multispecies YPR analysis so as to determine the optimum codend mesh sizes that will maximize biological yield in the New England groundfish fishery.