MAFMC RSA Program
NA03NMF4540025

Macuda
1/18/05

EFFECTS OF INCREASING MESH SIZE IN THE SUMMER FLOUNDER FISHERY IN SOUTHERN NEW ENGLAND AND INSHORE RHODE ISLAND WATERS

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November2004

URI FISHERIES CENTER TECHNICAL REPORT: 02-04

Rec'd 11/8/04

Sea Grant
Rhode Island

ABSTRACT

The effects of increasing codend mesh size on catch efficiency and size selectivity for summer flounder in southern New England and inshore Rhode Island waters was investigated. The alternate tow method was used to examine four experimental codend mesh sizes, 6.5-in diamond, 7.0-in square, 7.0-in diamond, and 8.0-in square, with a small mesh codend as the control. Length at retention values increased with increasing mesh size for each shape, however, the increases between 6.5-in diamond, 7.0-in square, and 7.0-in diamond were slight. The 8.0-in square had larger values of length at retention than the other three mesh sizes. All length at retention values were higher than the minimum size limit for summer flounder for all codends resulting in low retention of undersized fish. When comparing the parameter values calculated in this study to other studies conducted on summer flounder with smaller mesh sizes, it is apparent that an increase in mesh size would help reduce the retention of sublegal-size summer flounder especially from the current legal mesh size, however, when increasing to 8.0-in square, there is a significant decrease in the numbers of legal-size fish as well. It is important to have an acceptable balance between the retention of undersized fish and the escape of commercial sized fish.

INTRODUCTION

Summer flounder or fluke, *Paralichthys dentatus*, is found from Nova Scotia to Florida in shallow estuarine waters and along the outer continental shelf (Packer et al. 1999). They are found in greatest numbers from Cape Cod, Massachusetts to Cape Hatteras, North Carolina (Hildebrand and Schroeder 1928). Summer flounder migrate seasonally inshore and offshore. In warmer months from late spring through early autumn, the adults inhabit shallow coastal and estuarine waters, and in the colder months they migrate offshore to the outer continental shelf (Bigelow and Schroeder 1953; Grosslein and Azarovitz 1982; Terceiro 2001). Spawning occurs during the fall and late winter. The median length at maturity (50 th percentile, L_{50}) is 25.7-cm for males and 27.6-cm for femalesand the median age of maturity (50th percentile, A_{50}) was determined to be 1.0 years for males and 1.5 years for females (NEFC 1990). Maximum size for summer flounder has been estimated to be 61-cm for males and 94-cm for females (Richards 1980).

Summer flounder support important commercial and recreational fisheries. They are managed cooperatively by the Atlantic States Marine Fisheries Commission (ASMFC) and the Mid-Atlantic Fishery Management Council (MAFMC) under the Summer Flounder, Scup, and Black Sea Bass Fishery Management Plan (FMP). Management goals are achieved through the use of commercial quotas (allocated by state and season), recreational harvest limits, minimum mesh requirements, minimum fish sizes, possession limits and other gear restrictions (NMFS 1999). The current mesh regulation for summer flounder is 5.5-in (14.0-cm) diamond or 6.0-in (15.2-cm) square codend mesh size, and the minimum size limit is 14.0-in (35.6-cm).

Mesh size regulations are one of the main management tools utilized today. Mesh size regulations function on the theory that fish above a particular size will be caught and others will escape to recruit to the fishery later on (Robertson 1989). In general, the amount of undersized fish caught decreases with increasing mesh size (Smolowitz 1983). The reduction of undersized fish is most efficiently and practically done through changes in mesh characteristics. This reduction aids in fishery conservation and helps to ensure that fish stocks are utilized at their maximum potential (Bublitz 1995).

An obvious result of increasing mesh size is an increase in the mean size of fish caught; however, there are other direct as well as indirect effects on the fishing industry, resource management, and the ecosystem (Smolowitz 1983). Impacts for the fishermen themselves include a cleaner catch with less bycatch of small fish and unmarketable species. Increasing mesh size allows more fish to grow to a larger size which is a benefit to the resource by increasing the overall yield. Increasing the minimum mesh size would increase yield per recruit (YPR) and spawning stock per recruit (SSBPR), while decreasing fishing

mortality on the younger-aged fish. Eventually, there might be some mesh size that would maximize the yield from the fishery. In addition, there would be an increase in the number of age classes in the stock, thus increasing the spawning potential and possible future year class strengths (Smolowitz 1983).

Trawl codend mesh selection experiments can be conducted in a variety of methods. One method is the alternate tow (orhaul) technique. In the alternate tow method, an experimental mesh codend and small mesh codend are fished alternately from the same trawl net. This approach assumes that both codends are towed for equal time duration; it also assumes that the size distribution of the catch in the small mesh control codend is representative of the fish population entering the experimental codend over the whole length range of fish in which selection takes place (Wileman et al. 1996).

The main advantage of using this method is the lack of cover bias found when utilizing the covered codend method (Pope et al. 1975; Wileman et al. 1996). This results in a more accurate reflection of the real selectivity that would be found in the commercial fishery (Smolowitz 1983). The major drawback of the alternate tow approach is the need for a larger number of hauls to achieve the same precision of estimation as the other methods, which will increase the cost of the experiment. A serious technical difficulty can be the change in catching capacity of a net with increasing codend mesh size (Pope et al. 1975).

The effectiveness of bottom trawl codend mesh selectivity in the Northwest Atlantic is well documented (Clark 1963; Smolowitz 1983). However, there have been only very limited studies of mesh size selectivity on summer flounder in New England waters (Lange 1984; DeAlteris and Grogan 1997; DeAlteris et al. 1999). Without good data on selectivity for summer flounder on mesh sizes and shapes greater than the current minimum mesh sizes, there is resistance on the part of the resource managers and fishermen to consider this option despite its potential benefits.

Project Objective

The main objective of this study was to investigate the effect of increasing the mesh in the codend of a bottom trawl on the retained catch of summer flounder.

METHODS

Data Collection

Sampling was conducted onboard commercial fishing vessels based in Rhode Island. The alternate tow method was used with experimental codend mesh sizes of 6.5-in and 7.0-in diamond, 7.0-in and 8.0-in square, and a small mesh control codend (3.0-in) during the period April to September 2003. Tow duration was 1 hour. Four vessels participated in this study. The F/V *Deborah Lee* conducted 8 days of trawling; F/V *Linda Marie* conducted 5 days of trawling, and F/V *Grandville Davis* and F/V *Catherine and Gloria* conducted 4 days of trawling. The vessels fished in southern New England and inshore Rhode Island

waters (Figure 1). There was a haphazard distribution of codend mesh sizes per vessel; however, each experimental codend was used by at least 3 different vessels. There were a total of 18 paired tows for the 6.5-in diamond, 23 for the 7.0-in square, 20 for the 7.0-in diamond, and 19 for the 8.0-in square.

Two sea samplers from the University of Rhode Island Fisheries Center were onboard each vessel to measure and count fish. The catch was brought on board, then sorted and weighed by species to obtain catch composition. All summer flounder were measured for total length to the whole centimeter. Data were categorized into single centimeter increments represented by the middle number of the range (e.g. 19.5-cm includes fish from 19.1 to 20.0-cm).

Analysis

Catch Efficiency

Catch efficiency was investigated as a function of codend mesh size and numbers of fish and fish length for summer flounder, and fish weight for bycatch species. The hypotheses were as follows:

H_0: The mean size of summer flounder in the experimental codends is the same.

H_0: Codend mesh size has no significant effect on the catch rate of sublegal- and legal-size summer flounder.

H_0: The mean proportion by weight of bycatch in the experimental codends is the same.

Data was tested for normality and transformed as appropriate. A one-way ANOVA (α = 0.05) was performed to test for a difference among the mean length of summer flounder as well as the mean proportion by number with each experimental mesh codend (Zar 1999). Mean length for each mesh size was calculated as the mean of the means of the tows. The mean proportion in number per tow of sublegal (< 35.6-cm) and legal (≥ 35.6-cm) summer flounder caught by each experimental codend were examined, where mesh size was considered the factor. Data was transformed using the arcsine transformation defined as $p' = \arcsin\sqrt{p}$, where p is a proportion. If a significant difference was detected, the Tukey HSD test (α = 0.05) was applied to determine where significant differences were observed through a statistical pairwise comparison of mean catch values for all experimental mesh codends. Lengths were not obtained for bycatch species so mean proportion by weight of bycatch species transformed using the arcsine transformation was compared using an ANOVA and Tukey HSD test. Mean was calculated as the mean of the means of each tow.

Size Selection

The Kolmogorov-Smirnov (KS) two-sample test (α = 0.05) was used to determine whether the observed length-frequency distributions caught by the control codends were significantly different (Steel et al. 1997).

The SELECT approach was used to estimate selectivity parameters for each experimental mesh

configuration (Millar 1992; Millar and Walsh 1992). This method fits a curve to the observed proportions of fish retained at each length from the experimental codend and from this curve a selection curve is derived (Cadigan and Millar 1992; Millar and Fryer 1999). The SELECT model assumes that the number of fish caught in the experimental codend is binomially distributed with probability:

$$\phi(l)_e = \frac{r(l)}{1 + r(l)}$$

where *r(l)* represents the contact-selection (or *retention*) curve (Millar and Fryer 1999).

The retention probability *r(l)* is the probability that a fish of length *l* is captured given that it contacted the gear. This is most often described by a logistic function:

$$r(l)_e = \frac{e^{(a+bl)}}{1 + e^{(a+bl)}}$$

where $r(l)_e$ represents the selection curve of the experimental mesh codend and *a* and *b* represent the slope and intercept, respectively. The selectivity of the control mesh codend is assumed to be unity ($r_c = 1$) over the range of lengths encountered (Millar 1992; Millar and Fryer 1999).

Relative fishing efficiency, *p*, was assumed to be equal for the experimental and control codends ($p = 0.5$). The SELECT method does allow the option of assuming unequal efficiency between the codends, though preliminary analyses suggested the equal *p* assumption was adequate (Cadigan and Millar 1992; Millar 1992; Millar and Walsh 1992; Wileman et al. 1996; Millar and Fryer 1999; Mous et al. 2002).

The parameters *a* and *b* were estimated by maximizing the log-likelihood, *L*:

$$L = \sum_l n(l)_e \ln[\phi(l)] + n(l)_c \ln[1 - \phi(l)]$$

where $n(l)_e$ and $n(l)_c$ are the number of fish at length *l* that were caught in the experimental and control mesh codends, respectively.

Additional parameters were calculated to characterize the selection of fish in each experimental codend. The length at 25% retention (L_{25}), length at 50% retention (L_{50}), length at 75% retention (L_{75}), selection range (*SR*), and the selection factor (*SF*) were computed as:

$$L_{25} = \frac{-a - \ln(3)}{b} \qquad L_{50} = -\frac{a}{b} \qquad L_{75} = \frac{-a + \ln(3)}{b}$$

$$SR = L_{75} - L_{25} \qquad SF = \frac{L_{50}}{meshsize}$$

The standard errors of the a and b parameter estimates were estimated based on standard maximum likelihood theory (McCullagh and Nelder 1989; Millar and Walsh 1992; Wileman et al. 1996; Millar and Fryer 1999). The delta method was used to estimate standard errors for the derived parameters, L_{50} and SR (Millar and Walsh 1992;Wileman et al. 1996). Model deviances were calculated as a measure of goodness-of-fit for the various models. The structure of each model's residual errors was also inspected to detect if any distinctive patterns emerged, which is an indicator of potential lack-of-fit (LOF).

The approach used for the selectivity analysis was the combined haul analysis. The catch data were combined over all replicate hauls and analyzed as though it were a single haul (Wileman et al. 1996). Therefore, an important consideration that must be examined is the between-haul variability. The null hypothesis was:

H_0: No between-haul variation.

Between-haul variation was calculated using the Replication Estimate of Dispersion (REP). The proportion of length l fish taken by the codend over the r replicate tows is represented by:

$$y_l = \frac{\sum_i n_{l1}^i}{\sum_i n_{l+}^i}$$

where n_{l1}^i is the number of length l fish in the control codend and n_{l+}^i is the total number of length l fish for the tow (Wileman et al. 1996).

The REP is defined as (McCullagh and Nelder 1989):

$$\text{REP} = \frac{Q}{d.o.f.}$$

$$Q = \sum_l \sum_i \frac{\left(n_{l1}^i - n_{l+}^i y_l\right)^2}{n_{l+}^i y_l \left(1 - y_l\right)} \qquad (H-1)*$$

where $0.1 \le y_l \le 0.9$ and $d.o.f.$ is degrees of freedom defined as the number of length classes where and H is the number of hauls.

The value of Q has an approximate chi-square distribution with $d.o.f.$ degrees of freedom (Wileman et al.

1996) and is compared to the upper critical values of the chi-square distribution with matching *d.o.f.*. If $Q \leq$ critical value then fail to reject the null hypothesis. If $Q >$ critical value then reject the null hypothesis and the standard errors for the analysis should be multiplied by $\sqrt{\text{REP}}$.

RESULTS

The proportions of fish at length observed in the control and experimental mesh codends are shown in Figure 2. A total of 9,911summer flounder were captured and measured in this study: 1248 in the 6.5-in diamond, 1502 in the 7.0-in square, 866 in the 7.0-in diamond, and 412 in the 8.0-in square shaped mesh codend, and 5,883 in the 3.0-incontrol codend. Summer flounder ranged in size from 17.5-cm to 78.5-cm. However, in the experimental codends, the smallest fish caught was 26.5-cm. Mean length of summer flounder for the experimental codends ranged from 47.8 to 54.5-cm(Table 1). The control had a mean sizeof 43.6-cm. The results of the ANOVA indicated a significant differencein mean length between the 8.0-in square and the other three smaller experimental codends. The Tukey HSD test revealed that the 8.0-in square had a significantly higher mean length. The three smallest experimental codends were not significantly different from one another.

The results of the ANOVA also indicated that there was a significant difference ($p \geq 0.05$) among the mean proportion by number of sublegal and legal-size summer flounder caught by the experimental codends (Table 2). The Tukey HSD test revealed that the mean proportion of sublegal fish caught by the 6.5-in diamond was significantly different ($p < 0.05$) from the mean observed in the 8.0-in square mesh codend (Table 2). The 6.5-in diamond retaineda significantly higher proportion of sublegal-size summer flounder. For the legal-size summer flounder, the Tukey HSD test showed that the 6.5-in diamond differed significantly from the 8.0-in square and the 8.0-in square caught a significantly largerproportion of legal-size fish.

Bycatch species that were caught in the experimental codend mesh sizes, in order of mean weight, included skate, monkfish, scup, dogfish, butterfish, sea robin, tilefish, striped bass, lobster, black sea bass, winter flounder, whiting, squid, tautog, rock crab, bluefish, hake, sea raven, and shad (Table 3). Not all species were caught with each codend. Skate comprised the largest percentage of the bycatch with an average of 42.8% for all experimental codend mesh sizes. Monkfish (18.8%) and scup (13.7%) were the other two dominant species and combined with skate comprised 75% of the total bycatch.

There was a significant difference in the proportion by weight of black sea bass in the experimental codends. The 6.5-in diamond mesh codend caught a significantly higher proportion of black sea bass than both the 7.0-in and 8.0-in square mesh. It is important to note that the 8.0-in codend did not catch any

black sea bass.

The results of the KS analyses indicated no significant difference (D-statistic < critical value) between the length-frequency distributions of samples observed in the control codends. This suggests that the observed catches from the control tows were sampled from a similar length distribution. Figure 2 illustrates the similarity of the length distributions observed in the control mesh codends via visual comparison. From this it can be inferred that the catches in the experimental tows were also sampled from the populations with similar length distributions.

The SELECT statistical model was applied to the observed length frequency data to generate selectivity curves for summer flounder for all experimental codend mesh sizes (Figure 3). Estimated and derived parameter values are presented in Table 4. Estimates of length at 50% retention length ranged from 43.4-cm to 51.8-cm (Figure 4). Theparameter estimates for the 6.5-in diamond mesh codend and 7.0-in square mesh codend were very similar especially for the L_{25} and L_{50} estimates(6.5-indiamond: L_{25} = 40.6-cm; 7.0-insquare: L_{25} = 40.4-cm) (Figures 3-4). These mesh configurations yielded higher retention probabilities for sublegal-size fish (< 35.6-cm) than the 7.0-in diamond and especially the 8.0-in square (Figure 3). The selectivity curves suggest a considerable decrease in the retention of legal-size fish if the mesh size is increased to 8.0-in square. There was a slight decrease in the retention of legal-size fish if the diamond mesh codend increased from 6.5-in to 7.0-in.

For all experimental codend mesh sizes the value of Q was less than the chi-square value and therefore failed to reject the null hypothesis. Hence there was no between-haul variability so the standard errors did not have to be adjusted.

DISCUSSION

Due to the current management strategy, the status of the summer flounder stock has improved and the stock is considered to be not overfished and overfishing is not occurring relative to the current biological reference points. The fishing mortality rate declined from 1.32 in 1994 to 0.23 in 2002, below the overfishing definition reference point ($F_{threshold} = F_{target} = F_{max} = 0.26$). Total stock biomass has increased substantially since 1989, and on 1 January 2003 was estimated to be 56,100 mt, 5% above the biomass threshold (53,200 mt) (Terceiro 2003). The current commercial trawl mesh size regulation for summer flounder is 5.5-in diamond or 6.0-in square, and the minimum size limit (MSL) is 14.0-in (35.6-cm).

In this study, mesh sizes that were at least 1.0 inch larger than the current legal mesh size for both shapes were investigated using the alternate tow method. The modeling approach assumes that control and experimental gears sampled from populations with similar length distributions. If the gear variations under consideration sample from populations with different length distributions, then comparisons will be trivial; apparent differences in the selection properties of various experimental gears may be a consequence of differences in the size composition of the populations being sampled. The results indicated that the control codend sampled from the same size distribution for summer flounder; this suggests that the size composition encountered by the various experimental codend mesh sizes were similar.

Estimates of length at retention increased with increasing mesh size for each shape (Table 4). However, those increases wereminor for the 6.5-in diamond, 7.0-in square, and 7.0-in diamond indicating that increasing mesh size between those three would have the same general effect. The 6.5-in diamond and 7.0-in square had similar selectivity parameters and resulting selectivity curves that were almost identical (Figure 3). These results follow the hypothesis that for flatfish the equivalent square to diamond is 0.5-in larger. The 7.0-in diamond had a very similar curve to both the 6.5-in diamond and 7.0-in square but diverged slightly between just less than the minimum legal size (35.6-cm) and approximately 45.0-cm. In addition, the 7.0-in diamond had larger length at retention values than the 7.0-in square which is probably due to the laterally compressed shape of flatfish which allows greater escapement through the elongated diamond meshes. The 8.0-in square had larger values than the other three codend meshes which is evident when looking at the selectivity curves. The reason for the jump between 7.0-in and 8.0-in is the availability of the mesh. The 7.5-in mesh was not being manufactured at the time of the study.

Selection curves are used to evaluate the probability that fish of a given length are retained. Implementing minimum size limits and gear regulations based on selectivity data can reduce harvest pressure on undersize fish, which has long-term benefits for the resource and the fishery. Estimates of L_{25}, L_{50}, and L_{75} sometimes serve as a basis for setting MSL. For summer flounder, the all length at retention values for the experimental codend mesh sizes were greater than the current minimum size limit for the commercial fishery (MSL = 35.6-cm) resulting in low retention of undersized fish. Although this allows for the escapement of most of the small fishes it also results in losses of commercially sized individuals. Therefore, the ideal situation would be an acceptable balance between the retention of undersized individuals and the escape of commercial sized fish. An increase to 8.0-in square certainly does not provide this balance. Increasing to the 8.0-in square eliminates not only sublegal-size fish but significantly decreases the numbers of legal-size fish over the other meshes which is obvious when looking at the selectivity curves (Figure 3).

The selection factors were similar for all experimental mesh sizes. Selection factors should be consistent

for a species and can then be used to determine L_{50} for different mesh sizes. The values of SR, or the steepness of the curve, showed no obvious pattern. Fonteyne and M'Rabet (1988) found no difference in SR for plaice. However, Cooper and Hickey (1989) found that the SR for plaice was lower for square mesh codends.

The size at which the species of interest becomes sexually mature is another consideration when setting a MSL to further ensure protection of immature fish. The selectivity parameters estimated for summer flounder suggest that most summer flounder are at or near maturity when caught in any of the experimental codend mesh sizes evaluated here. Estimates of all length at retention parameters exceeded the length at 50% maturity ($L_{50\%}$ maturity = 25.7-cm males; 27.6-cm females (NEFC 1990)). In fact, the estimates of L_{50} and L_{75} generally exceeded the length of the largest immature fish (39.9-cm males; 43.9-cm females (Morse 1981)). The only exception was the L_{50} values estimated for the 6.5-in diamond and 7.0-in square, which were slightly smaller.

The reduction of bycatch species would be another consideration when increasing codend mesh size. However, for the mesh sizes studied here increasing mesh size provided no clear benefit of minimizing bycatch.

There have not been many selectivity studies on summer flounder, especially larger mesh sizes. This study was a proactive investigation looking ahead to the future. The current legal mesh size was not investigated therefore straightforwardcomparisons can not be made to see how the values would change when increasing to sizes larger than the legal mesh size. However, selectivity curves were created based on information from previous studies and compared against the selectivity curves developed in this study (Figure 5). A study conducted by Lange (1984) investigated the selectivity of summer flounder in 5.5-in diamond mesh, the current legal mesh size, and found an average L_{50} of 35.0-cm approximately equal to the current MSL. In addition, the University of Rhode Island conducted a selectivity experiment in 1999 that looked at a variety of different flatfish species including summer flounder (DeAlteris et al. 1999). That study examined the legal mesh sizes for groundfish, 6.0-in diamond and 6.5-in square, and found L_{50} values of 40.3 and 41.3, respectively. Based on those selectivity curves it is apparent that an increase in mesh size would help reduce the retention of sublegal-size summer flounder especially from the current legal mesh size.

Since the summer flounder stock is on the road to recovery, there are greater numbers of summer flounder available to the gear. However, there are still strict quotas in place for summer flounder resulting in regulatory discards. The quotas during the time of this study ranged from 0 pounds (closed fishery) to 300

pounds. In many cases, the quota was reached with one 1-hour tow for all the experimental codends (Table 5). The largest catch of summer flounder was almost 1000 pounds in 1 tow in the 7.0-in square and the quota for that day was 150 pounds. Examining the data against the 2004 quotas which ranged from 100 to 750 pounds during the time of the study, there are many cases again where the quota was reached in one 1-hour tow. During the latter half of April when the quota was the largest at 750 pounds, the quota would have been reached in 4 tows using these larger codend mesh sizes.

Thereare a variety of benefits of fishing with a larger codend mesh size. There is a benefit on the summer flounder resource itself. The larger codend mesh sizes will aid in reducing the catch of not only sublegal-size summer flounder but also reduce the capture of legal fish that are in the smaller range creating a shift of those fish captured to meet the quota to larger fish, thereby, letting the small fish escape. The larger mesh sizes may actually create a natural high-grading that occurs before the fish are brought on board reducing the discard mortality associated with sorting on deck. An increase in mesh size would effectively remove medium size summer flounder from the market. Medium size summer flounder usually bring the lowest market price and their protection from harvest would minimize the practice of "high grading." This involves the economic decision of retaining certain species and sizes based on price and markets available (Smolowitz 1983). There will be increased revenue for the same weight of fish. In addition, less individual fish are required to reach the same weight quota. The final possible benefit to increasing the codend mesh size and thereby increasing the minimum fish size is the equalization of the minimum fish size between the commercial and recreational sectors. Currently the Rhode Island minimum fish size is 14-in commercially and 18-in recreationally which is a point of disparity between these two user groups.

The results of this project could be incorporated into stock assessment models for summer flounder or considered in development of a management program that includes gear regulations. Designing or modifying gear to select for larger sizes of summer flounder should improve the economic return to the industry while improving the sustainability of the stocks. In addition to gear selectivity, the exploitation pattern of a fishery is influenced by factors such as the time of year, areas that are fished, and the species life history (e.g. migration patterns). For these reasons, interpreting selectivity estimates requires consideration of the experimental design and the assumptions of the model(s) used to estimate selection parameters.

REFERENCES

Bigelow, H.B. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. United States. Fish and Wildlife Service, Fishery bulletin 74. 577 pp.

Bublitz, C. G. 1995. Mesh Size and Shape: Reducing the Capture of Undersize Fish. Pages 95-99 In Solving Bycatch: Considerations for Today and Tomorrow. Alaska Sea Grant College Program Report No. 96-03., University of Alaska, Fairbanks.

Cadigan, N.G. and R.B. Millar. 1992. Reliability of selection curves obtained from trouser trawl or alternate haul experiment. Canadian Journal of Fisheries and Aquatic Sciences 49: 1624-1632.

Clark, J. R. 1963. Size selection of fish by otter trawls: Results of recent experiments in the Northwest Atlantic. Pages 24-96 *In* The Selectivity of Fishing Gear. ICNAF Spec. Publ. No. 5.

Cooper, C.G. and W.M. Hickey. 1989. 1988 Selectivity experiments with square mesh cod-ends of 135, 140, and 155 mm. Project Report No. 154. Fisheries Development and Fishermen's Service Division. Halifax, Department of Fisheries and Oceans.

DeAlteris, J. and C. Grogan. 1997. An Analysis of Harvesting Gear Size Selectivity for Eight Groundfish Species in the NW Atlantic Ocean. URI Fisheries Technical Report No. 1. 181 pp.

DeAlteris, J., L. Skrobe, G. Hovermale, and D. Beutel. 1999. Results of a size selectivity study for 15.2 cm (6.0 in) diamond-shaped and 16.5 cm (6.5 in) square-shaped codends capturing flatfish in New England waters. URI Technical Report. 10 pp.

Fonteyne, R. and R. M'Rabet. 1988. Selectivity experiments with square mesh codend in the sole beam trawl fishery. Pages 27-36 *In* Proceedings of the Square Mesh Workshop, St. Johns, Newfoundland. Sandwich, MA, Massachusetts Division of Marine Fisheries.

Grosslein, M.D. and T.R. Azarovitz. 1982. Fish distribution. MESA New York Bight Atlas Monograph 15, NY Sea Grant Institute, Albany, NY. 182 pp.

Hildebrand, S.F. and W.C. Schroeder. 1928. Fishes of Chesapeake Bay. Bulletin of the United States Bureau of Fisheries 43(1). 366 pp.

Lange, A. M. T. 1984. Long-term effects of change in mesh size on yield of summer flounder. NOAA/NMFS/NEFSC Laboratory Reference Document No. 84-04, Woods Hole, MA.

McCullagh, P. and J.A. Nelder. 1989. Generalized Linear Models – Second Edition. Chapman and Hill, London. 511 pp.

Millar, R.B. 1992. Estimating the size-selectivity of fishing gear by conditioning on the total catch. Journal of the American Statistical Association 87(420): 962-968.

Millar, R.B. and R.J. Fryer. 1999. Estimating the size-selection curve of towed gears, traps, nets and hooks. Reviews in Fish Biology and Fisheries 9: 89-116.

Millar, R.B. and S.J. Walsh. 1992. Analysis of trawl selectivity studies with an application to trouser trawls. Fisheries Research 13: 205-220.

Morse, W.W. 1981. Reproduction of the summer flounder, *Paralichthys dentatus* (L.). Journal of Fish Biology 19: 189-203.

Mous, P.J., W.L.T. van Densen, and M.A.M. Machiels. 2002. The effect of smaller mesh sizes on catching larger fish with trawls. Fisheries Research 54: 171-179.

National Marine Fisheries Service (NMFS). 1999. Our Living Oceans. Report on the status of U.S. living marine resources, 1999. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-41, on-line version, http://spo.nwr.noaa.gov/unit1.pdf.

Northeast Fisheries Center (NEFC). 1990. Report of the Eleventh NEFC Stock Assessment Workshop Fall 1990. NEFC Reference Document. No. 90-09. 121 pp.

Packer, D.B., S.J. Griesbach, P.L. Berrien, C.A. Zetlin, D.L. Johnson, and W.W. Morse. 1999. Essential Fish Habitat Source Document: Summer Flounder, *Paralichthys dentatus*, Life History and Habitat Characteristics. NOAA Technical Memorandum NMFS-NE-151. 43 pp.

Pope, J.A., Margetts, A.R., Handey, J.M., Akyuz. 1975. Manual of methods for fish stock assessment. Part III. Selectivity of Fishing Gear. FAO Fish. Tech. Pap. No. 41, Rev. 1: 1 46.

Robertson, J. H. B. 1989. The effect of trawl codend design on selection characteristics. Pages 48-50 *In* Proceedings of the World Symposium on Fishing Gear and Fishing Vessel Design. Marine Institute, St. John's, Newfoundland, Canada.

Smolowitz, R. J. 1983. Mesh Size and the New England Groundfishery – Applications and Implications. NOAA Technical Report NMFS SSRF-771. 60 pp.

Steel, R.G.D., J.H. Torrie, and D.A. Dickey. 1997. Principles and Procedures of Statistics: A Biometrical Approach – Third Edition. McGraw-Hill, Boston. 666 pp.

Terceiro, M. 2001. Summer flounder. *In* S. H. Clark (ed). Status of Fishery Resources off the Northeastern United States for 1998. NOAA Tech. Memo. NMFS-NE-115, on-line version, http://www.nefsc.nmfs.gov/sos/spsyn/fldrs/summer.html.

Terceiro, M. 2003. Stock assessment of summer flounder for 2003. Northeast Fisheries Science Center Reference Document 03-09. 179 pp. Available from: National Marine Fisheries Service, 166 Water St., Woods Hole, MA 02543-1026.

Wileman, D. A., R. S. T. Ferro, R. Fonteyne, and R. B. Millar (eds). 1996. Manual of methods of measuring the selectivity of towed fishing gears. ICES Cooperative Research Report No. 215. International Council for the Exploration of the Sea Copenhagen, Denmark. 126 pp.

Zar, J.H. 1999. Biostatistical Analysis – Fourth Edition. Prentice Hall, New Jersey. 663 pp.

Table 1. Results of the single factor ANOVA test ($\alpha = 0.05$) for differences among the mean length per tow observed in the experimental mesh codends.

Test for Difference Among Means			Tukey HSD			
Codend	Mean	SE*		7.0-in Square	7.0-in Diamond	8.0-in Square
6.5-in Diamond	47.8	0.61	6.5-in Diamond	*n.s.*	*n.s.*	**
7.0-in Square	49.6	0.54	7.0-in Square	*n.s.*	*n.s.*	**
7.0-in Diamond	49.6	0.58	7.0-in Diamond	*n.s.*	*n.s.*	**
8.0-in Square	54.5	0.60				
ANOVA	$p < 0.05$**					

* Standard error uses a pooled estimate of error variance

** Means are significantly different

n.s. not significantly different

Table 2. Results of the single factor ANOVA test ($\alpha = 0.05$) for differences among the proportion of mean numbers per tow observed in the experimental mesh codends.

Test for Difference Among Means				Tukey HSD			
	Codend	Mean	SE*		7.0-in Square	7.0-in Diamond	8.0-in Square
Sublegal	6.5-in Diamond	0.136	0.025	6.5-in Diamond	*n.s.*	*n.s.*	**
< 35.6-cm	7.0-in Square	0.063	0.022	7.0-in Square	*n.s.*	*n.s.*	*n.s.*
	7.0-in Diamond	0.111	0.023	7.0-in Diamond	*n.s.*	*n.s.*	*n.s.*
	8.0-in Square	0.027	0.024				
	ANOVA	$p < 0.05$**					
	Codend	Mean	SE*		7.0-in Square	7.0-in Diamond	8.0-in Square
Legal	6.5-in Diamond	1.436	0.024	6.5-in Diamond	*n.s.*	*n.s.*	**
≥ 35.6-cm	7.0-in Square	1.509	0.022	7.0-in Square	*n.s.*	*n.s.*	*n.s.*
	7.0-in Diamond	1.460	0.023	7.0-in Diamond	*n.s.*	*n.s.*	*n.s.*
	8.0-in Square	1.543	0.024				
	ANOVA	$p < 0.05$**					

* Standard error uses a pooled estimate of error variance
** Means are significantly different
n.s. not significantly different

Table 3. Mean proportion of bycatch species by mesh size including the mean for all experimental codend mesh sizes.

	Mesh Size				
Species	**6.5 D**	**7.0 S**	**7.0 D**	**8.0 S**	**Mean**
Skate	0.528	0.488	0.382	0.537	0.482
Monkfish	0.110	0.269	0.287	0.341	0.255
Scup	0.138	0.121	0.162	0.035	0.114
Dogfish	0.040	0.016	0.029	0.033	0.029
Butterfish	0.000	-	0.001	-	0.000
Sea Robin	0.021	0.021	0.015	0.003	0.015
Tilefish	0.019	-	0.027	-	0.011
Striped Bass	0.024	0.011	0.004	0.021	0.014
Lobster	0.016	0.005	0.005	0.023	0.012
Black Sea Bass	0.015	0.001	0.007	-	0.005
Winter Flounder	0.023	0.005	0.001	0.004	0.008
Whiting	-	-	0.007	-	0.002
Squid	0.001	-	0.002	-	0.001
Tautog	0.010	0.003	0.001	-	0.003
Rock Crab	0.009	0.011	-	-	0.005
Bluefish	0.001	0.006	0.001	0.004	0.003
Hake	-	-	0.006	-	0.002
Sea Raven	0.001	-	0.000	-	0.000*
Shad	-	-	0.001	-	0.000**

* Caught in only 2 tows
** Caught in only 1 tow

Table 4. Summary of selectivity parameter estimates for summer flounder alternate haul experiment. Standard errors for selected parameters are given in parentheses.

	6.5-in Diamond		7.0-in Square		**7.0-in Diamond**		**8.0-in Square**	
Parameter								
L_{25} (cm)	40.6		40.4		42.0		48.1	
(*inches*)	*16.0*		*15.9*		*16.5*		*18.9*	
L_{50} (cm)	43.8	(0.30)	43.4	(0.28)	44.9	(0.35)	51.8	(0.57)
(*inches*)	*17.3*		*17.1*		*17.7*		*20.4*	
L_{75} (cm)	47.0		46.4		47.9		55.4	
(*inches*)	*18.5*		*18.3*		*18.9*		*21.8*	
SR (cm)	6.4	(0.38)	5.9	(0.38)	6.0	(0.45)	7.4	(0.57)
(*inches*)	*2.5*		*2.3*		*2.3*		*2.9*	
SF (cm)	6.7		6.2		6.4		6.5	
(*inches*)	*2.7*		*2.4*		*2.5*		*2.5*	

Table 5. Amount of summer flounder in pounds per tow with 2003 and 2004 quotas. Data was totaled for each mesh size on each day.

Date	Mesh	Pounds (per tow)	Total	2003 Quota (pounds)	2004 Quota (pounds)
4/13/03	6.5D	121.3			
		277.8			
		295.4			
		231.5	925.9	100	300
4/21/03	7.0D	200.6			
		293.2	493.8	100	750
4/21/03	7.0S	202.8			
		299.8			
		280.0			
		227.1	1009.7	100	750
4/22/03	7.0D	244.7			
		284.4	529.1	100	750
4/22/03	8.0S	152.1			
		183.0			
		132.3			
		277.8	745.2	100	750
5/5/03	7.0D	127.9			
		119.0	246.9	100	100
5/5/03	7.0S	198.4			
		125.7			
		112.4			
		86.0	522.5	100	100
5/6/03	7.0D	90.4			
		103.6	194.0	100	100
5/6/03	8.0S	46.3			
		52.9			
		90.4	189.6	100	100
5/27/03	6.5D	123.5			
		154.3			
		88.2			
		90.4	456.4	100	100
6/9/03	7.0D	37.5			
		70.5			
		72.8			
		130.1	310.9	100	100
6/10/03	7.0S	79.4			
		39.7			
		50.7			
		66.1	235.9	100	100
6/11/03	6.5D	138.9			
		79.4			
		110.2			
		81.6	410.1	100	100

Date	Mesh	Pounds (per tow)	Total	2003 Quota (pounds)	2004 Quota (pounds)
6/23/03	8.0S	123.5			
		114.6			
		75.0			
		99.2			
		70.5	482.8	0	100
7/11/03	6.5D	271.2			
		172.0			
		251.3			
		200.6	895.1	0	150
7/14/03	8.0S	48.5			
		22.0			
		44.1			
		33.1	147.7	0	150
7/18/03	6.5D	313.1			
		205.0	518.1	0	150
7/21/03	7.0D	198.4			
		198.4			
		110.2	507.1	0	150
7/29/03	7.0S	50.7			
		72.8	123.5	0	150
9/5/03	7.0S	**996.5**			
		377.0			
		352.7			
		229.3			
		359.4	2314.9	150	200
9/24/03	7.0D	105.8			
		83.8			
		61.7			
		94.8	346.1	150	300
9/29/03	7.0S	41.9			
		39.7	81.6	150	300
9/29/03	8.0S	52.9			
		79.4			
		26.5			
		72.8	158.7	150	300
9/30/03	7.0S	55.1			
		57.3	112.4	150	300

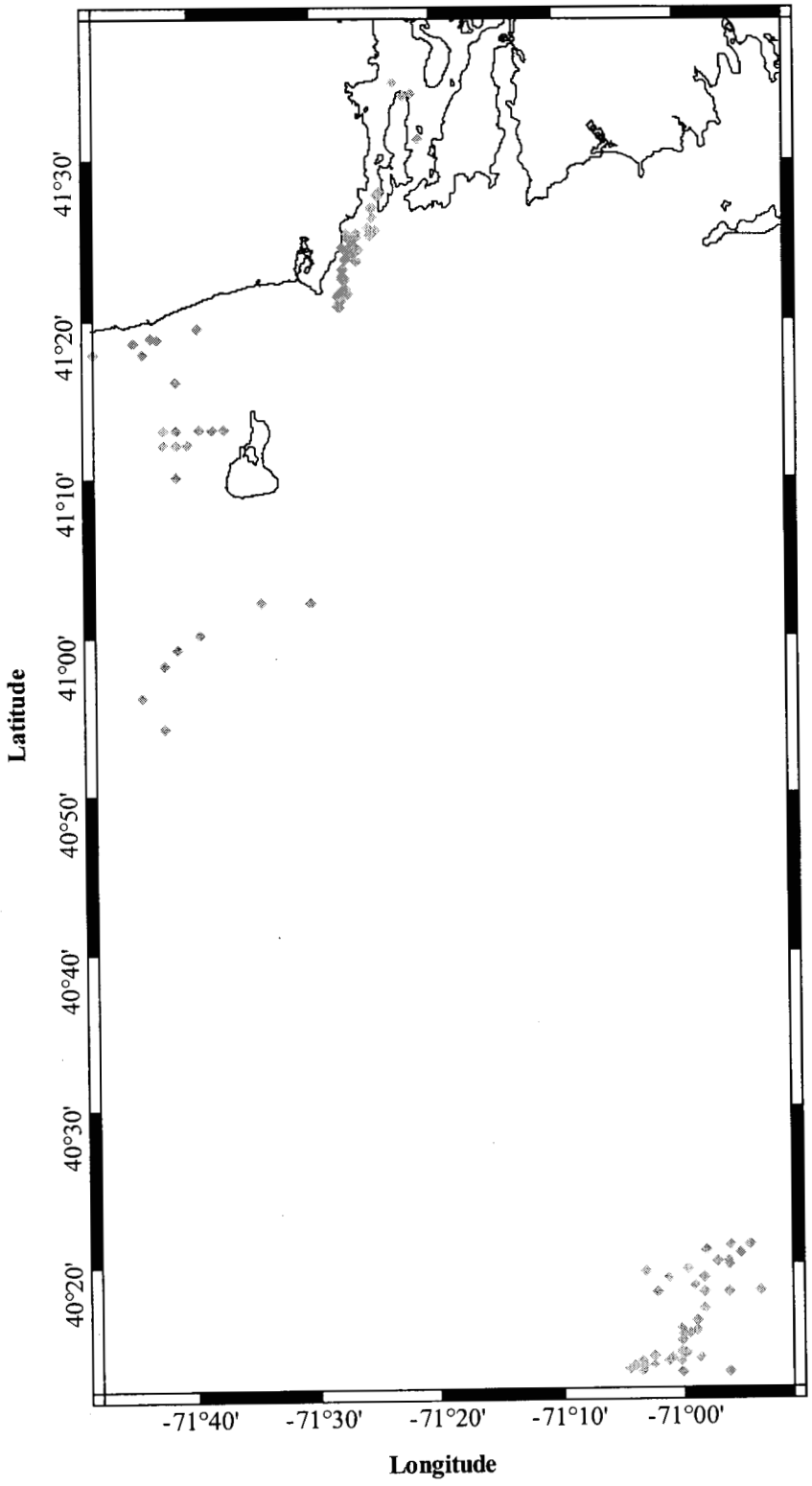
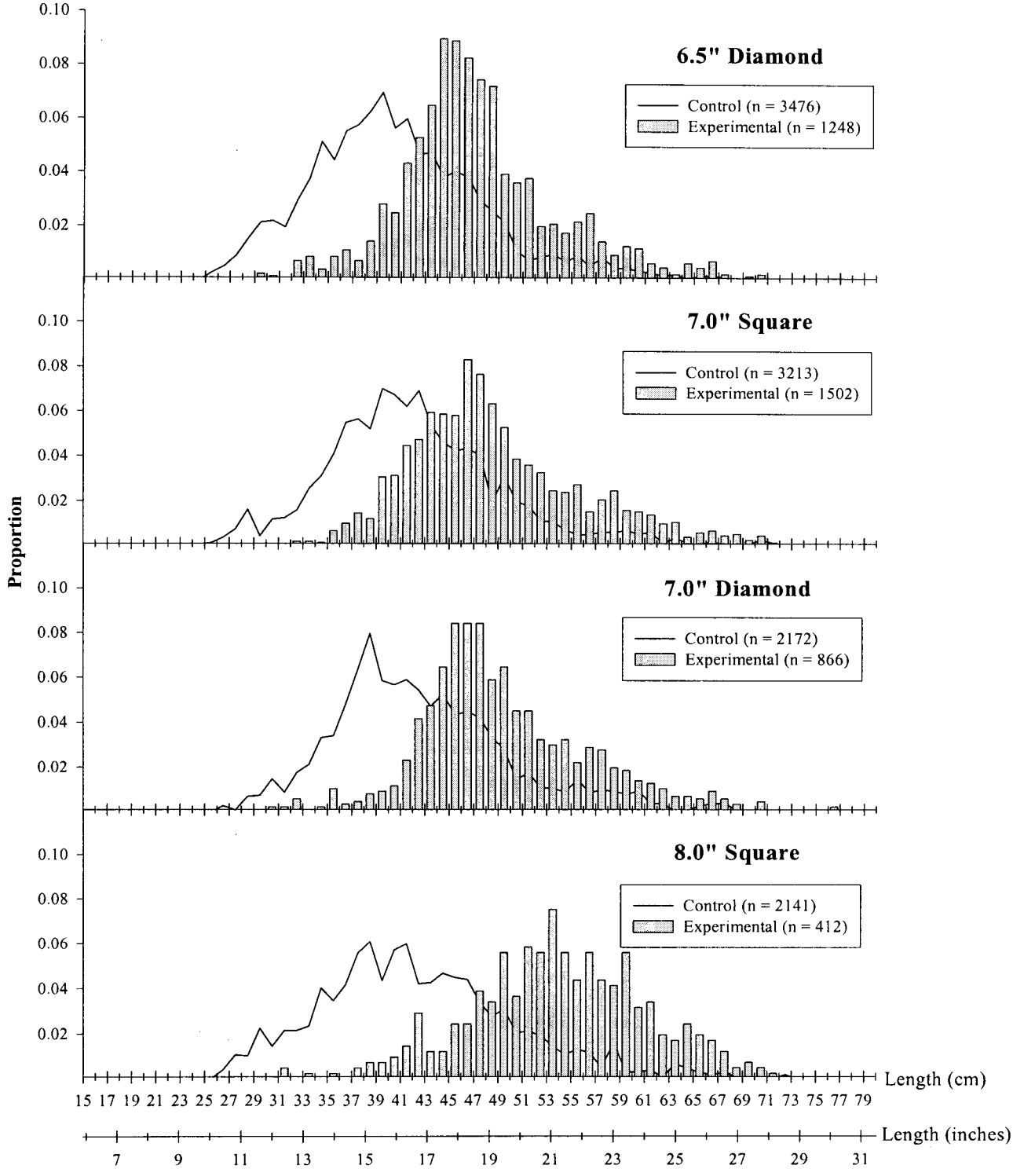

41°30'
41°20'
41°10'
41°00'
40°50'
40°40'
40°30'
40°20'
Latitude
-71°40'
-71°30'
-71°20'
-71°10'
-71°00'
Longitude

Figure 1. Map of towing locations. Diamonds represent beginning coordinates of the tows.

Figure 2. Length-frequency distributions of summer flounder observed in control and experimental mesh codends. The lines represent distributions for the control codends and bars represent distributions for the experimental codends.


6.5" Diamond
Control (n = 3476)
Experimental (n = 1248)
7.0" Square
Control (n = 3213)
Experimental (n = 1502)
7.0" Diamond
Control (n = 2172)
Experimental (n = 866)
8.0" Square
Control (n = 2141)
Experimental (n = 412)
Proportion
0.10
0.08
0.06
0.04
0.02
Length (cm)
15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79
Length (inches)
7 9 11 13 15 17 19 21 23 25 27 29 31

Date	Mesh	Pounds (per tow)	Total	2003 Quota (pounds)	2004 Quota (pounds)
13/03	6.5D	121.3			
		277.8			
		295.4			
		231.5	925.9	100	300
21/03	7.0D	200.6			
		293.2	493.8	100	750
21/03	7.0S	202.8			
		299.8			
		280.0			
		227.1	1009.7	100	750
22/03	7.0D	244.7			
		284.4	529.1	100	750
22/03	8.0S	152.1			
		183.0			
		132.3			
		277.8	745.2	100	750
5/03	7.0D	127.9			
		119.0	246.9	100	100
5/03	7.0S	198.4			
		125.7			

Date	Mesh	Pounds (per tow)	Total	2003 Quota (pounds)	2004 Quota (pounds)
6/23/03	8.0S	123.5			
		114.6			
		75.0			
		99.2			
		70.5	482.8	0	100
7/11/03	6.5D	271.2			
		172.0			
		251.3			
		200.6	895.1	0	150
7/14/03	8.0S	48.5			
		22.0			
		44.1			
		33.1	147.7	0	150
7/18/03	6.5D	313.1			
		205.0	518.1	0	150
7/21/03	7.0D	198.4			
		198.4			
		110.2	507.1	0	150
7/29/03	7.0S	50.7			
		72.8	123.5	0	150

es)

nes)

Figure 3. Predicted selection curves for summer flounder. Dashed line represents current minimum size limit (MSL = 35.6-cm *or* 14.0-in).

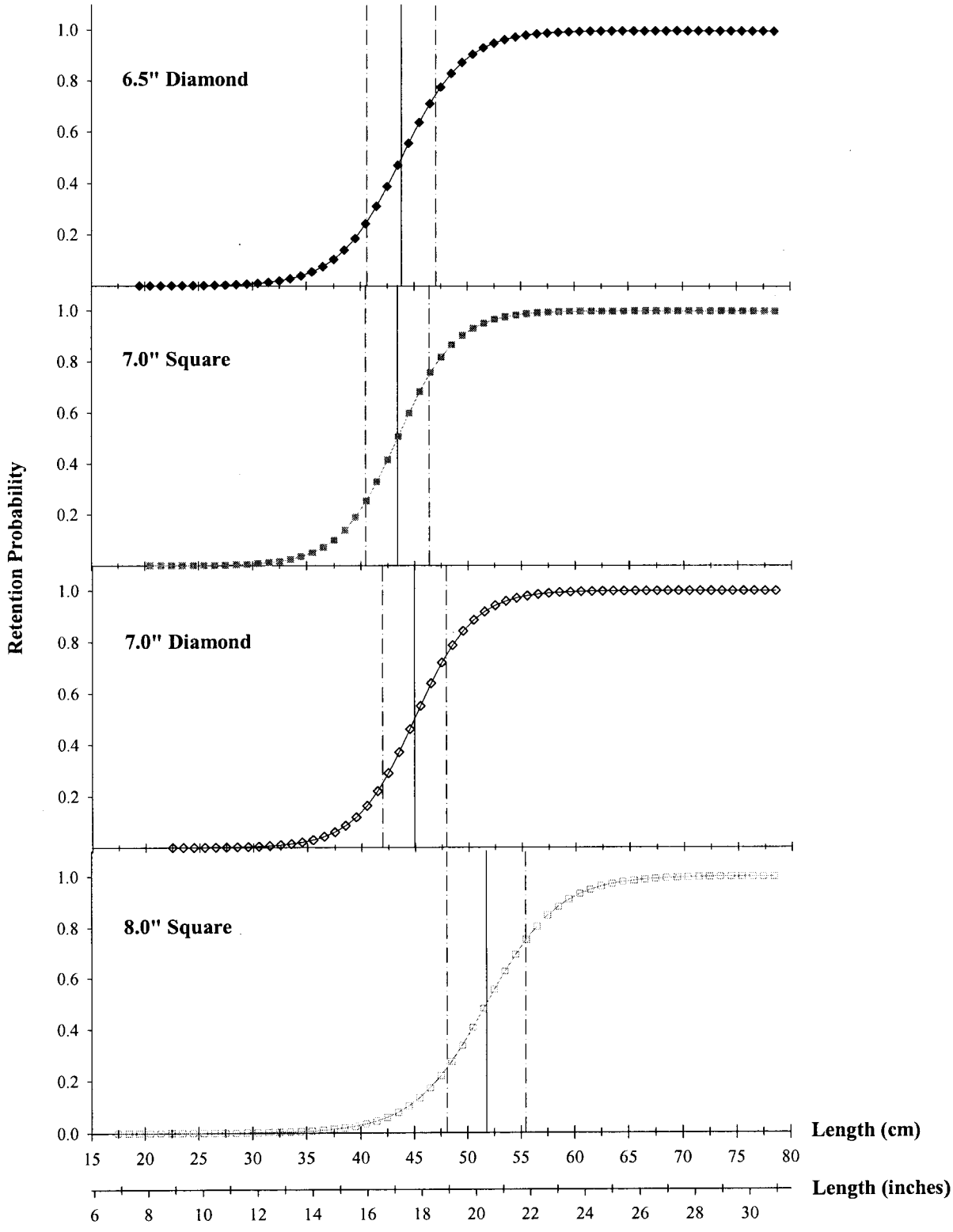


Figure 4. Predicted selection curves for summer flounder. The reference lines indicate the

lengths at 25%, 50%, and 75% retention that were estimated for each experimental codend. The solid line represents L_{50} with dashed-dotted lines denoting L_{25} and L_{75} to the left and right, respectively.

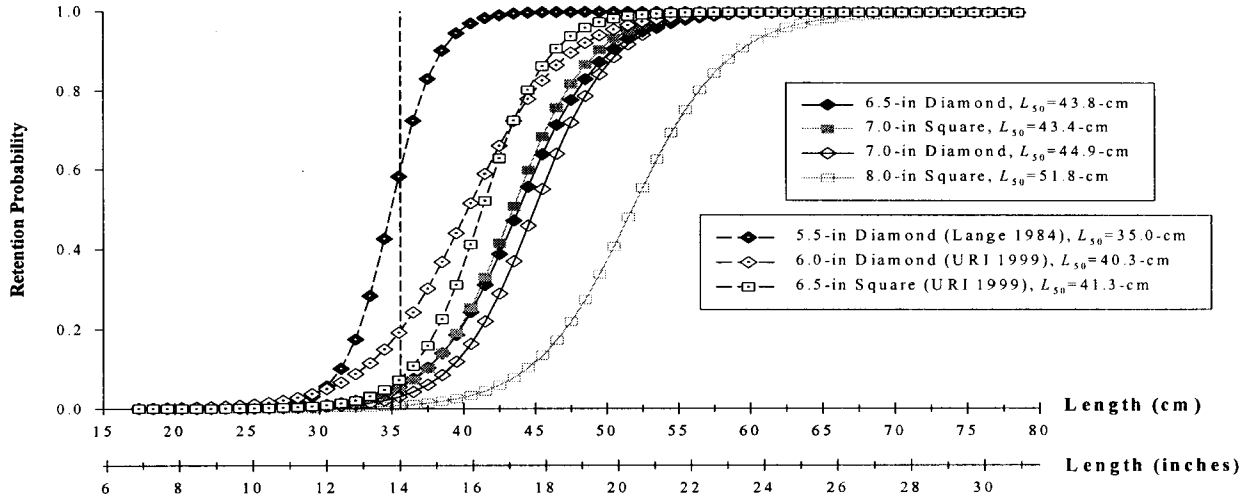


Figure 5. Predicted selection curves for summer flounder from the current study, study conducted by Lange (1984), and past URI study (DeAlteris et al. 1999).