UNITED STATES
DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
State, Federal &Constituent Programs Office

FINAL REPORT

Grantee: National Fisheries Institute

Project No: 04-RSA-002

Grant No: NA05NMF4540053

Project Title: Loligo Squid Mesh Selectivity Study to Reduce Bycatch of Juvenile Loligo Squid and Other Species

Period Covered: 1/1/2005 – 2/28/2007

Prepared by:

Approved by

Date: December 14, 2007

Statutory Funding Authority:

_Anadromous Fish Conservation Act (P.L. 89-304)
_Chesapeake Bay Studies
_Endangered Species Act
_Interjurisdictional Fisheries Act (Title ill of P.L. 99-659)
_Magnuson Act
_Oyster Disease Research
_Saltonstall-Kennedy
_Unallied Industry Projects
_Unallied Science Projects

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Joyce —
RIN to HEM

Haskin Shellfish Research Laboratory

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December 14, 2007

Dr. Harold Mears
State, Federal and Constituent Programs Office
National Marine Fisheries Service
1 Blackburn Drive
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Dear Dr. Mears:

Please find enclosed the revision of our final report. My apologies for the length of time this has taken. We received the review from NMFS, but felt for a number of reasons that it did not comprehensively evaluate the document. As a consequence, we asked an independent party to obtain three additional reviews. The reviews are included with this transmission, for your records. The reviewers were Joe DeAlteris, Chris Hager, and William DuPaul. In aggregate, the four reviews, provided by NMFS plus the three academics, identified a number of issues that needed to be addressed. These included the addition of a second data table, a clearer description of the tow order, additional information on how catch was calculated, a more thorough discussion of the standardization procedure with particular focus on the relationship of our procedure with the ratio method, the consistent usage of the terms control and experimental versus codend-effect and vessel-effect, the addition of a statistical test addressing the influence of catch volume on size frequency, the addition of a number of figures, and a more complete explanation of the effect size used in the power analyses. In addition, we have taken DeAlteris' advice and modified the title. As you can see, the outside reviewers were generally supportive of the document and provided substantive suggestions for improvement not covered by the NMFS review. As a consequence, the additional reviews have complemented the NMFS review, rather than being redundant of the NMFS review. Accordingly, the outside reviews have provided a much improved report, and as a consequence justify the added time involved in their acquisition.

Sincerely,

Eric N. Powell
Director
Haskin Shellfish Research Laboratory

Cc. Sarah King
Greg DiDomenico
Eleanor Bochenek
John Connelly

FINAL Report (1/1/05 - 2/28/07)

04-RSA-002
NA05NMF4540053

Effect of an Increase in Codend Mesh Size on Discarding in the *Loligo* Squid-Directed Fishery: A Commercial-Scale Test

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Abstract

Discard reduction of juvenile fish and other unwanted bycatch species has been identified as a primary tool in achieving rebuilding and mortality objectives of current fishery management plans. Management of the offshore *Loligo pealei* squid fishery is particularly challenging because the legal codend mesh size is smaller than other regulated commercial fisheries. Co-occurrence of adult *Loligo* with juveniles and other Mid-Atlantic species of concern, such as scup (*Stenotomus chrysops*), silver hake (*Merluccius bilinearis*) and butterfish (*Peprilus triacanthus*), coupled with the high volume of landings may lead to high discarding of non-target species. To address this concern, an increase in codend mesh size from the present legal size of 1.875″ was evaluated as a means to reduce the capture of submarket-size squid, butterfish, and other species of concern, without materially impacting the catch of

market-size squid. To evaluate the influence of fishing practice, a commercial-scale test was undertaken.

A 2.5″ mesh codend significantly reduced the catch of *Loligo* squid. However, in addition to the desired reduction of juveniles, substantial decreases in the catch of market-size (10-13 cm) *Loligo* squid occurred without any significant reductions in the bycatch, in weight or numbers, of butterfish, silver hake, or spiny dogfish. The size-frequency distribution for *Loligo* squid was shifted toward larger size classes in tows using the experimental codend. No significant shifts in the 25th, 50th, and 75th percentiles or the mean size of butterfish or female or male spiny dogfish were observed between codends. To recover total catch of market-size squid with the 2.5″ mesh codend would require an increase in fishing effort of 73.9%. Even with that increase, total juvenile squid discards would be reduced by 52.7%. However, total discards of other bycatch species could be substantially increased. Codend mesh size could only be an effective option if discarding of other species was inconsequential or if avoidance of unwanted catch could be achieved through area management.

Introduction

Discard reduction is a component of the statutory requirements implemented by the "Sustainable Fisheries Act" Amendments to the Magnuson Stevens Fishery Conservation and Management Act (Anonymous, 1996). Approaches to managing discards have included gear modifications, area-time closures, and regulatory reform (e.g., Lök et al., 1997; Murawski, 1996; Karp et al., 2001). In the Mid-Atlantic, much effort has been directed at bycatch reduction in the small-mesh fisheries for *Loligo* squid (*Loligo pealei*) and silver hake (*Merluccius bilinearis*), emphasizing the reduced capture of juvenile scup (*Stenotomus chrysops*) (NEFSC, 2000; Kennelly, 1999; Glass et al., 2002). However, a number of additional species discarded by small-mesh fisheries might also be a source of concern. One of these, butterfish (*Peprilus triacanthus*), has gained prominence recently because discarding in the *Loligo* squid fishery is considered a dominant source of fishing mortality (NEFSC, 2004).

Loligo pealei has a life span of less than one year (Brodziak and Macy, 1996). These squid grow rapidly and are thought to spawn throughout the year (Macy and

Brodziak, 2001). *Loligo* squid migrate inshore in late spring (May-June) supporting an inshore commercial fishery during the summer. The offshore commercial fleet capitalizes on *Loligo* that move offshore in late fall (November-December) and reside along the outer continental shelf during the winter and early spring (January-April) (Brodziak and Hendrickson, 1998).

For a number of target species, such as *Loligo* squid, silver hake, and butterfish, a substantial portion of total discards are juveniles that are too small to be marketed. Discarding of juveniles reduces the number of individuals that reach sexual maturity and spawn and, thus, impacts spawning stock biomass. The Mid-Atlantic Fishery Management Council (MAFMC), Atlantic States Marine Fisheries Commission (ASMFC), and National Marine Fisheries Service (NMFS) have identified the targeting of mature adult fish and the avoidance of juvenile fish as a primary tool in achieving the rebuilding and mortality objectives of current management plans.

Among the highest discards in the *Loligo* squid fishery is *Loligo* itself (Powell et al., 2004). Most of these discarded squid are below market size. Discards of *Loligo*, silver hake, and butterfish account for more than half of all discards in *Loligo* squid-targeted tows (Powell et al., 2003). Moreover, anecdotal information from fish processors suggests that an additional significant number of squid are discarded ashore due to their small size. However, this wastage does not appear amongst the discards, as these squid are counted as landings, but does represent an economic loss to the fishery and potentially a loss to the reproductive stock generating the next generation (Buresch et al., 2006; Macy and Brodziak, 2001). Accordingly, any gear improvements directed at reducing the catch of small *Loligo* may positively impact the economics of the squid fishery and the population dynamics of the stock. In addition, gear improvements may address other important discard issues in this fishery, namely the discarding of juvenile scup, silver hake, and butterfish. Consequently, reducing discards of juvenile *Loligo* is an important goal.

Several previous studies have examined codend selectivity for squid (Hastie, 1996; Lange, 1980), but these studies have not emphasized commercial-scale fishing activities. Thus, the objective of this study was to determine if an increase in codend mesh size from the present legal size of 1.875″ (4.76 cm) can effectively reduce the

capture of submarket-size squid, butterfish, silver hake, and other species of concern, without materially impacting the catch of market-size squid. In addition, this study emphasized a directed-*Loligo* commercial-scale test of a 2.5″ (6.35 cm) codend mesh to evaluate performance under standard commercial conditions. Powell et al. (2004) have emphasized the desirability to evaluate the effectiveness of gear in commercial application as increased tow times and catch volumes, plus vessel-to-vessel variations in fishing procedures, can substantially affect gear performance (e.g., Graham et al., 2004; Powell et al., 2004).

Methods

Field Program

Vessel-to-vessel differences, that include differences in net design, are critical variables to be assessed. The field protocol was designed to provide some information on the likely variability in codend mesh performance between vessels. As a consequence, vessels fished their standard gear with the exception of varying codend mesh size (Table 1). However, due to financial limitations restricting total sample number, vessels were chosen of relatively similar size that fished relatively similar gear, namely millionaire nets. As a variety of nets are fished for *Loligo*, extrapolation of the results reported herein to a wider range of gear types should be done with caution.

Table 1. Vessel and gear description.

	Hull length	Net Type	Headrope	Footrope	Ground cable	Control codend	Experimental codend
Vessel I	23.47 m	Millionaire	44.20 m	44.20 m (wire/rope)	82.30 m (cable/wire)	Single twine diamond hung 4.92-cm mesh with a 15.10-cm mesh strengthener	Single twine diamond hung 6.26-cm mesh with a 15.14-cm mesh strengthener
Vessel II	22.89 m	Millionaire	41.15 m	41.15 m (rubber cookies)	82.30 m (cable/wire)	Single twine diamond hung 4.92-cm mesh with a 15.11-cm mesh strengthener	Single twine diamond hung 6.46-cm mesh with 15.26-cm mesh strengthener
Vessel III	22.40 m	Millionaire	41.15 m	41.15 m (rubber cookies)	82.30 m (cable/wire)	Single twine diamond hung 4.92-cm mesh with a 15.11-cm mesh strengthener	Single twine diamond hung 6.46-cm mesh with a 15.26-cm mesh strengthener

In commercial mode, tows are long, often >2 hr, and catches are large. Catches of *Loligo* squid and other species are significantly affected by time-of-day (Walsh,

1988; Serchuk and Rathjen, 1974; NEFSC, 2002; Gillis, 1999). The assumption was that net performance would vary to some degree over catch size and with time of day and that vessel effects might become more important as catch size increased. As a consequence, during this commercial-scale test, two vessels fished in parallel under standard commercial conditions. Each vessel towed the legal codend used in the fishery with a mesh size of 1.875″ (A), hereafter termed the control codend, and the experimental 2.5″ mesh codend (B) in an offset ABBA sequence, to allow pairwise comparisons to be made over a four tow sequence: A_1A_2, B_1A_2, B_1B_2, and A_1B_2, where the subscripts refer to the paired vessels. Depths, locations, and gear deployment methodology were standard for the fishery. However, two constraints were imposed. First, tows did not exceed 3 hours in duration to assure minimally four tows per day as tows were restricted to daylight hours only, as is typical for the fishery. Second, parallel tows of equivalent duration were made to retain direct comparability between tows. Tow speeds were in the range of 2.9-3.2 knots. This speed is standard for the squid fishery.

Since *Loligo* squid are on a subannual growth cycle, it was important to evaluate mesh selectivity during the times of year when the offshore *Loligo* fishery occurred. Thus, forty of the tows were taken during February-April, 2005, and the remaining forty tows were taken in December, 2005. However, during the interim between the field programs, one of the vessels (Vessel II, Tables 1 and 2) incurred major damage and was unavailable for the second half of the study. Thus, a third vessel carried out the remainder of the paired experiment in December, 2005 (Vessel III, Tables 1 and 2).

Vessel position and time were recorded in one-minute intervals during each tow using DGPS. A Vemco data recorder collected water temperature and depth data every minute during the tow and these temperature/depth profiles were employed to make a relatively precise determination of time-on-bottom and time-off-bottom, thus permitting an accurate reconstruction of tow distance, and a direct evaluation of any differential in depth between the two parallel tows. Budgetary constraints did not permit inclusion of door spread or net height sensors on all of the vessels and therefore, were excluded from all analyses. However, as the nets fished by the vessels were of similar size and configuration, total catch provided an adequate

estimate of effort within and between paired tows.

For each tow, the catch was sorted and weights were obtained for all caught species. In cases where the catch was large, NMFS-approved subsampling protocols were employed. Target species for length measurement included: *Loligo* squid, scup, silver hake, butterfish, black sea bass, summer flounder, and male and female spiny dogfish. One-hundred randomly selected lengths, catch permitting, were obtained on each tow for each species. Catch numbers for any size class c, n_i, were estimated from:

$$n_c = \frac{n_{s_c}}{w_{s_c}} w_c \tag{1}$$

where s_c is value of the subsample measured and w is weight.

Statistical Analysis

Exploratory analysis demonstrated differences in the magnitude of the total catch on each cruise due to temporal differences in the availability of squid. To control for the influence of time-of-year and the consequent necessary changes in the locations fished, catch weight per tow for each species j was standardized across all cruises using the species' global median catch weight with the standard 1.875″ mesh codend as follows:

$$C_{STD_{i,j}} = \frac{C_{Global_j}\, C_{T_{i,j}}}{C_{Local_{T_j}}} \tag{2}$$

where C_{STD} is the standardized catch weight for a given species in kg tow^{-1}, C_{Global} is the global median catch weight per tow using the control codend for that species, C_{T_i} is the species' catch weight for trip T, tow i, and C_{Local_T} is the within-cruise median catch weight per tow using the control codend on trip T. The global and within-cruise median were used rather than the respective means because subsequently-described statistical analyses used nonparametric methods. As described subsequently, most statistical analyses focused on the difference in catches between parallel tows. This difference, ΔC_{STD}, is a difference between ratio estimators standardized for clarity to the global median. For any species j and tow i, from equation (2):

$$\Delta C_{STD_{i,j}} = \left(\frac{C_{T_{Vessel\,1_{i,j}}} - C_{T_{Vessel\,2_{i,j}}}}{C_{Local_{T_j}}} \right) C_{Global_j} \tag{3}$$

Thus, statistical analyses are based on catch ratios to minimize the influence

of between-trip variations in availability that can be expected to occur between seasons, locations, and year-to-year.

The equivalent method was used to calculate the numbers of individuals caught of that species per tow by replacing each occurrence of catch weight for catch in numbers in equation (2). In addition, the total catch weight per tow and total catch minus *Loligo* catch per tow, respectively, were substituted for catch weight per tow, C_{T_i}, in equation (2). *A posteriori* examination with ANOVA confirmed the absence of significant time-of-year or between-trip effects after standardization.

Since one objective was to evaluate whether an increase in mesh size would reduce bycatch of submarket size, mostly juvenile, *Loligo* squid, butterfish, silver hake, and spiny dogfish, each species was binned based on size classes of interest. Catch of *Loligo* in numbers was binned into the following market categories: <10 cm (small), 10-13 cm (medium), and ≥13 cm (large). Dealers emphasized a desire to eliminate <10 cm squid and to retain without loss, squid ≥13 cm. The medium category represented the critical size range where some codend mesh selectivity was anticipated to reduce capture of squid <10 cm in size, but in which a large reduction in catch was not desired. Butterfish catch in numbers was binned into small (<12 cm) and large (≥12 cm) categories based on the size at 50% maturity (Cross et al., 1999; Penttila et al., 1989). Catch of silver hake in numbers was binned into small (<12 cm) and large (≥12 cm) categories, which correspond to fish age 1 and older (Penttila et al., 1989). Male and female spiny dogfish catches in numbers were binned into pups (<36 cm) and adults (≥36 cm) (Rago et al., 1998). These values were scaled to the global median as defined in equation (2).

Because vessels fished in parallel, the difference in the standardized catch weight, $Diff$ ($= \Delta C_{STD}$ in equation (3)), between simultaneous tows was calculated for the four pairwise net configurations (A_1A_2, B_1A_2, B_1B_2, and A_1B_2):

$$Diff_{AA\ or\ BB} = C_{A_1} - C_{A_2}\ or\ C_{B_1} - C_{B_2} \tag{4}$$

$$Diff_{AB\ or\ BA} = C_{A_1} - C_{B_2}\ or\ C_{A_2} - C_{B_1} \tag{5}$$

where $Diff_{AA\,or\,BB}$ is the difference in standardized species' catch weight (kg tow^{-1}) for a given paired tow in which both vessels towed the same codend and $Diff_{AB\,or\,BA}$ is the difference in standardized species' catch weight (kg tow^{-1}) for a given paired tow in which the one vessel towed the control codend and the

other towed the experimental codend. C_{A_1} and C_{A_2} are the standardized species' catch weights as defined in equation (2) for a given paired tow on vessels 1 and 2, respectively, using the standard codend (A). C_{B_1} and C_{B_2} are the standardized species' catch weights as defined in equation (2) for a given paired tow on vessels 1 and 2, respectively, using the experimental codend (B). Equation (4) was employed under the expectation that the two vessels would operate equivalently when fishing the same codend mesh size. Equation (5) was employed under the expectation that catch would decline with the 2.5″ codend; thus B was always subtracted from A. Null hypotheses formulated with paired tows AA and BB were two-tailed. Null hypotheses formulated with paired tows AB and BA were one-tailed. The equivalent method was used to calculate differences in the numbers of individuals caught of that species by replacing each occurrence of catch weight for catch in numbers in equations (4 and 5). In addition, the total catch weight per tow and total catch minus *Loligo* catch per tow, respectively, were substituted for catch weight per tow in equation (4 and 5).

Due to the variability in catch between tows, non-parametric statistics were emphasized (Sokal and Rohlf, 1998; Daniel, 1978; Conover, 1980). Three basic types of statistical tests were used. The differential performance of the two vessels using the same gear was evaluated by ranked ANOVA, the differences between vessel catches [equation (2)] being ranked prior to the test. The null hypothesis was that the differential in catch between the two vessels fishing the same codend was not different, regardless of the codend simultaneously fished. Any bias in performance between the two vessels for either of the two codends would generate a significant difference in this test. We extended this test to consider AB tows. In this case, we expected the differential in catch to be unbiased regardless of which vessel towed the 2.5″ mesh codend. To identify cruise effects on catch statistics, a cruise main effect was included in this ANOVA. The cruise main effect includes a set of confounding variables including location, time-of-year, and the change in the second vessel between the spring and fall field programs. Ranked dependent catch variables included the species' catch weight, the number of individuals caught by species, the difference in standardized species' catch weight per paired tow, the difference in standardized number of individuals caught per paired tow per species and size class, the difference in total catch weight per paired tow, and the difference

in total catch weight minus *Loligo* catch weight per paired tow.

The second statistic tested the null hypothesis that the difference between the catches in a paired tow did not differ from zero. A two-tailed Wilcoxon Signed-rank test was chosen as the primary statistical tool to evaluate whether differences in species' catch weight between simultaneous tows using the same codend type (AA and BB) varied significantly from zero (Conover, 1980). Thus, we expected performance on the two vessels with the two codends to be unbiased and, furthermore, we expected that both vessels' catch would be equivalent if the same codend mesh size was towed.

The third test compared catches between paired tows with different codends (AB or BA). The null hypothesis was that there was no difference in catch against the alternative hypothesis that the 2.5″ codend caught fewer fish. A one-tailed Wilcoxon Signed-rank test was used for this analysis.

In addition, the binomial test (Conover, 1980) was used to evaluate a possible bias caused by a variable distribution in tow time or tow depth between tows with the two codend mesh configurations. *A posteriori* Tukey's Studentized Range tests were used to identify the location of significant differences within ranked ANOVAs. Unless otherwise noted, all tests were conducted at the $\alpha = 0.05$ significance level.

A posteriori power analyses were used to examine the power of the statistical tests comparing differences between codends. These analyses determined the likelihood of rejecting a null hypothesis when the alternative hypothesis was correct. In other words, given the variability in the catch data, what was the probability that the test would detect an effect given that the effect truly exists (Thomas and Krebs, 1997)? All power analyses were *a posterior*. In each case, the effect size was calculated *a posterior* from the data and the power of the test was calculated for the significance level observed in the test. For the ANOVAs, power analysis followed Faul et al. (in press) with Cohen's f used for effect size (Cohen, 1988). Values are presented as $1-\beta$ for $\alpha \leq 0.05$ and as β for $\alpha > 0.05$. For the Wilcoxon Signed-rank test, power analysis was conducted for the less conservative sign test (Faul et al, in press) and, therefore, values of β or $1-\beta$ provided are conservative. Cohen's effect size g was used as a measure of effect size (Cohen, 1988).

Size-frequency distributions were compared with ANOVA by first computing descriptive variables for each species for each tow. These dependent variables were: mean size, the percentiles of size (25th, 50th, 75th), the interquartile range, and the range. Independent variables included codend mesh size, cruise, and the interaction term. Dependent variables were ranked prior to analysis. For some tests, total catch was included as a covariate.

Results

Descriptive Statistics

A total of eighty tows (40 paired tows) were successfully completed during four cruises, half of which took place during February 26-27 and March 30-April 1, 2005 and the other half of which occurred during December 12-14, and December 21-22, 2005 (Table 2). Thus, the dataset consisted of four cruises at three distinctly different times of year. Tows occurred on the offshore *Loligo* fishing grounds between Spencer and Baltimore Canyons (Figure 1). On average, tow times varied from 1.24-2.39 h and were longest during Trip 2 because more daylight hours were available during that trip (Table 2, Figure 2). Mean depth ranged from 142-202 m. The deepest tows occurred during Trip 4. Mean tow speeds fell within 10% of the target tow speed of 5.56 km h^{-1} and Vessel III tended to tow at a slightly slower rate than Vessels I and II. Average scope, which is the amount of wire paid out (m) divided by the depth (m), ranged from 2.26-3.56. Bottom temperatures were fairly constant despite the fact that trips occurred at different times and depths during the year and ranged from 11.2-12.3°C (Table 2). These average tow characteristics and their variability are typical of standard *Loligo* fishing operations with the exception that tow times may be biased low.

The four cruises occurred during three distinctly different times of year and therefore, by necessity, each cruise had preferred depths and tow times that were unique (Figure 2). Trip 1 was characterized by intermediate tow times and tow depths in comparison to the other trips. Tows were longest during Trip 2 and depths tended to be shallower. Trip 3 had the most variable tow times and depths but, in general, both fell intermediate in comparison to other trips. Trip 4, which notably occurred during the winter solstice when daylight is at its minimum in the

Table 2. Description of trips and tows.

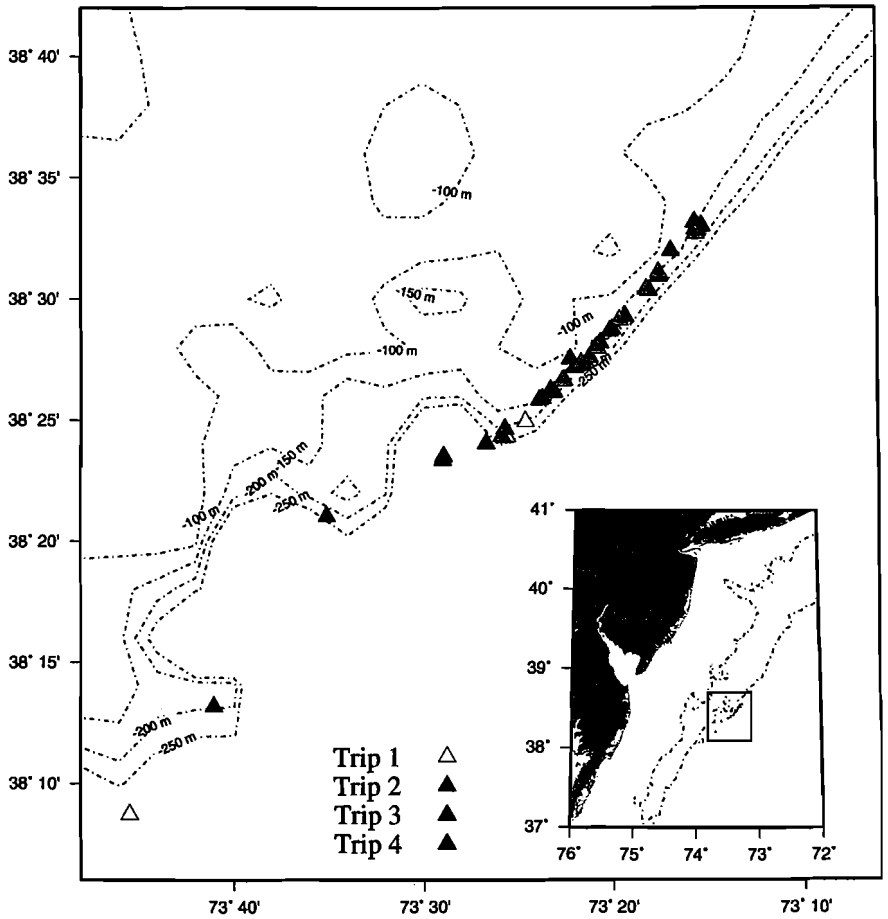
	Number of tows	Tow time (h)	Depth (m)	Tow speed (km h^{-1})	Scope	Bottom temperature (°C)	Total Catch (kg)
Trip 1: 26-27 Feb							
Vessel I	8	1.49	162.8	5.15	3.06	12.1	3209.4
Vessel II	8	1.50	166.2	5.16	2.99	11.9	3701.4
Trip 2: 30 Mar-1 Apr							
Vessel I	12	2.39	147.9	5.27	3.39	11.2	1775.9
Vessel II	12	2.35	142.4	5.20	3.56	11.4	1662.3
Trip 3: 12-14 Dec							
Vessel I	11	1.69	173.9	5.17	2.88	11.8	2014.8
Vessel III	11	1.70	145.9	5.09	3.43	12.3	1412.5
Trip 4: 21-22 Dec							
Vessel I	9	1.24	174.6	5.16	2.69	11.8	2161.8
Vessel III	9	1.29	202.4	5.00	2.26	11.9	1652.6

northern hemisphere, was characterized by the shortest and deepest tows (Figure 2). Of eighty tows, only four outliers were apparent: two long tow times during Trip 1, one short tow time occurred during Trip 2, and one unusually shallow tow occurred during Trip 4 (Figure 2). This incidence of outliers is not unusual (Bros and Cowell, 1987). These outliers were considered part of the normal variability associated with *Loligo* fishing trips and were retained for statistical analysis.

Total catch (kg) tended to increase with tow time (Figure 3). Spearman's ρ was positive for all cruises. In general, all four cruises had a substantial amount of variability associated with total catch. Although tow times averaged more than one hour longer during Trip 4 than during Trip 2, with Trips 1 and 3 falling in between, the range of total catches observed during all trips was similar (Figure 3). Spearman's Rank Correlation revealed that total catch weight increased significantly with tow time only for Trips 1 and 4, however ($\alpha = 0.05$). Comparison to other catches showed that the two long and one short outlier tow times were not associated with unusually large or small catches, respectively.

The influence of a positive correlation between tow times and total catch coupled with the fact that, in the Mid-Atlantic, offshore depth gradients are steep

Figure 1. Map of the Mid-Atlantic Bight between Spencer Canyon and Baltimore Canyon showing the locations of tows taken in this study. Depth in m.



so that vessels potentially might have fished simultaneously at different depths, necessitated that tow times and tow depths be unbiased with respect to codend fished. In other words, half of the tow times and depths in each codend fished on each cruise should fall above the median tow time and depth for that cruise. Tow times and depths were found to be homogeneously distributed above and below the trip median tow time and depth for the two codend configurations on each vessel (Binomial test, $\alpha = 0.05$). Thus, tow times and depths did not bias subsequent codend comparisons and the variability is retained as part of the variance in the data without further correction. Differences in tow times and depths between cruises were considered part of the overall cruise effect, as discussed hereafter (Figures 2-3).

Figure 2. Plot of tow depth (m) versus tow time (h). Control tows are represented by solid symbols and experimental tows are represented by open symbols.

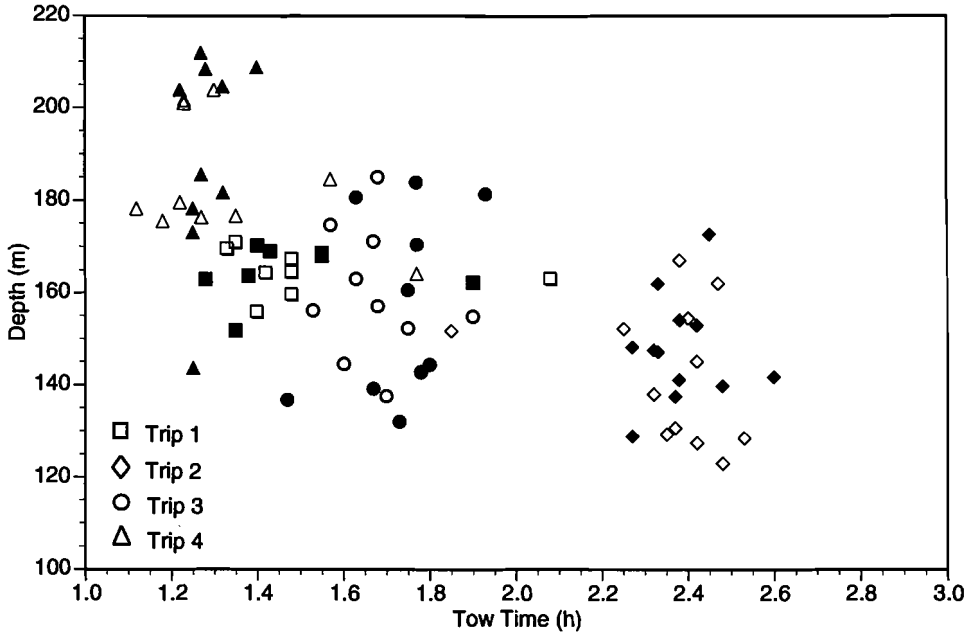


Figure 3. Plot of total catch (kg) versus tow time (h) for tows using the 1.875″ mesh codend.

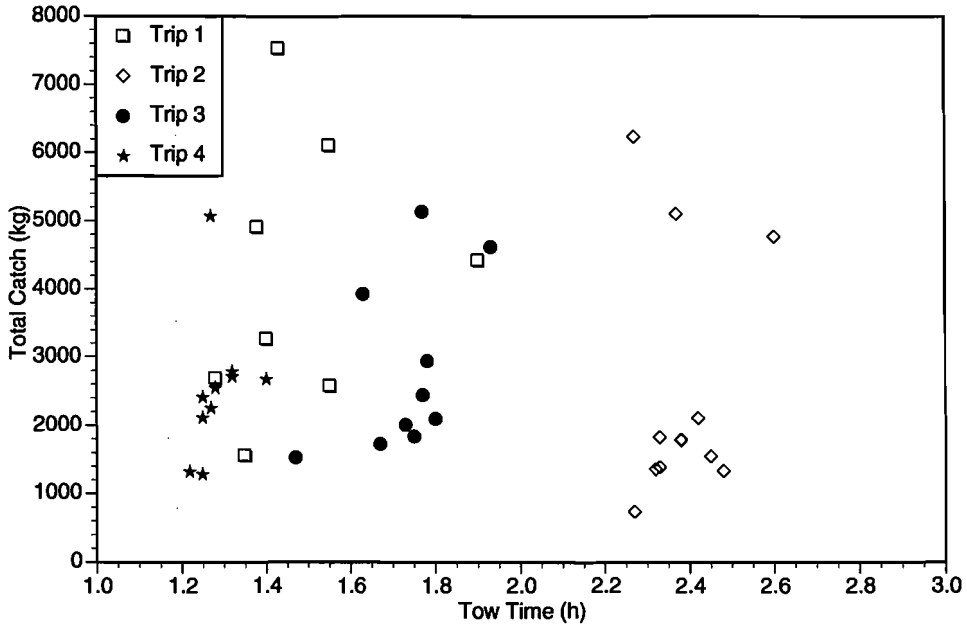


Table 3. The median catch weight per tow and median number caught per tow for selected species using the 1.875″ control codend.

Species	Trip 1	Trip 2	Trip 3	Trip 4
Catch Weight (kg)				
Loligo squid	2,752.95	1,581.10	1,746.35	2,154.75
Butterfish	10.00	117.15	0.65	0.75
Silver Hake	3.25	48.90	2.80	2.95
Female Spiny Dogfish	2.25	0.00	2.00	5.80
Male Spiny Dogfish	1.75	0.00	19.05	74.95
Numbers Caught				
Loligo squid	44,409.00	20,621.00	37,830.50	20,647.00
Butterfish	178.00	1,753.50	8.50	7.00
Silver Hake	29.00	466.00	20.00	18.50
Female Spiny Dogfish	3.00	0.00	1.00	7.00
Male Spiny Dogfish	2.00	0.00	14.50	55.00

Cruise effects on catch weight and number in paired tows

Four species of commercial importance were caught with sufficient frequency for full analysis: *Loligo* squid, butterfish, silver hake, and female and male spiny dogfish. Time-of-year and location, plus the change in vessels between the February-April and December cruises perforce were confounding factors. Median catch in weight and numbers varied considerably over the cruises for *Loligo* squid and butterfish, and less so for silver hake and male and female spiny dogfish (Tables 3 and 4). One cruise was associated with unusually high catches of silver hake (Trip 2) and male spiny dogfish (Trip 4) in comparison to the other three. Spiny dogfish, remarkably, were captured at a very low abundance on Trip 2. Catches were not obviously higher in the Spring (Trips 1 and 2) in comparison to the following winter (Trips 3 and 4) for *Loligo*. Catches of butterfish, and to a lesser extent silver hake, were higher in the Spring. The opposite was true for spiny dogfish with higher catches recorded in the following winter. *Loligo* squid comprised a majority of the catch during all trips. As a consequence, to minimize cruise effects, catch weight and numbers caught were scaled to the global median catch for each species. ANOVA analysis of standardized catch confirmed the anticipated absence of significant differences in species-catch between cruises after standardization (ranked ANOVA, $\alpha = 0.05$).

Table 4. The median catch weight per tow and median number caught per tow for selected species using the 2.5″ experimental codend.

Species	Trip 1	Trip 2	Trip 3	Trip 4
Catch Weight (kg)				
Loligo squid	1,851.90	323.50	370.50	548.55
Butterfish	68.70	28.90	0.40	1.10
Silver Hake	.55	17.50	10.60	6.40
Female Spiny Dogfish	7.95	.65	4.05	3.80
Male Spiny Dogfish	3.45	1.35	19.20	131.15
Numbers Caught				
Loligo squid	28,268.00	3,555.50	5,381.00	4,999.00
Butterfish	1,035.00	594.00	7.50	8.00
Silver Hake	4.00	126.50	17.50	38.50
Female Spiny Dogfish	13.50	1.00	3.00	4.00
Male Spiny Dogfish	7.00	1.00	15.00	100.50

Vessel effects on catch weight and number in paired tows

$H_0 : Diff_{A_1A_2} = Diff_{B_1B_2}$

Further analysis of catch weight and number focused on the difference in catch between paired tows. An evaluation of paired tows using the same codend on each vessel (A_1A_2 and B_1B_2) using ranked ANOVAs revealed that the two vessels performed equivalently for *Loligo* squid when both were towing the control codend (AA tows) or the experimental codend (BB tows). In other words, the differential in catch between the two vessels was statistically similar regardless of which codend was towed, AA or BB (ranked ANOVA, $\alpha = 0.05$). This result was confirmed for catch weight, number, and number by size (Tables 5-7). Thus, vessel effects did not influence catch performance for *Loligo* in paired tows.

Relative vessel performance when simultaneously towing control or experimental codends (AA or BB) did not differ significantly for other species either, regardless of species or size class (Tables 5-7). However, despite standardizing catch to the global median, some cruise effects still remained for the differences in catch weights of butterfish and female and male spiny dogfish, and catch numbers for small butterfish and large male spiny dogfish (ranked ANOVA, $\alpha = 0.05$) (Tables 5-7). Tukey's tests showed that Vessel I caught relatively more butterfish than Vessel II in the

Table 5. Results of ranked ANOVA and Wilcoxon Signed-rank tests on the differences in catch weight per paired tow for selected species. Vessel-effect tows were A_1A_2 and B_1B_2 codend combinations. Codend-effect tows were A_1B_2 and A_2B_1 codend combinations. A, control codend; B, experimental codend. β values are provided for non-significant results at α=0.05. $1-\beta$ values are given for significant results and are computed at α=0.05 rather than at the reported probability level. –, not significant at $\alpha = 0.05$.

Variable	*Loligo* squid	Butterfish	Silver Hake	Female Spiny Dogfish	Male Spiny Dogfish	Total Catch	Total Catch minus *Loligo* Catch
Vessel-effect tows							
ANOVA:							
Codend	–	–	–	–	–	–	–
	β =0.786	β =0.857	β =0.562	β =0.942	β =0.943	β =0.802	β =0.948
Cruise	–	P=0.021	–	P=0.028	P=0.004	–	–
	β =0.906	$1-\beta$ =0.939	β =0.742	$1-\beta$ =0.831	$1-\beta$ =0.986	β =0.856	β =0.853
Codend*Cruise	–	P=0.052	–	–	–	–	–
	β =0.226	$1-\beta$ =0.840	β =0.739	β =0.896	β =0.760	β =0.384	β =0.576
Wilcoxon Signed Rank Test:							
AA only	–	–	–	–	–	–	–
	β =0.979	β =0.979	β =0.952	β =0.984	β =0.984	β =0.979	β =0.979
BB only	–	–	–	–	–	–	–
	β =0.952	β =0.851	β =0.851	β =0.984	β =0.984	β =0.952	β =0.979
AA and BB combined	–	–	–	–	–	–	–
	β =0.938	β =0.873	β =0.938	β =0.987	β =0.987	β =0.938	β =0.959
Codend-effect tows							
ANOVA:							
Codend	–	–	–	–	–	P=0.035	P=0.006
	β =0.784	β =0.558	β =0.643	β =0.485	β =0.629	$1-\beta$ =0.799	$1-\beta$ =0.975
Cruise	–	–	–	P=0.013	P=0.040	–	–
	β =0.493	β =0.551	β =0.318	$1-\beta$ =0.876	$1-\beta$ =0.748	β =0.551	β =0.471
Codend*Cruise	–	–	–	–	–	–	–
	β =0.867	β =0.851	β =0.201	β =0.430	β =0.403	β =0.713	β =0.734

February cruise (Trip 1) in comparison to the differential between Vessels I and III in the December cruise (Trip 4) (Tukey's Studentized Range test, $\alpha = 0.05$). For male and female spiny dogfish, Vessel I caught much less dogfish by weight and, for

Table 6. Results of ranked ANOVA and Wilcoxon Signed-rank tests on the differences in numbers caught per paired tow for selected species. Vessel-effect tows were A_1A_2 and B_1B_2 codend combinations. Codend-effect tows were A_1B_2 and A_2B_1 codend combinations. A, control codend; B, experimental codend. β values are provided for non-significant results at α=0.05. $1-\beta$ values are given for significant results and are computed at α=0.05 rather than at the reported probability level. –, not significant at $\alpha = 0.05$. NA, not applicable.

Variable	*Loligo* squid	Butterfish	Silver Hake	Female Spiny Dogfish	Male Spiny Dogfish
Vessel-effect tows					
ANOVA:					
Codend	–	–	–	–	–
	β =0.741	β =0.915	β =0.343	β =0.926	β =0.949
Cruise	–	P=0.035	–	–	P=0.006
	β =0.732	$1-\beta$ =0.893	β =0.658	β =0.664	$1-\beta$ =0.976
Codend*Cruise	P=0.013	–	–	–	–
	$1-\beta$ =0.968	β =0.209	β =0.793	β =0.930	β =0.779
Wilcoxon Signed Rank Test:					
AA only	–	–	–	–	–
	β =0.624	β =0.952	β =0.952	β =0.984	β =0.984
BB only	–	–	–	–	–
	β =0.979	β =0.952	β =0.851	β =0.984	β =0.984
AA and BB combined	–	–	–	–	–
	β =0.754	β =0.959	β =0.938	β =0.987	β =0.987
Codend-effect tows					
ANOVA:					
Codend	–	–	–	P=0.002	–
	β =0.769	β =0.788	β =0.817	$1-\beta$ >0.999	β =0.536
Cruise	–	–	–	–	P=0.017
	β =0.777	β =0.543	β =0.386	β =0.915	$1-\beta$ =0.881
Codend*Cruise	–	–	–	–	–
	β =0.936	β =0.915	β =0.392	β =0.738	β =0.464

males, by number than Vessel II in February (Trip 1) relative to the catch differential observed between Vessels I and III in December (Trip 4). Thus, all significant cruise main effects were caused by differences in catch between the two vessels in

Table 7. Results of ranked ANOVA and Wilcoxon Signed-rank tests on the differences in catch numbers per paired tow for selected size classes of *Loligo* squid. Vessel-effect tows were A_1A_2 and B_1B_2 codend combinations. Codend-effect tows were A_1B_2 and A_2B_1 codend combinations. A, control codend; B, experimental codend. β values are provided for non-significant results at α=0.05. $1-\beta$ values are given for significant results and are computed at α=0.05 rather than at the reported probability level. –, not significant at $\alpha = 0.05$. U, undefined due to small sample size.

Variable	*Loligo* Squid <10 cm	*Loligo* Squid 10-13 cm	*Loligo* Squid >13 cm	Butterfish <12 cm	Butterfish ≥12 cm	Silver Hake ≥12 cm	Female Spiny Dogfish ≥36 cm	Male Spiny Dogfish ≥36 cm
Vessel-effect tows								
ANOVA:								
Codend	–	–	–	–	–	–	–	–
	β =0.790	β >0.661	β =0.936	β =0.939	β =0.949	β =0.343	β =0.891	β =0.916
Cruise	–	–	–	P=0.018	–	–	–	P=0.005
	β =0.665	β >0.644	β =0.765	$1-\beta$ =0.908	β =0.202	β =0.658	β =0.530	$1-\beta$ =0.984
Codend*Cruise	–	–	–	–	P=0.029	–	–	–
	β =0.467	β >0.260	β =0.638	β =0.873	$1-\beta$ =0.913	β =0.793	β =0.922	β =0.744
Wilcoxon Signed Rank Test:								
AA only	–	–	–	–	–	–	–	–
	β =0.979	β >0.851	β =0.952	U	β =0.979	β =0.952	β =0.978	β =0.978
BB only	–	–	–	–	–	–	–	–
	β =0.979	β >0.952	β =0.979	β =0.952	β =0.952	β =0.851	β =0.911	β =0.978
AA and BB combined	–	–	–	P=0.027	–	–	–	–
	β =0.959	β =0.754	β =0.938	$1-\beta$ =0.150	β =0.938	β =0.938	β =0.927	β =0.974
Codend-effect tows								
ANOVA:								
Codend	–	–	P<0.001	–	–	–	–	–
	β =0.727	β >0.793	$1-\beta$ =0.999	β =0.935	β =0.689	β =0.817	β =0.400	β =0.461
Cruise	–	–	–	–	–	–	–	P=0.017
	β =0.871	β >0.785	β =0.669	β =0.329	β =0.542	β =0.386	β =0.904	$1-\beta$ =0.957
Codend*Cruise	–	–	–	–	–	–	–	–
	β =0.664	β >0.695	β =0.739	β =0.950	β =0.908	β =0.392	β =0.940	β =0.340

February relative to other trips and particularly Trip 4 in December. Interestingly, the same two vessels worked during Trip 2 (in late March), but without a similar

differential. One reason for this disparity might be the absence of large dogfish catches during Trip 2. Equivalent differences did not exist between Vessel I and Vessel III that participated in Trips 3 and 4.

$H_0 : Diff_{A_1 A_2} = 0 \; and \; Diff_{B_1 B_2} = 0$

The differential in catch between vessels did not vary when towing the control 1.875″ or experimental codend, but did the vessels catch equivalently? Analysis of the vessel-effect tows in which the same codend was towed by both vessels ($A_1 A_2$ and $B_1 B_2$) indicated that differences in *Loligo* catch, by weight and numbers, when both vessels fished the control codend (AA tows) and when both vessels fished the experimental codend (BB tows) did not differ significantly from zero (Wilcoxon Signed-rank test, $\alpha = 0.05$) (Tables 5 and 6). The same was true in the analysis of small, medium, and large squid. Overall, only small butterfish offered a minor exception and the power of this test was low (Table 7). Accordingly, performance of the vessels during vessel-effect tows using the control codend was equivalent (Table 7), as was the performance using during vessel-effect tows using the experimental codend. Thus, the two vessels performed with equivalent bias when simultaneously towing the control and experimental codends.

$H_0 : Diff_{A_1 B_2} = Diff_{A_2 B_1}$

The experimental codend was anticipated to catch differentially from the control codend, but did that difference depend on the vessel towing the experimental codend? An evaluation of paired tows using different codends on each vessel ($A_1 B_2$ and $A_2 B_1$) using ranked ANOVAs revealed that the relationship in catch between codends was equivalent regardless of which vessel towed the experimental codend and which vessel towed the control codend. The relationship in catch between the $A_1 B_2$ tows and $A_2 B_1$ tows did not differ significantly for squid catch, in weight or by numbers (ranked ANOVA, $\alpha = 0.05$) (Tables 5 and 6). Because this was true, combining the $A_1 B_2$ tows and the $A_2 B_1$ tows in some subsequent tests was justified.

The same result was obtained for other species by weight and number. The cruise effects for female and male spiny dogfish catch weight and large male spiny dogfish catch in numbers remained in the comparison of codend-effect tows in which one vessel towed the experimental codend and the other the control codend (AB

and BA), however (Tables 5-7). These were consistent vessel-to-vessel differences in performance. Further analysis indicated that these significant cruise effects resulted from the February cruise, during which time Vessel II consistently caught more male spiny dogfish than Vessel I (75% of the codend-effect hauls on Vessel I caught no male spiny dogfish).

The only exception to this trend was that total catch tended to be higher when Vessel I towed the control codend (Table 5). This result was not corroborated by the trend in squid catch that dominated total catch and the statistical result was more significant when *Loligo* was removed from total catch (Table 5). Thus, the trend is primarily a function of total bycatch. This differential occurred because Vessel I catches averaged higher than Vessel III catches on both December cruises. The differential was not sufficient to influence squid catch or the catch of analyzed bycatch species. This was the only observed vessel-to-vessel difference between Vessels I and III.

Effect of control codend on catch weight and number in paired tows.

$H_0 : Diff_{A_1B_2} = 0 \text{ and } Diff_{A_2B_1} = 0$

Analysis of the experimental tows (A_1B_2 and A_2B_1 codend configurations), revealed that significantly less *Loligo* squid was caught by the larger mesh by both weight and numbers (Wilcoxon Signed-rank test, $\alpha = 0.05$) (Table 8). This was true regardless of which vessel fished the experimental codend (B) (Table 8, Figure 4). Total catch, which was largely a function of *Loligo* catch, was also significantly reduced in the larger-mesh codend. When *Loligo* was removed from the total catch, codend type no longer influenced catch (Table 8).

Analysis of the number of *Loligo* squid caught in the three size classes showed that significantly fewer small- and medium-size individuals were caught by the larger mesh codend, regardless of which vessel towed the experimental codend (Wilcoxon Signed-rank test, $\alpha = 0.05$) (Table 9, Figure 5). The results for large squid (>13 cm) were inconsistent and were significantly reduced by the larger mesh codend only when Vessel I towed the control codend and when the two codend combinations were combined. Thus, large *Loligo* tended to escape capture in the experimental codend but the difference in capture efficiency was small (Table 9, Figure 5). Previous

Table 8. Results of the Wilcoxon Signed-rank tests on the differences in catch weight and numbers per paired codend-effect tow, A_1B_2 and A_2B_1, for selected species. A, control codend; B, experimental codend. β values are provided for non-significant results at α=0.05. $1-\beta$ values are given for significant results and are computed at α=0.05 rather than at the reported probability level. –, not significant at $\alpha = 0.05$. NA, not applicable.

Variable	*Loligo* squid	Butterfish	Silver Hake	Female Spiny Dogfish	Male Spiny Dogfish	Total Catch	Total Catch minus *Loligo* Catch
Catch weight							
AB only	P=0.002 $1-\beta$ =0.736	– β =0.628	P=0.007 $1-\beta$ =0.736	– β =0.912	– β =0.980	P=0.003 $1-\beta$ =0.736	P=0.042 $1-\beta$ =0.736
BA only	P=0.005 $1-\beta$ =0.376	– β =0.954	– β =0.959	P=0.031 $1-\beta$ =0.335	P=0.016 $1-\beta$ >0.999	P=0.005 $1-\beta$ =0.376	– β =0.954
AB and BA combined	P=0.001 $1-\beta$ =0.933	– β =0.879	P=0.054 $1-\beta$ =0.617	– β =0.933	– β =0.603	P<0.001 $1-\beta$ =0.933	– β =0.755
Numbers Caught							
AB only	P=0.002 $1-\beta$ =0.736	– β =0.628	P=0.024 $1-\beta$ =0.736	P=0.016 $1-\beta$ >0.999	– β =0.980	NA	NA
BA only	P=0.001 $1-\beta$ >0.999	– β =0.954	– β =0.959	P=0.031 $1-\beta$ >0.999	P=0.016 $1-\beta$ >0.999	NA	NA
AB and BA combined	P<0.001 $1-\beta$ >0.999	– β =0.879	– β =0.383	– β =0.981	– β =0.603	NA	NA

analyses suggest that the two vessels performed equivalently when towing the two codends; thus, the inconsistent statistical results were likely due to variance in the minor differences in catch between the two codend mesh sizes. For small and medium *Loligo*, the results are unequivocal. Towing the experimental codend resulted in a reduction of both catch weight and numbers of *Loligo* squid (Tables 8 and 9, Figures 4 and 5).

For other species of concern, the experimental codend did not reduce catch weight or catch in numbers significantly, as a rule (Figures 6-9, Tables 8-9). A few exceptions can be noted. Significantly less large silver hake were caught (in weight and numbers) when Vessel I towed the 1.875″ codend (Wilcoxon Signed-rank test, $\alpha = 0.05$) (Tables 8 and 9), but not when Vessel I towed the experimental codend

Figure 4. Box and whisker plot of *Loligo* catch with control (A) and experimental (B) codends on three participating vessels. The box encompasses the interquartile range, with the median as the central line, the mean as the ■ and the whiskers as the range.

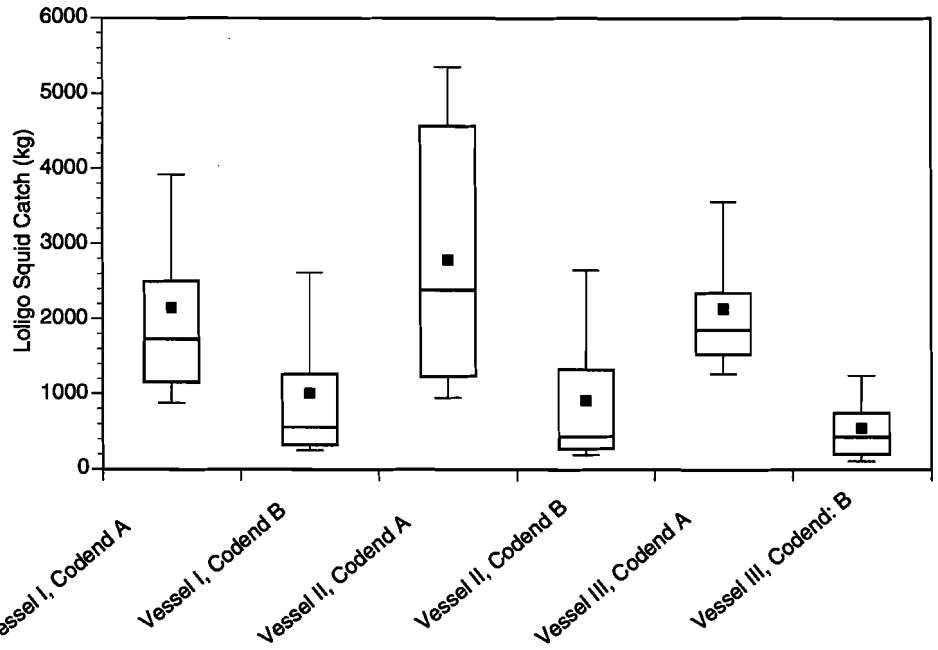
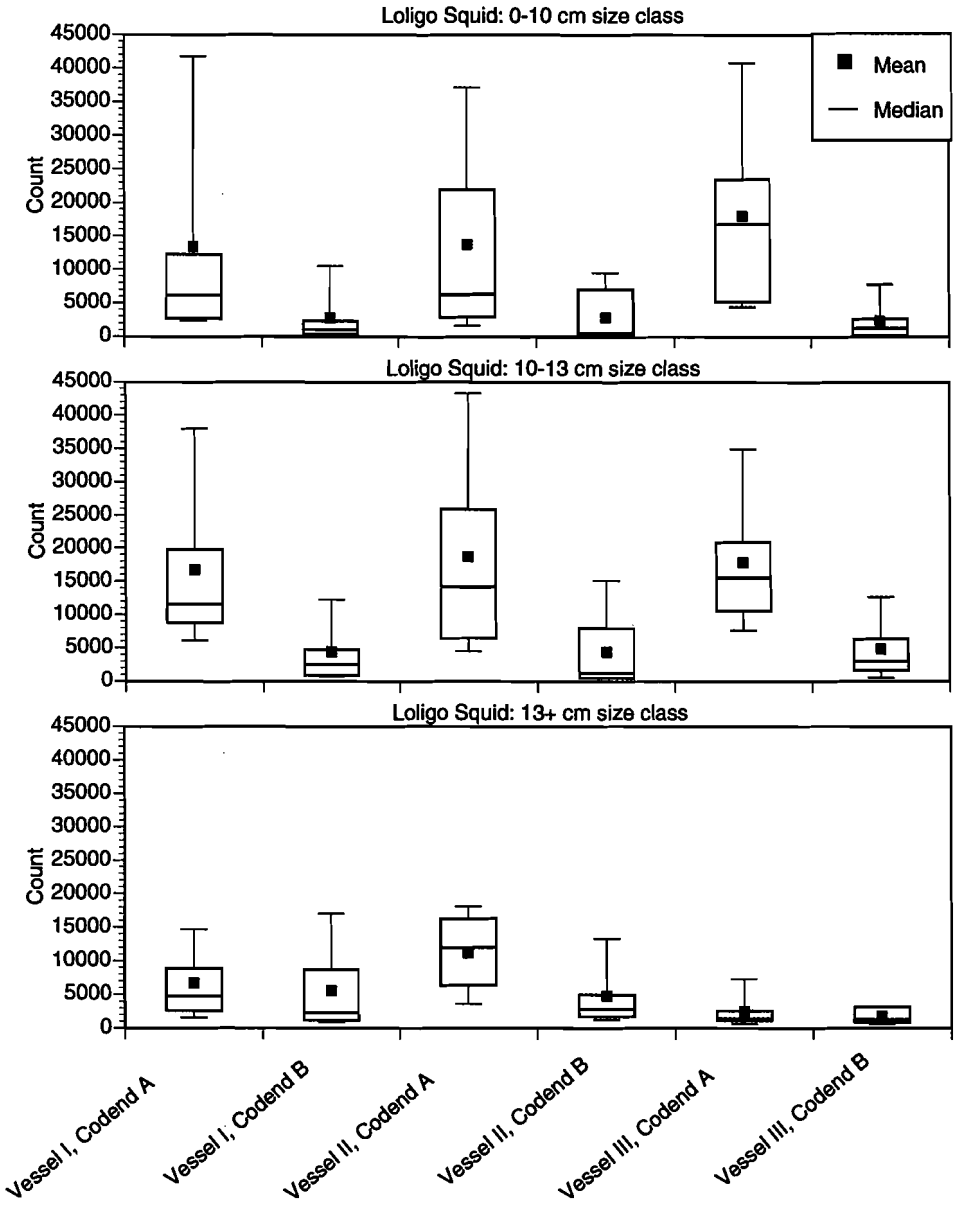


Table 9. Results of Wilcoxon Signed-rank tests on the differences in catch numbers per paired codend-effect tows (A_1B_2 and A_2B_1) for selected size classes of *Loligo* squid, butterfish, silver hake, female and male spiny dogfish. A, control codend; B, experimental codend. β values are provided for non-significant results at α=0.05. $1-\beta$ values are given for significant results and are computed at α=0.05 rather than at the reported probability level. –, not significant at $\alpha = 0.05$.

Variable	*Loligo* Squid <10 cm	*Loligo* Squid 10-13 cm	*Loligo* Squid >13 cm	Butterfish <12 cm	Butterfish ≥12 cm	Silver Hake ≥12 cm	Female Spiny Dogfish ≥36 cm	Male Spiny Dogfish ≥36 cm
AB only	P=0.003	P=0.002	P=0.001	–	–	P=0.024	–	–
	$1-\beta$ =0.736	$1-\beta$ =0.736	$1-\beta$ >0.999	–	β =0.628	$1-\beta$ =0.736	β =0.980	β =0.665
BA only	P=0.019	P=0.001	–	–	–	–	–	P=0.016
	$1-\beta$ =0.736	$1-\beta$ >0.999	β =0.989	–	β =0.954	β =0.959	β =0.001	$1-\beta$ =0.999
AB and BA combined	P<0.001	P<0.001	P=0.027	–	–	–	–	
	$1-\beta$ =0.989	$1-\beta$ >0.999	$1-\beta$ =0.617	β =0.959	β =0.879	β =0.383	β =0.603	β =0.939

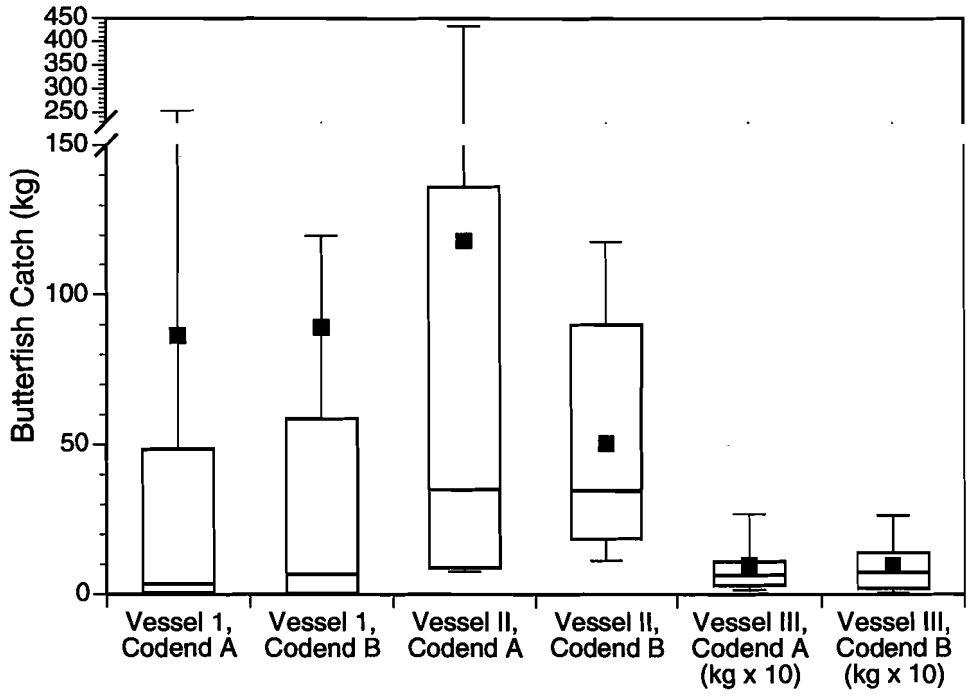
Figure 5. Box and whisker plot of *Loligo* catch broken down by size class with control (A) and experimental (B) codends on three participating vessels. The box encompasses the interquartile range, with the median as the central line, the mean as the ■ and the whiskers as the range.



or when the two codend combinations were tested simultaneously. The catch weight and numbers of male spiny dogfish were significantly lower when Vessel I towed the experimental codend (Tables 8 and 9), whereas the same was true for the number of

female spiny dogfish captured only when Vessel I towed the control codend (Table 8). These latter results were products of the lower spiny dogfish catches on Vessel I during Trip 1 (February), regardless of codend towed.

Figure 6. Box and whisker plot of butterfish catch with control (A) and experimental (B) codends on three participating vessels. The box encompasses the interquartile range, with the median as the central line, the mean as the ■ and the whiskers as the range.

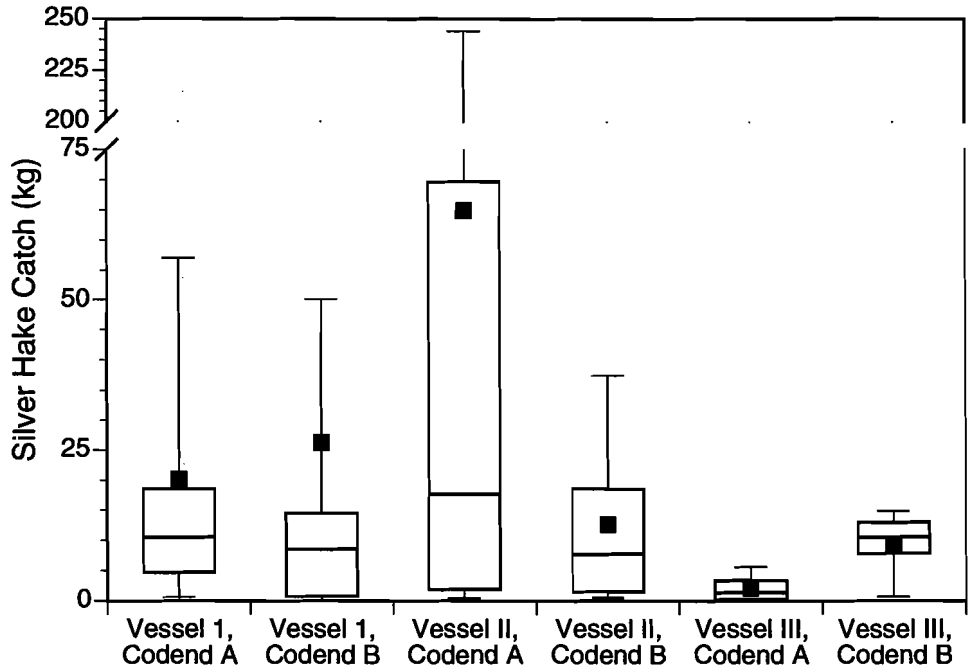


Changes in size-frequencies

An increase in escapement of smaller squid and finfish, while retaining market-sized squid and larger finfish, was anticipated with the larger experimental codend and confirmed in previous analyses. Thus, size-frequency distributions were expected to shift toward larger size classes in tows using the experimental codend. Enough data were present to evaluate the size-frequencies of *Loligo* squid, butterfish, silver hake, and male and female spiny dogfish (Table 10).

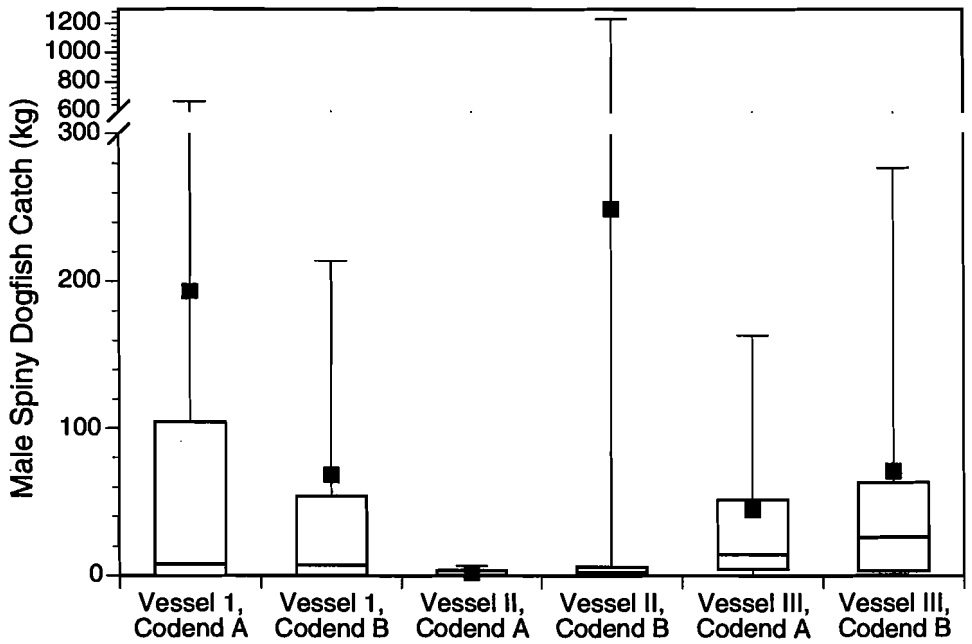
As expected, the percentiles (25th, 50th, and 75th), mean size, and the

Figure 7. Box and whisker plot of silver hake catch with control (A) and experimental (B) codends on three participating vessels. The box encompasses the interquartile range, with the median as the central line, the mean as the ■ and the whiskers as the range.



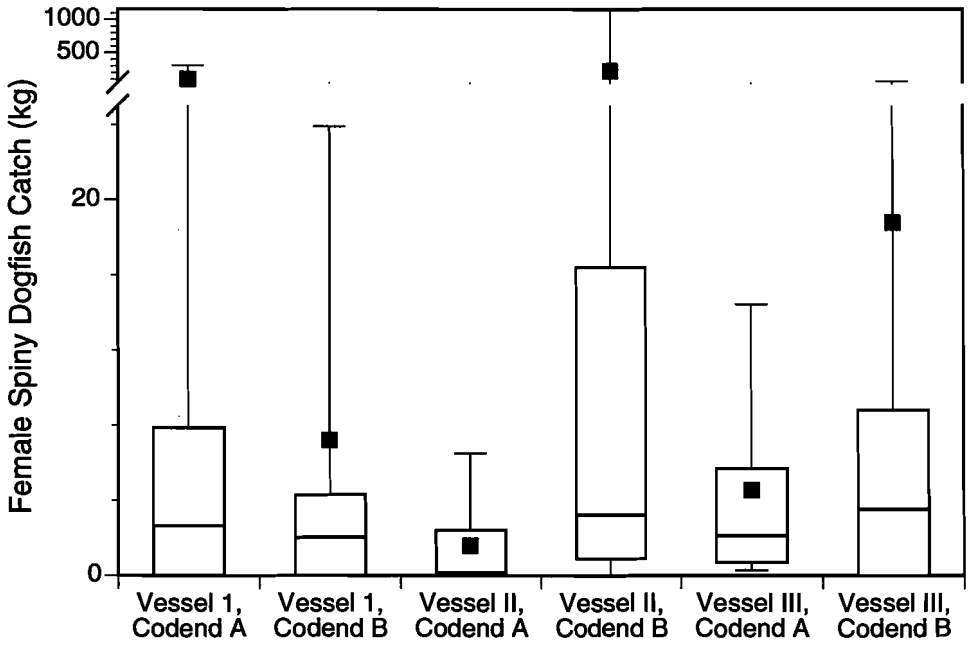
interquartile range and range of *Loligo* squid were significantly larger in tows using the experimental codend in comparison to tows using the control 1.875″ codend (ranked ANOVA, $\alpha = 0.05$) (Tables 10 and 11). A significant cruise effect was also present in all cases (Table 10). The size of fish available to the trawl changed from one cruise to another as would be anticipated by the dynamic nature of these species on the outer shelf (Colvocoresses and Musick, 1983; Shephard and Terceiro, 1994; Jenson, 1965; Murawski, 1993). Cruise effects also were significant in all analyses of the 25th, 50th, and 75th percentiles and mean size for all bycatch species, with the exception of female spiny dogfish (Table 10). Cruise effects were also found for the interquartile range and range for silver hake and butterfish size distributions (Table 10); however, for no bycatch species were the control and experimental codends significantly different for any size metric, percentile, mean, interquartile range, or range.

Figure 8. Box and whisker plot of male spiny dogfish catch with control (A) and experimental (B) codends on three participating vessels. The box encompasses the interquartile range, with the median as the central line, the mean as the ■ and the whiskers as the range.



Total catch may influence the size-frequency distribution of species because fuller nets may limit the release of smaller-sized individuals. Total catch exerted a significant influence on size class in two species, *Loligo* squid and silver hake (Table 10). In particular the results for *Loligo* squid are ambiguous because *Loligo* squid contributed the bulk of the catch and larger catches may simply be associated with the availability of smaller-sized squid. The cruise and codend main effects for *Loligo* squid related in Table 10 did not materially change if total catch was included as a covariate or not; therefore, the ambiguity did not compromise other inferences obtained from the statistical analysis. Silver hake never contributed materially to total catch; nevertheless, larger catches of smaller silver hake were associated with larger total catches. The weak relationship was driven by a tendency for a few tows yielding larger percentile sizes to be associated with tows with lower total catches (Figure 10).

Figure 9. Box and whisker plot of female spiny dogfish catch with control (A) and experimental (B) codends on three participating vessels. The box encompasses the interquartile range, with the median as the central line, the mean as the ■ and the whiskers as the range.



Statistical Power

We evaluated the confidence in the statistical results by calculating values of β or $1 - \beta$ after Cohen (1988). For non-significant results, β routinely fell above 0.70. Exceptions exist and these are reported in Tables 5-9; however, in most cases acceptance of the null hypothesis was associated with a satisfactory degree of confidence. For significant results, $1 - \beta$ values routinely fell above 0.75 and frequently exceeded 0.90 (Tables 5-9). Thus, the likelihood of incorrectly falsifying a null hypothesis was low for nearly all of the reported significant effects.

Discussion

The small-mesh fisheries of the Mid-Atlantic Bight are particularly troublesome due to the perception, and often the reality, that these fisheries are responsible for substantial discarding of juvenile fish (Kennelly, 1999; Powell et al., 2004;

Table 10. Results of ranked ANOVA on the size-frequency parameters for selected species. Codend is A or B. –, not significant at $\alpha = 0.05$.

Variable	25th Percentile	50th Percentile	75th Percentile	Mean Size	Interquartile Range	Range
Loligo squid						
Codend	P=0.031	P=0.0002	P<0.0001	P<0.0001	P=0.0014	P=0.0003
Cruise	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001
Codend*Cruise	–	–	–	–	–	–
Total catch	P=0.003	P=0.016	P=0.0068	P=0.019	–	–
Butterfish						
Codend	–	–	–	–	–	–
Cruise	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P=0.095	P<0.0001
Codend*Cruise	–	–	–	–	–	–
Total catch	–	–	–	–	–	–
Silver Hake						
Codend	–	–	–	–	–	–
Cruise	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P=0.0011	P=0.04
Codend*Cruise	–	–	–	–	–	–
Total catch	P=0.014	P=0.0003	P=0.0056	P=0.0012	–	–
Female Spiny Dogfish						
Codend	–	–	–	–	–	–
Cruise	–	–	–	–	–	–
Codend*Cruise	–	–	–	–	–	–
Total catch	–	–	–	–	–	–
Male Spiny Dogfish						
Codend	–	–	–	–	–	–
Cruise	P<0.0001	P=0.002	P=0.0025	P=0.0009	–	–
Codend*Cruise	–	–	–	–	P=0.014	–
Total catch	–	–	–	–	–	–

Hendrickson, 2005). A small-mesh codend is a necessary design feature of nets used for the capture of squid because of their marketable size range (e.g., Lange, 1980; Hastie, 1996). Nevertheless, management of codend mesh size has not been vigorously pursued as a mechanism to address discarding, even of juvenile squid (Powell et al., 2004; Hendrickson, 2005). Recent concerns about the influence of the *Loligo* fishery on butterfish discard mortality and the desire on the part of dealers to reduce the volume of submarket-size squid landed jointly led to the evaluation of mesh-size selectivity in this fishery.

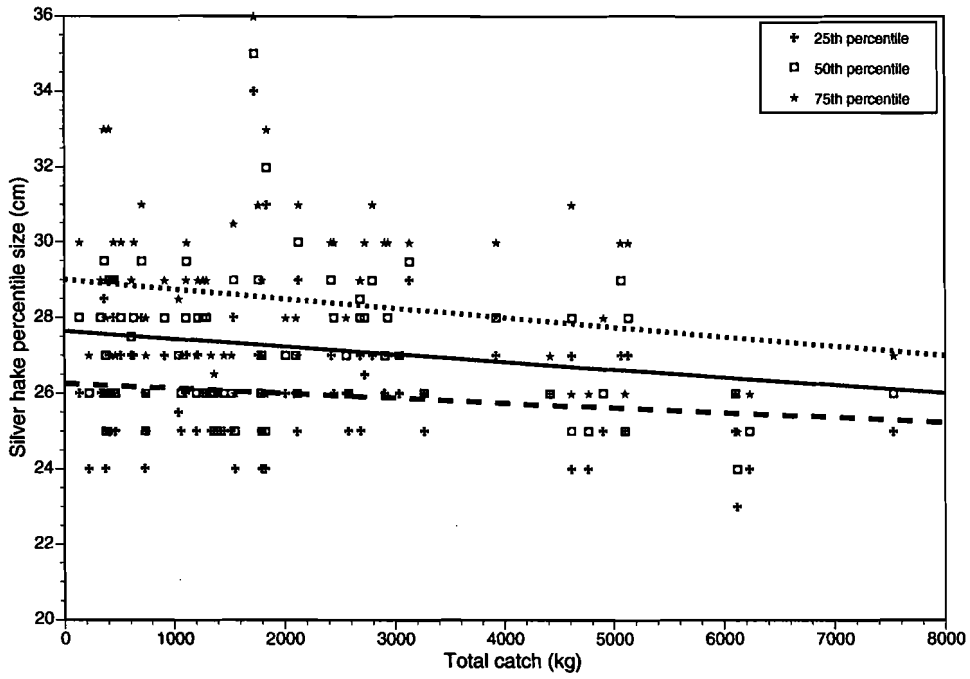
Table 11. Summary of mean, percentiles, interquartile range, and range of the size-frequency distributions (in cm) for *Loligo* squid, butterfish, silver hake, and female and male spiny dogfish caught in each codend.

	25th Percentile	50th Percentile	75th Percentile	Mean Size	Interquartile Range	Range
Loligo squid						
Control Codend	10.00	11.00	13.00	11.58	3.00	12.00
Experimental Codend	11.00	13.00	15.00	13.25	4.00	14.00
Butterfish						
Control Codend	14.00	15.00	15.00	14.81	2.00	7.00
Experimental Codend	14.00	15.00	16.00	14.98	2.00	7.00
Silver Hake						
Control Codend	26.00	27.00	28.00	27.00	2.00	8.00
Experimental Codend	26.00	27.00	29.00	27.63	3.00	10.00
Female Spiny Dogfish						
Control Codend	57.50	60.50	63.00	61.49	5.00	13.00
Experimental Codend	60.00	64.00	70.00	65.00	8.00	14.00
Male Spiny Dogfish						
Control Codend	69.00	72.00	74.50	71.14	5.00	19.00
Experimental Codend	69.00	72.00	74.00	71.00	6.00	19.00

Net selectivity studies vary widely in the number of replicate tows (e.g., Ragonese et al., 2001, 2002; Kynoch et al., 2004; Millar et al., 2004). Generally, tow-to-tow variability in catches is large. Luckily, large differences are also desired outcomes, as the introduction of net regulations resulting in small changes in catchability are not economically desirable and produce little advantage in sustainability of the stock. Accordingly, this study fielded a large number of tows to provide an adequate database. Power analysis indicates that the number of tows resulted in unambiguous results with little probability of incorrectly accepting or falsifying a null hypothesis in nearly all statistical tests.

The design of the experiment included two critical components for subsequent use in management. First, the tows were of commercial scale and used commercial fishing practices. The only compromise made was the restriction of tow lengths to <3 hr to permit minimally four tows per day and the restriction in the range of net designs used to millionaire nets. Second, the study explicitly included field

Figure 10. The relationship between total catch and the percentiles of size for silver hake. Dashed line, the linear relationship for the 25th percentile of size with total catch; solid line, the 50th percentile; dotted line, the 75th percentile.



programs covering a range of fishing seasons and used multiple vessels. These choices interposed a number of issues of potential bias into the analysis, however. The first potential bias was the possibility that tows with experimental or control codends might be biased by depth or tow time. Statistical evaluation revealed no such biases. The second was the reality that fishing in different locations and times, as fishermen do, introduced large variations in median catch size between field programs and substantively influenced the volume and species proportions of bycatch (Murawski, 1996). These differences were adequately resolved by standardizing catches between field programs, as subsequent statistical analyses demonstrated.

The second component of design was the decision to use paired tows (Powell et al., 2004; Hendrickson, 2005). The purpose was to provide as unbiased an evaluation of vessel effects as possible while maintaining a commercial-scale test. In order for net regulations to be successful, the regulation must be effective over

a range of vessels, fishing at least somewhat differently. Powell et al. (2004) describe one such instance where vessel effects resulted in widely different results, in some cases undesirable, in comparison to regulatory goals. Thus, identification of potential vessel-to-vessel differences in performance is an important component of evaluating the potential for a change in codend mesh size in management of a fishery. This concern is specific to the goal of evaluating a mesh size change in the fishery and recognizes that commercial scale catches often influence the dynamics of gear selectivity (Graham et al., 2004) and that different vessels may influence fish behavior and catchability differentially (Handegard and Tjøstheim, 2005).

Vessel effects were limited in this study. Detailed evaluation of the relative performance of control and experimental nets revealed no significant differences in performance for the target species, *Loligo pealei*. We examined the relative catchability between the two vessels with paired vessels towing each codend design simultaneously. We also examined the absolute differences in catch between vessels with paired vessels towing each codend design simultaneously. Finally, we examined the relative catchability between the two vessels with paired vessels towing the two different codend designs simultaneously. In none of these cases were vessel effects identified, with two exceptions. For butterfish, and much more strongly for dogfish, catches varied between Vessel I and Vessel II in February (Trip 1), the first field effort. In the most interesting case, Vessel I avoided the capture of dogfish nearly totally, in comparison to Vessel II, during the February field program. We can offer no explanation for this happenstance.

Three bycatch species were caught commonly enough and were of sufficient importance in management to be rigorously quantitated. The bycatch-to-target species ratio, by catch weight, for these species were: butterfish, 0.0029; silver hake, 0.005; female dogfish, 0.050; and male dogfish, 0.017. These ratios are based on the total catch for all four cruises restricted to tows with the present legal-size mesh control codend. The four cruises cover months representative of the winter *Loligo* fishery and took place in areas typically fished by the fleet at these times. The field programs, therefore, were likely to have been representative of the 2005 fishery in the Mid-Atlantic Bight off the coast of New Jersey. The ratios are remarkably lower than what might be expected from previous discard estimates (e.g., Kennelly,

1999; Powell et al., 2004). The representativeness of the present data cannot be unequivocally demonstrated; however, the times, locations, vessel sizes, and gear used are not obviously outside the norm. These low bycatch-to-target species ratios suggest that the *Loligo* fishery can be prosecuted much more cleanly than previous discard estimates would indicate to be the case. Powell et al. (2004) presented analogous results, also from the winter fishery in the Mid-Atlantic region. These two studies suggest that a more focused program evaluating case histories of high and low discarding in *Loligo*-targeted tows might provide guidance as to changes in fishing practice (e.g., Andrew and Pepperell, 1992) that might significantly reduce discarding in this small-mesh fishery.

As a consequence of the absence of vessel effects, catch of *Loligo* could be unambiguously evaluated. The larger mesh codend, 2.5″, resulted in much reduced capture of squid, by weight and number, and this difference was dominated by a reduction in the catch of squid <13 cm in size. Among these squid is a size range desired for landing, namely the squid 10-13 cm in size. Catch of larger squid was reduced somewhat, but the differences were small, and of limited statistical significance. In comparison to squid, the experimental 2.5″ codend did not differ significantly from the control codend in catch, by weight or number, for any other investigated species, including silver hake, dogfish, and butterfish, even if statistical analysis was limited to the smaller size fractions. Thus, of the species and size classes desired for discard reduction, the goal of discard reduction was achieved only for small squid <10 cm. Of note is the fact that vessel effects, by chance, impacted only species without reduced catchability in the codend mesh comparisons and did not influence relative vessel performance with the two nets. Accordingly, although extant in the data set, vessel effects exerted little influence on the outcome of statistical analyses pertinent to the primary purpose of the study.

Considerable effort was expended in evaluating the differential in vessel performance to assure that vessel effects did not compromise interpretation of catch differences between codend mesh sizes. Fully one half of the tows compared the same codend simultaneously fished. These tows resolved vessel effects, particularly for spiny dogfish catch efficiency, and demonstrated equivalent performance for *Loligo* squid among vessels for both codend mesh sizes. Furthermore, the number of tows

yielded adequate power as $1 - \beta$ values for significant results routinely exceeded 0.75 and often 0.90 and β values for non-significant results seldom fell below 0.70.

The largest and most consistent vessel effect was a differential in capture of spiny dogfish. This differential was apparent by catch weight regardless of the test, but results by number were inconsistent. For spiny dogfish catch weight, a single set of comparative tows between A_1B_2 and A_2B_1, for example, would have yielded this information and all AA and BB tows could have been foregone. Information by number, and for butterfish by weight and number, regarding vessel effects would have been lost or misinterpreted however, as the differences were less consistent. Whether this knowledge adequately repaid the extra effort, a full doubling of the number of tows, is unclear. However, investigation into the most cost effective way to evaluate vessel effects would seem to be a noteworthy fiscal goal.

Increasing codend mesh size is a frequently employed option to reduce discard mortality. The influence of such a regulatory change, if examined at all, is normally examined in the context of pairwise comparisons of tows taken simultaneously or in alternating sequence between the mesh-size options. Rarely is the influence of such differences evaluated at the fishery level. In the case of this study, the 2.5″ codend dramatically reduced the capture of submarket-size squid, but at the cost of a decline in capture of market-size squid per hour towed. Consider the case of the global median catch calculated using all tows taken in all four field programs for each of the two codend mesh sizes tested. For the smaller codend mesh size, the median catch of marketable squid >10 cm in size was 17,059 kg tow^{-1}. The catch of the same size classes using the 2.5″ mesh was 4,458 kg tow^{-1}. This is a decrease in catch of 73.9%. To catch the equivalent weight of marketable squid achieved by the smaller codend mesh with the larger one would require an increase in tow time of the same order. The catch of small squid in the smaller codend mesh size was 7,753 kg tow^{-1}. Only 959 kg tow^{-1} were caught by the larger codend mesh size. Increasing effort to maintain landings volume would result in the capture of about 3,670 kg of small squid, based on the presumed extension of swept area per trip by 73.9%. This increased catch is still about half the original value. Thus, the larger mesh is advantageous in reducing discard mortality of small squid even with the requirement of the longer tow time to maintain total marketable landings.

Of course, an economic evaluation would show increased vessel costs also, so that the approach is not necessarily economically valuable, though it may be of value biologically.

But, consider the influence of the same scenario on other species. No other species demonstrated significant reductions in catch with the larger mesh size. Thus, the discarding of juvenile butterfish, silver hake, and dogfish would increase 73.9% with the increased codend mesh size. This is precisely the opposite result of that desired, and clearly would be diametrically opposite to the results necessary to alleviate the concerns of the influence of butterfish discards in *Loligo*-targeted tows on the butterfish stock. Were the fishery typically prosecuted with the bycatch-to-target species catch ratios observed in this study, such an increase in bycatch might be insufficient to counterweigh the advantage generated by reducing the volume of juvenile squid discarded, because observed bycatches of these other species were small in this study. However, that inference would require further assessment as to the origin of the apparent dichotomy between generally assumed discarding rates in the *Loligo* squid fishery and those observed here and by Powell et al. (2004).

On the other hand, restricting catch volume by limiting tow duration might significantly reduce discarding of small silver hake, and possibly small *Loligo* squid. The experimental design of this study did not include varying tow duration consistently to adequately evaluate this option. However, the tendency for larger catches of silver hake and *Loligo* squid to be characterized by a greater fraction of small fish indicates a promising direction for future research, in that modifying tow duration to limit catch volume may be one of the few options for discard management in small-mesh fisheries where an increase in codend mesh size is unlikely to limit discarding of non-target species without gravely impacting target-species landings.

The data support the conclusion that codend mesh size management is not necessarily an appropriate option for the *Loligo* squid fishery. A regulatory increase in codend mesh size to 2.5″ would lead to an increase in discarding of other species, and possibly by substantive amounts. The cost-to-benefit ratio achieved by the concomitant reduction in the discard mortality of juvenile squid is beyond the ambit of this analysis, but would need to be considered before a change in mesh

size was introduced to address the discarding of juvenile squid. Such an estimate might include the assessment of the effect of the anticipated increase in swept area trawled (e.g., Collie et al., 1997; Jennings and Kaiser, 1998; Thrush et al., 2001) that would be an expected outcome of an increase in legal codend mesh size on the benthic communities accessed by the fishery.

Acknowledgments

We would like to express our gratitude to the owners, captains and crew of the fishing vessels *Starbrite*, *Nightwatch*, and *Abracadabra*, who participated in the field sampling component of this project. Special thanks as well to the Rutgers scientific crew members, Tom Whitehead and Becky Marzec, for their hard work in the field and in the laboratory. This project was funded by a grant from the Mid-Atlantic Fishery Management Council's Research Set-Aside Program to the National Fisheries Institute Scientific Monitoring Committee (NFI-SMC). We appreciate the financial and logistical coordination provided by Daniel Cohen and Greg DiDomenico (NFI-SMC) and to all of the vessels who purchased and fished the Research Set-Aside quota, which funded this study.

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UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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August 31, 2007

Mr. John Connelly, President
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Dear Mr. Connelly:

We have completed our preliminary technical review of the final progress report for the Institute's Mid-Atlantic Research Set-Aside Project 04-RSA-002, "Loligo Squid Mesh Selectivity Study to Reduce Bycatch of Juvenile Loligo Squid and Other Species", under NOAA Grant No. NA05NMF4540053.

On the basis of our review, we are requesting a revised report addressing the following areas of concern, particularly relating to suggestions for presentation of information and data analyses:

The subject report summarizes experiments to evaluate the selective properties of 1.875" (4.76 cm) and 2.5" (6.35 cm) codend meshes. Parallel haul studies were conducted during four trips that occurred between February and December, 2005 on three different vessels. A total of 40 tows were taken during four separate trips. The vessels and nets were matched as best as possible (table 1) and the investigators tried to adapt to the unavailability of Vessel II in the second half of the study. The authors' exercise to illustrate the potential consequences of reduced catch rates of Loligo on the bycatch of other species is also useful. It highlights an often overlooked tradeoff aspect of gear technology adjustments.

However, there are major deficiencies in the statistical design, presentation of information and analyses completed for this study.

Major Concerns with Design

The design is unbalanced in terms of providing a sufficient number of paired tows to be analyzed. There is also a glaring problem with overall sample size. The number of experimental net vs. control net paired tows is inadequate. There is also a lack of standardization in tow duration, warp scope and depth, factions that may affect catch rates and selectivity. If the tows were paired, how can the average depth fished by each vessel differ by 18 m (Trip 3, Vessel I vs. III)? There are also many confounding effects,

for example tow time and depth by trip (Fig. 2) and total catch and tow time (Fig. 3), providing a weak basis for a time effect. In addition, the vessel and trip effects were subsumed in the "cruise" effect tested for in the catch rate analyses.

Concerns with Presentation of Information

The level of detail regarding study design and results are inadequate. A basic data table of vessel, codend mesh size, depth, speed, date, locations, catch by species and size group etc, by trip and tow, is essential and not included in the document. Otherwise, one is left to speculate about the vessel and codend pairings. For example, why is the cumulative catch of Vessel III so different from Vessel I? In both instances, Vessel III appears to have fished at different depths and with different warp scopes than Vessel I. A basic data table would also help clarify the apparent deep water tow in Fig. 1, south of 38° 20'. Table 3 summaries the median catch rates by species and trip for the 1.875' mesh. Where is the comparable table for the 2.5' mesh?

Concerns with Analyses

Much of the statistical power of matched pairs comes from the reduction of random effects that might otherwise confound interpretation of the primary design variable, codend liner mesh size. This study did little to reduce these random effects because they were not accounted for in the design. As a result, the observed differences in catch rates are consequences of differences in codend mesh selectivity confounded by uncontrolled factors that affected catch rates within and between paired tows.

The standardization approach used in Eq. 1 is unconventional, in that it uses the median as the measure of central tendency and adjusts the responses variable C_{STD} to a global median (presumably over all tows) in proportion to the ratio of the catch in tow i to median catch in trip T. However, it is not clear whether or not "trip" refers to the overall median of both vessels in trip. This approach may allow for some adjustment in true relative abundance of Loligo between trips, but it fails to account for the paired tows.

Combinations of parametric and non-parametric methods are used throughout the report. Presumably the use of the non-parametric methods is motivated by the lack of normality in the catch data or some other factor. Transformations of the data or the generalized linear models, using a negative binomial error structure should be considered. More customary analyses using paired t tests on catch rate differences between control and experimental codend pairings should be used. The α and β probability levels summarized throughout the report should be considered provisional. Greater detail on the methodology should be incorporated, particularly with respect to inferences on multiple tests.

Finally, the report appears to contain some useful information on the size-specific selectivity of the alternative codends. However, there are no formal analyses that estimate the selectivity changes by length. The author's use of stratification by length

group addresses this in part. More formal analyses, such as those suggested in the cited paper by Millar et al. 2004 would be helpful.

We would appreciate receiving the revised final report no later than September 30, 2007. Should you have any questions, please do not hesitate to contact me.

Sincerely,

Harold C. Mears

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

cc: Eric N. Powell
Dan Furlong (MAFMC)
Eleanor A. Bochenek

T/22 .
Reviewed by Chris Hager (PhD)
Fisheries Bycatch Specialist
Virginia Sea Grant
Virginia Institute of Marine Science

Introduction

The introduction is clear, however, the second, third and forth paragraphs (P) should be reconstructed and or combined to avoid repetitiveness and increase strength. The last sentence of the first P also seems out of place. A single paragraph should be constructed from all these parts. It should explain why bycatch is a problem (P3), species of concern (last sentence P1, Powell citation; used twice in first sentence of second P and second sentence of fourth) and fate of this bycatch. The fifth P is good and explains objectives well, these objectives are worthy of study, well suited and applicable to improving management of fishery.

Methods

Second P, ninth line down: word offset describing sequence is unclear. Sequence had to be ABBA (vessel 1) and ABAB (vessel 2) in order to get the four pair wise comparisons listed. Clarity would be improved if sequence of four pairs listed was changed to A1A2, B1B2, B1A2, and A1B2. Did this sequence alternate on a given vessel so that vessel 1 towed ABBA on first sequence of four then ABAB on next sequence? I believe this is what is implied; it is just unclear.

In third paragraph: inshore offshore component of seasonal efforts should be stated again. It should also be stated if it was vessel one or two that had to be replaced in December efforts. You can figure this out with some careful reading later but just state it.

How was catch number calculated? In table 3 the exact same number of Loligo was captured in trip 2 as in trip 4. Not likely. Number must have been determined from subsample. This method should be stated.

Statistical Analysis

No reference was given for multiplying by the global mean catch weigh. In several discussions with mathematicians we could not figure out why the numerator was multiplied by a constant. Multiplying by a species specific constant does not change your C_{std} relationships.

In my opinion, clearly stating the time of year effects on size class ratios and magnitude of species specific catch would be far more interesting to managers then getting rid of them through mathematical manipulation, after all temporal and spatial based factors can be valuable tools for avoiding bycatch.

Another concern, one that a mathematician could better address, with this approach is if the magnitude of differences within cruise (C_t) vastly exceeds variations in species specific

categorical catch weights in paired tows due to mesh manipulations isn't this standardization minimizing the differences you are attempting to elucidate?

P two line 12 sign on large hake category is reversed.

The statistical methods of analysis seem appropriate and thorough. Concern lies with manipulation of data before analysis to get rid of species catch differences between cruises and affect this has on overall differences in designated size categories due to mesh alterations.

Vessel analysis, often overlooked in such work, is a good idea and is well designed.

Results

In general, descriptive stats. are very complete.

To allow for better insight and common sense self analysis by mangers 2.5" mesh data by trip/cruise should be added to Table 3.

This would also greatly improve a reviewer's ability to test accuracy of analysis and propose alternate hypothesis for results.

Under DiffA1A2=Diff B1B2 second P line 7and 8 no need to repeat butterfish.

Get rid of writing below Table 4-6, confusing. Hard to follow thought and flip pages.

Though it is interesting to a manager of spiny dogfish whether bycatch consisted of males or females the physical blocking of meshes by larger fish occurs regardless of sex. What would be interesting is to examine interactions between bycaught species; ie. does volume of one affect retention of another. The effect of total catch on size selectivity is acknowledged in the paper but the effect this has on size class ratios is not examined. For example if dogfish total number affects selectivity, this effect and retention could be greatly reduced with use of culling grid that exclude their retention from the codend.

Page 25, line 9 left out of between number and tows.

Results seem plausible given information provided. I would like some information not provided, as mentioned above, to make my common sense/simple comparisons between mesh size performances. I feel non-transformed comparisons between meshes based on catch ratios (with respect to species specific size classes) are best. If analysis of raw data will not answer objectives without transformation there is an increased need to supply access to raw data (table 3 reference above). If this is not done, especially in the case when results may be used for managerial purposes, there is less transparency and thus an inherent tendency to mistrust results.

Discussion

Well summarized. Good discussion of impacts if employed perhaps a little more where we go from here discussion is warranted.

Thought: Perhaps these alterations would have a different effect on nets that are not constructed in a millionaire configuration. Is this investigation warranted? Maybe the percentage of fishers using millionaire nets in fishery should be given somewhere to address this question.

Why don't they use the currently discarded/undersized squid for the bait market.

1Manuscript - "An Evaluation of Codend Mesh Selectivity in the *Loligo* Squid-Directed Fishery: A Commercial-Scale Test"

Review by - William D. DuPaul
November 15, 2007

The project report by King et al which describes the results of a series of tests to evaluate the performance of a 1.875" versus a 2.5" mesh cod liner in the mid-Atlantic squid (*Loligo*) fishery is quite complete and accomplishes the project objective(s). The results are quite clear in that a 2.5" mesh codend reduced the catch of both market and non-market *Loligo* and such a gear change (from 1.875" to 2.5" mesh codend) could not be justified. Loss of market Loligo was significant to the degree that buy-in by the fishing industry would be unlikely.

The difficult part of the project stems from the necessity of conducting paired (parallel) tows using two vessels of different sizes and in some cases, slightly different nets. However, the project report was sufficiently successful in treating the catch data in such way as to minimize the influence of non-essential variables to elucidate the changes in catch attributed to the difference in mesh size. The project report is clear in that the results should not be extrapolated to different nets that may be in use in the fishery. Two factors or variables that are different to deal with are: (1) tow to tow variability which is a common problem in evaluating comparative gear performance. One way around tow to tow variability is to conduct more observations which is expensive and time consuming; the other is hope that the differences in catch are significantly and consistently different on each tow. Fortunately, in this case, a little of both appears to be sufficient to overcome the problem.

The other confounding issue is that of the influence of the catch of target species by the catch of non-target (bycatch) species. Clearly, with a small mesh codend, the catch of larger non-target species (i.e. dogfish) creates a problem in data analysis. The report did an excellent job in treating cruise effects.

In all, the report does an excellent job in the statistical treatment of the results. The experimental design was robust enough for the investigators to engage in some interesting statistical treatments.

Although the loss of *Loligo* catch in the 10-13 cm size range was significant and would probably result in an economic loss to the vessel, would the price differential (if there is one) for 13+ cm be attractive enough to support a gear change? It appears that the 2.5" mesh codend may be approaching a 100% retention for *Loligo* 13" cm. Is there any useful purpose in developing a retention level:mesh size relationship?

The project and project report represents a worthwhile investment of resources to support the research. A good value for the funds expended.

Although probably not part of the research, some consideration in the report could be made in reference to the market or potential market for small squid. If gear is not the solution, then seafood product development/marketing may be a less than optimal resolution, but the report might have included some information on the topic.

28 October 2007

Joseph DeAlteris

Review of manuscript entitled: An evaluation of codend mesh selectivity in the *Loligo* squid-directed fishery: a commercial scale test, by S. King, E. Powell, E. Bochenck, and J. Gendek

The manuscript reports on the results of a comparison of the catches of two different mesh size codends in the *Loligo* squid fishery. The data was collected aboard commercial fishing vessels following typical operating procedures in terms of area fished, season, tow duration, tow speed, etc. The two codends examined were a traditional 1.875 inch stretch-mesh, and a larger 2.5 inch stretch-mesh. The codends were rotated aboard each vessel in an ABBA pattern, and the catch from each tow was sorted, sub-sampled as necessary, weighed and enumerated. Lengths of target and bycatch species were collected. The analyses were rigorous investigating catch differences by size class for the two codends for both the target and bycatch species. Posteriori power analyses were included in the analyses. The effects of individual vessels on the catches were also investigated within and between codend mesh sizes.

Forty paired tows were conducted over four cruises. The results of the analyses are reported for four species, *Loligo* squid, butterfish, silver hake, and dogfish. A point of confusion that may be clarified in the text is the reference to control and experimental tow comparisons. Typically the control net is the standard net and the experimental net is the variation on the control net, and the authors use this terminology in the discussion section of the manuscript. However in the Methods and Results sections, the authors refer to the control tow comparisons as A_1A_2 and B_1B_2, and then refer to the experimental tow comparisons as A_1B_2 and A_2B_1. The first pair of comparisons is really the vessel effect comparison, and the second comparison is the codend effect evaluation. Additionally, I assume that the codend effects tows are truly paired in time (simultaneous) between vessels 1 and 2, which is why the only codend effect pairs are between vessels, because within a single vessel subsequent tows so far apart that they could not be paired (i.e. A_1B_1 and A_2B_2). Thus, I would not use the terms control and experimental as used in the Methods and Results sections of this manuscript, and suggest that the authors refer to vessel and codend effect comparisons, as I think that this would be clearer. With regard to the power analyses, I believe that this an important and valuable aspect of the reported research, however, it would be useful for the authors to indicate the specific criteria used to evaluate the power of their analyses and the references supporting the choice of that criteria.

The authors utilize the results of their research to evaluate the potential consequences of a management driven increase in the mesh size on the catch of squid, the target species and the bycatch species in their discussion section. The results of the field experiments and the analyses clearly indicate that the catch of small squid will be reduced by increasing the codend mesh size, and that the catch of the bycatch will not be effected. The authors then project or speculate that fishermen in an effort to make-up for lost squid catch will increase effort, and that will result in greater bycatch, thus defeating any benefit of increasing mesh size on the bycatch species. While I agree with this speculation, it is based on the

assumption that the squid fishery will be operating in the future with no effort limitations for the target species or quotas on the bycatch species, and this should be clearly stated.

Finally, I believe that the research reported on in this manuscript by the authors is excellent in terms of the experimental design, collection of the field data, and implementation of the analyses. However, I believe that the research as reported does not evaluate the selectivity of these gears in the traditional sense. Typically the result of a selectivity analysis for a trawl codend mesh size and shape operating on a particular species is a logistic model that describes the proportion retained as a function of the length of the species. The selectivity analysis is based on a comparison of the catches of the specified larger mesh codend compared to a smaller mesh codend that retains all sizes vulnerable to both codends. The result of this study, as reported in this manuscript, is a statistically powerful comparison of the catch of two different codends, and the title of the paper should so reflect the content of the manuscript. I suggest that the title should either refer to a comparison of the catches of two different mesh size codends in the squid fishery, or the effects of increasing mesh size on the catch in the squid fishery. As a final note, while the authors have investigated using a larger diamond mesh codend, it appears that the problem is one of increasing the steepness of the size selection curve of the codend for the target species, and this reviewer speculates that a 2 inch square mesh extension and codend may be the solution to separating small, juvenile squid from marketable squid during the capture process. Typically square mesh has been found to provide a steeper selection curve thus allowing for more knife edge selection by size. However, this will probably no effect on the bycatch species.

Overall, I believe that this is a well written manuscript, and accurately describes the research conducted. My suggested revisions would only clarify potential points of confusion.