Testing of Scallop Dredge Bag Design for Flatfish Bycatch Reduction

Final Report

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Project Summary

Throughout the duration of this project, from March 1, 2012 through May 31, 2013, four separate research trips were completed. The Coonamessett Farm Turtle Deflector Dredge (CFTDD) rigged with a control bag (8 ring apron and 60 mesh twine top) was compared to the CFTDD experimental bag (5 ring apron, 45 mesh twine top), the Low Profile Dredge (LPD) rigged with an experimental bag and a CFTDD experimental bag with windows for catch comparisons. The results indicate that the experimental CFTDD reduced yellowtail by 33%, winter by 40%, windowpane by 46%, summer by 19%, without a significant loss in scallop catch by weight. This project is a continuation of a 2011 Gear Testing RSA Project (NA11NMF4540021).

Vessel	Start Date	End Date	Number of Tows	Experimental Dredge Frame
Concordia	8/26/2012	8/31/2012	106	CFTDD
Freedom	10/19/2012	10/23/2012	80	CFTDD
Diligence	2/25/2013	3/1/2013	80	LPD
Westport	5/14/2013	5/18/2013	76	LPD

Introduction

The Georges Bank sea scallop (*Placopecten magellanicus*) fishery is well managed and economically productive. This is due in part to the involvement and cooperation of the commercial scallop fishing industry in mitigating groundfish bycatch and ultimately creating a more sustainable fishery. With consumer demand for more sustainably harvested seafood increasing, there is an overwhelming need to change fishing habits to avoid excessive bycatch. The severity of current bycatch management tools, like fishing ground closures, has resulted in the loss of millions of dollars in revenue in the past. Gear modifications in conjunction with gear restricted zones represent a new economically viable tool for the fishery management toolkit.

The rigorous testing of the Coonamessett Farm Turtle Deflector Dredge (CFTDD) has shown it to be successful in reducing the bycatch of loggerhead sea turtles (*Carretta carreta*) without any loss in scallop catch efficiency. The dredge frame was designed to smoothly guide turtles over the top of the dredge by moving the cutting bar forward and eliminating most of the bale bars so not to impede escape (Smolowitz et al. 2010; Smolowitz et al. 2012). During the 2011 RSA Seasonal Bycatch Survey, a CFTDD was simultaneously fished alongside New Bedford dredges supplied by the participating vessels (NA11NMF4540027). It was observed that the difference between the bycatch rates of yellowtail flounder (*Limanda ferruginea*) for New Bedford dredges with an apron greater than 8 rings and a higher twine top hanging ratio and the CFTDD was greater than the difference between New Bedford dredges with an apron less than or equal to 8 rings and a lower twine top hanging ratio (Tables 1 and 2). The scallop fleet typically fishes dredge bags with twine tops 80-90 meshes across (3:1 hanging ratio) and aprons between 7-13 rings long (Tables 1 and 2). Since 2011, CFF has been using a control dredge bag with a twine top 60 meshes across and an 8 ring apron that typically has lower bycatch than commercial gear.

Building on this observation, a proposal was drafted to determine if a shorter apron and a lower twine top hanging ratio than the control dredge would reduce the bycatch rate. Twine top and apron length are two gear characteristics that depend upon one another and are therefore tested together in this project. We hypothesized that a reduced apron size reduces flatfish bycatch by increasing the area through which flatfish can escape and that a lower twine top hanging ratio further increases the probability for flatfish escapement by creating larger openings. This bag design was tested on both a CFTDD and a Low Profile Dredge (LPD).

The LPD frame was tested to determine if a modified frame further reduces bycatch as compared with the CFTDD frame. We hypothesized that a lower angled depressor plate which reduces head bail height off the seafloor would enable fish to swim over the dredge and avoid capture.

In past projects, CFF has also tested the effectiveness of windows (openings cut in the twine top or ring bag) in allowing fish to escape without adversely influencing scallop catch. We further tested the use of windows cut into the sides of the dredge bag in a separate experiment associated with this project.

Methods

We compared catch data from four trips: two testing the CFTDD frame and two testing the LPD frame. All of the trips were conducted on Georges Bank (in open and closed areas) and in Southern New England (SNE) open areas. Tow locations were chosen for their high abundance of fish as well as scallops (Figure 1).

On the first two trips, each vessel was outfitted with two 4.57 m (15 ft) wide CFTDDs: an experimental and a control dredge. The control dredge was rigged with an eight row apron (8R) and a twine top with a hanging ratio of 2 meshes to a ring (Table 3, Figure 2). We chose to use this frame and bag design as a control because this control dredge was used on past projects as well as the current 2013 RSA Bycatch Survey (NA13NMF4540011). The experimental dredge was rigged with a five row apron and a twine top with a hanging ratio of 1.5 meshes to a ring (Table 3, Figure 2). On the last two trips, the vessels were outfitted with the control dredge and a low profile dredge (LPD) rigged with a 5 row apron and a twine top hung with a 1.5:1 hanging ratio as the experimental dredge (Table 3).

In an additional experiment, two by six ring windows in the sides of the experimental bag were tested on the last 30 tows of the first trip of the project. Windows were not tested on subsequent trips in an effort to standardize the gear, maximize sample size, and limit the number of changes. We decided to focus specifically on assessing the effects of a short apron and low twine top hanging ratio on the relative catches of sea scallops and important bycatch species.

While at sea, the dredges were towed at a vessel speed of 4.6-4.8 knots using 3:1 wire scope. The tows were 30 minutes in duration unless lengthened to one hour in bad weather and rough seas. All tow parameters were recorded including start and end positions, depth, and sea conditions. Tows where one or both of the dredges experienced a technical failure (e.g. twine top fouled in tail chain hook) were declared invalid and eliminated from the analysis.

For each paired tow, the catch from each dredge was separated by species and individually counted. The entire scallop catch was recorded as bushels (bu=35.2 liters). A one bushel subsample of scallops from each dredge was picked at random from each tow. These subsamples were measured in 5 millimeter incremental groups to estimate the length frequency of the entire catch. The size frequency of the entire catch was estimated by expanding the catch at each shell height of the subsample by the total number of baskets sampled. The commercially important finfish species and barndoor skates were measured to the nearest centimeter. Winter and little skates were counted together, but not measured, and categorized as "unclassified skates." Table 4 lists all species that were measured and/or counted by common and scientific name. Composition and estimated quantity of "benthos" (including rocks, sand dollars, crabs, sea stars, clams and shell debris) was also noted.

Gear Comparisons

The objective of the analysis was to determine if the experimental and control dredges performed differently and how those differences might affect catch rates and size selection of both scallops and the major finfish bycatch species. For a particular species our analysis only focused on tows where that species was caught in at least one of the dredges.

Catch weights and bycatch rates of the experimental and control dredges were compared for each trip. Finfish species weights were calculated using NEFSC length-weight relationships (Wigley et al. 2003). Scallop weight was calculated using shell height meat weight projections for Georges Bank and Southern New England provided by VIMS using data collected on the 2013 RSA Seasonal Bycatch Survey (NA13NMF4540011). Bycatch rate was calculated for each of the major flatfish species as the ratio of pounds of flatfish divided by the pounds of scallop meats. Catch weight data was tested for normality using a Shapiro-Wilk test and for equality of variance using an F-test. We tested for a significant difference in catch weights between the control and experimental dredge bags using either a two-tailed Student's t-test for normally distributed data (Shapiro-Wilk test, $p > 0.05$) or a Mann-Whitney Rank Sum Test for nonparametric data (Shapiro-Wilk test, $p < 0.05$). All statistical analysis was done using SigmaPlot® v. 12.5.

To determine if bag fullness influenced fish and scallop catch in the experimental CFTDD and control dredges, we examined the 145 tows from the first two trips with the CFTDD frame in which scallops were caught. Total volume in bushels was calculated by adding the bushels of benthos, scallops, skates, and flatfish together. The number of fish per bushel was estimated for this analysis as 85 skates, 80 yellowtail, 75 winter, 200 windowpane, and 10 summer flounder based on observations made during the four research cruises. We then calculated the proportion of benthos, scallops, skates, and flatfish to the total catch for the 30 largest tows and the 30 smallest tows.

In addition, a Generalized Linear Mixed Model (GLMM) was used to analyze the paired catch data and test for differences in both the pooled length catch data as well as test for differences in the length composition of the catch. The GLMM was used to analyze catch as numbers of animals. Within this modeling framework, the random effects acknowledge the potential for differences that may have occurred at both the trip and individual tow levels. The GLMM groups all the data and gives an overall perspective on how the two gears compare.

This approach has the advantage of mirroring the actual biotic and abiotic conditions under which the dredge will operate. Multiple vessels and slight variations in gear handling and design were included in the experimental design and, while this variability exists, the GLMM modeling approach detailed in the next section accounts for the variability and allows for a more broad inference (relative to vessels) to be made.

Statistical Models – GLMM

Catch data from the paired tows provided the information to estimate differences in the relative efficiency for the gear combinations tested. In addition we tested the influence of frame design on the relative efficiencies of catching various species as a fixed effect. This analysis is based on the analytical approach in Cadigan et al. 2006.

Assume that each gear combination tested in this experiment has a unique catchability. Let q_r equal the catchability of the experimental dredge (5R apron) and q_f equal the catchability of the control dredge (8R apron) used in the study. The efficiency of the experimental relative to the control will be equivalent to the ratio of the two catchabilities:

$$\rho_l = \frac{q_r}{q_f} \tag{1}$$

The catchabilities of each gear are not measured directly. However, within the context of the paired design, assuming that spatial heterogeneity in scallop/fish and fish density is minimized, observed differences in scallop/fish catch for each vessel will reflect differences in the catchabilities of the gear combinations tested.

Let C_{iv} represent the scallop/fish catch at tow location i by dredge v, where $v=r$ denotes the experimental dredge and $v=f$ denotes the control dredge. Let λ_{ir} represent the scallop/fish density for the i^{th} tow by the experimental dredge and λ_{if} the scallop/fish density encountered by the control dredge. We assume that due to random, small scale variability in animal density as well as the vagaries of gear performance at tow i, the densities encountered by the two gears may vary as a result of small-scale spatial heterogeneity as reflected by the relationship between scallop/fish patch size and coverage by a paired tow. The probability that a scallop/fish is captured during a standardized tow is given as q_r and q_f. These probabilities can be different for each vessel, but are expected to be constant across tows. Assuming that capture is a Poisson process with mean equal to variance, then the expected catch by the experimental dredge is given by:

$$E\left(C_{if}\right) = q_f \lambda_{if} = \mu_i \tag{2}$$

The catch by the control dredge is also a Poisson random variable with:

$$E\left(C_{ir}\right) = q_r \lambda_{ir} = \rho \mu_i \exp(\delta_i) \tag{3}$$

where $\delta_i = \log(\lambda_{ir}/\lambda_{if})$. For each tow, if the standardized density of scallops /fish encountered by both dredges is the same, then $\delta_i=0$.

If the dredges encounter the same scallop/fish density for a given tow, (i.e. $\lambda_{ir}=\lambda_{if}$), then ρ can be estimated via a Poisson generalized linear model (GLM). This approach, however, can be complicated especially if there are large numbers of tows and scallop/fish lengths (Cadigan et al. 2006). The preferred approach is to use the conditional distribution of the catch by the CFTDD at tow i, given the total non-zero catch of both vessels at that tow. Let c_i represent the observed value of the total catch. The conditional distribution of C_{ir} given $C_i=c_i$ is binomial with:

$$\Pr\left(C_{ic} = x \middle| C_i = c_i\right) = \binom{c_i}{x} p^x (1-p)^{r_i - x} \tag{4}$$

where $p=\rho/(1+\rho)$ is the probability that a scallop/fish captured by the experimental dredge. In this approach, the only unknown parameter is ρ and the requirement to estimate μ for each tow is eliminated as would be required in the direct GLM approach (equations 2 & 3). For the binomial distribution $E(C_{\mathrm{ir}})=c_i p$ and $Var(C_i r)=c_i p/(1-p)$. Therefore:

$$\log\left(\frac{p}{1-p}\right) = \log(\rho) = \beta \tag{5}$$

The model in equation 5, however, does not account for spatial heterogeneity in the densities encountered by the two gears for a given tow. If such heterogeneity does exist then the model becomes:

$$\log\left(\frac{p}{1-p}\right) = \beta + \delta_i \tag{6}$$

where δ_i is a random effect assumed to be normally distributed with a mean=0 and variance=σ^2. This model is the formulation used to estimate the gear effect $exp(\beta_0)$ when catch per tow is pooled over lengths.

Often, gear modifications can result in changes to the length based relative efficiency of the two gears. In those instances, the potential exists for the catchability at length (l) to vary. Models to describe length effects are extensions of the models in the previous section to describe the total scallop catch per tow. Again, assuming that between-pair differences in standardized animal density exist, a binomial logistic regression GLMM for a range of length groups would be:

$$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \delta_i + \beta_1 l, \delta_i \sim N(0,\sigma^2), i = 1,\ldots,n. \tag{7}$$

In this model, the intercept (β_0) is allowed to vary randomly with respect to tow.
The potential exists, however, that there will be variability in both the number as well as the length distributions of scallops/fish encountered within a tow pair. In this situation, a random effects model that again allows the intercept to vary randomly between tows is appropriate (Cadigan and Dowden 2009). This model is given below:

$$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \delta_{i0} + \beta_1 * l, \delta_{ij} \sim N(0,\sigma_j^2), i = 1,\ldots,n, j = 0,1. \tag{8}$$

Adjustments for sub-sampling of the catch

Additional adjustments to the models were required to account for sub-sampling of the catch. In most instances, due to high scallop catch volume, particular tows were sub-sampled. This is accomplished by randomly selecting a one bushel sample for length frequency analysis. Finfish were always sampled without subsampling. One approach to accounting for this practice is to use the expanded catches. For example, if half of the total catch was measured for length frequency, multiplying the observed catch by two would result in an estimate of the total catch at length for the tow. This approach would overinflate the sample size resulting in an underestimate of the variance, increasing the chances of spurious statistical inference (Millar et al. 2004; Holst and Revill 2009). In our experiment, the proportion sub-sampled was not consistent between tows as only a one bushel sub-sample was taken regardless of catch size. This difference must be accounted for in the analysis to ensure that common units of effort are compared.

Let q_{ir} equal the sub-sampling fraction at tow i for the vessel r. This adjustment results in a modification to the logistic regression model:

$$\log\left(\frac{p_i}{1+p_i}\right) = \beta_0 + \delta_i + (\beta_1 * l_i) + \log\left(\frac{q_{ir}}{q_{if}}\right), \delta_{ij} \sim N(0,\sigma_j^2), i = 1,...,n. \quad (9)$$

The last term in the model represents an offset in the logistic regression (Littell et al. 2006).

Our analysis of the efficiency of the experimental dredge relative to the control dredge consisted of multiple levels of examination. For all species, the full model consisted of unpooled (by length) catch data, including a categorical variable to denote dredge frame (i.e. CFTDD, LPD):

$$\log\left(\frac{p_i}{1+p_i}\right) = \beta_0 + \delta_i + (\beta_1 * l_i) + (\beta_2 * f_{ij}) + \log\left(\frac{q_{ir}}{q_{if}}\right), \delta_{ij} \sim N(0,\sigma_j^2), i = 1..n, j = 0,1\ldots.(10)$$

The symbol f_{ij} equals the categorical variable denoting dredge frame configuration. Model fit was assessed by AIC. If AIC and factor significance indicated that length was not a significant factor in predicting relative efficiency, the data was pooled over length. The random intercept model, including f_{ij} was evaluated to asses relative differences in total catch (see equation 6).

We used SAS/STAT® PROC GLIMMIX v. 9.2 to fit the generalized linear mixed effects models.

Results

Catch Weight and Bycatch Rate

Total catch in numbers of fish and bushels of whole scallops is presented in Table 5. In terms of catch volume, fish represent a greater proportion of the catch (4.96% in the control and 2.99% in the Experimental CFTDD) in the low volume tows as compared with the high volume tows (1.04% in the Control and 0.83% in the Experimental dredges) (Table 6). Skate catch comprised a higher proportion of the catch for low volume tows compared to high volume tows, which had more scallops and benthos (Table 6).

A total of 148 valid tows were conducted to compare catch weights of the experimental (CFTDD with the 5R apron/ 45 mesh twine top and no windows) and control dredges. Tables 7, 9 and 11 only present analysis of tow pairs where species of interest were caught. There was a 10% reduction in scallop meat weight and a 19% decrease in summer flounder weight in the experimental (5R, 45 mesh twine top) dredge as compared with the control that did not test significant (Table 7). Yellowtail, winter, and windowpane flounder catch weights were reduced by 33%, 40% and 46% respectively and there was a significant difference between dredges (Table 7). Bycatch rate of all flatfish species was lower in the experimental dredge, especially yellowtail flounder (Table 8).

For the LPD, 150 tows were used for comparison. Catch weight of all four species of flatflish and scallops was reduced by 40%-68%, however scallop catch was also significantly reduced by 31% (Table 9). Bycatch rates for all species were lower for the experimental dredge than the control dredge with a more pronounced difference for windowpane and summer flounder (Table 10).

Out of the 30 tows with the two by six windows in the sides of the experimental dredge, 28 of the tows were analyzed as valid tows. There was no significant difference in catch weight of yellowtail, summer flounder, or sea scallops (40%, 19%, and 6% reductions, respectively) between dredges for these tows (Table 11). For winter and windowpane flounder (47% and 88% reduction, respectively), there was significantly less catch by weight in the experimental dredge with windows (Table 11). There was a reduction in bycatch rate for all species in the experimental dredge (Table 12).

GLMM Results

Catch data

The data from the four research trips were treated as a single data set for the purposes of this analysis. The two apron configurations influenced twine top length and hanging ratio, therefore these two characteristics were treated as a combined effect. An additional difference between the experimental gears was dredge frame configuration. On two of the trips a CFTDD frame was used, while on the other two cruises the experimental dredge consisted of a LPD frame. The control dredge configuration was consistent on all cruises.

Overall, this data set consisted of 298 valid tow pairs that were examined in the analysis. A number of tows (30 tows) in which windows were cut into the experimental dredge bag were excluded from the analysis.

Statistical models

This analysis attempted to construct a model that would predict the relative efficiency of the experimental (5R) dredge relative to the control dredge based on a variety of covariates. In some instances, especially since gear modifications may alter the relative size composition of the catch, it was informative to analyze relative catch at length to determine length-based relative efficiency. Length was not a significant predictor of relative efficiency for most species, in which case pooled catch data were analyzed. The effect of dredge frame was also examined for its impact on the relative efficiency of the experimental dredge relative to the control dredge.

Model Results

For some species, there was simply not enough data to provide meaningful results from the model. Most cases involved a small number of tow pairs where there were non-zero observations and the model failed to converge. Table 13 shows the best model fit as determined by AIC for the various species in the analysis. Parameter estimates associated with the best model fit are shown in Tables 14-17. Graphical representations of the observed catches (either pooled or unpooled depending upon best model fit) and predicted relative efficiencies derived from the model output are shown in Figures 3, 5-10.

Sea scallops were the only species for which the data were best fit by a length-based model that includes dredge frame as a fixed effect. There was an overall reduction in relative scallop catch efficiency using the experimental dredge configuration relative to the control dredge (Table 14, Figure 3). There was also a significant length effect, since the experimental dredge was less efficient at capturing smaller scallops than the control dredge (Table 14, Figure 4). It is important to understand the impact of the observed difference in relative efficiency with respect to expected scallop catch. One important aspect of size selectivity is discards of small scallops during shucking, which is not regulated. Size selectivity during shucking can considerably influence scallop catch depending on cull point (Tables 18 and 19).

Summer flounder were the only other species that demonstrated a significant length-based effect on the estimated relative efficiency. There was a significant reduction in relative summer flounder catch efficiency in the experimental dredge compared to the control dredge (Table 15, Figure 4). Dredge frame was not significant in predicting relative efficiency in this case. Catch efficiency of summer flounder increased with length (Figure 5).

Animal length was not a significant predictor of relative efficiency for the remaining species analyzed and the catch data was pooled over length. For barndoor and unclassified skates, there was an overall reduction of relative efficiency for the experimental dredge relative to the control dredge (Table 16, Figures 6-7). Dredge frame was also significant for these species. The experimental dredge reduced the catch of yellowtail flounder, winter flounder, windowpane flounder and monkfish, relative to the control dredge (Table 17, Figures 8-11). Parameter estimates were negative indicating reduced catch in the experimental dredge (Table 17).

The reduction in relative scallop catch efficiency was greatest between the LPD and control dredge frames (Figure 3). The LPD dredge frame also produced a greater reduction in fish bycatch relative to the control dredge frame.

Discussion

The results indicate that the experimental CFTDD reduced bycatch and trash with a slight reduction in scallop catch, while the LPD had a similar reduction in bycatch but a much larger decrease in scallop catch. There was a reduction of bycatch species in the experimental CFTDD without a significant difference in sea scallops, though scallop catch was slightly (10%) lower. The LPD was not ideal; while bycatch was also reduced, there was a significant (31%) loss in scallop catch. The GLMM analysis indicates that the lower scallop catch in the LPD as compared with the CFTDD was not a function of size selectivity, since there were fewer scallops over all size classes (Figure 2).

Despite the significant loss in scallop catch observed in this study, the LPD still has the potential to be an effective means of reducing bycatch in the scallop fishery. In past studies, the LPD caught less volume of benthos and demonstrated scallop size selectivity (NA11NMF4540021). The 22.5° angle of the depressor plate may be too extreme causing the cutting bar to lift off the seafloor bottom and reducing scallop catch. In future studies we will test the performance of an LPD frame with a higher depressor plate angle.

Tows with zero catches for a given species were excluded from the catch weight analysis. Incorporating the zero catch tows increases the variance of the data. Tows with zero catches for a given species are uninformative in gear testing, since there is no way to differentiate between lack of catch due to fish absence and lack of catch due to gear selectivity.

Results from catch weight analysis indicated that there was a significant difference in catch weight for all species except sea scallops and summer flounder between the CFTDD experimental and the control dredges (Table 7). GLMM analysis yielded a difference in numbers of animals between dredges for all species caught, including sea scallops and summer flounder (Tables 14-17). This can be explained by size selectivity, since sea scallops and summer flounder were the only two species for which there was a length-based effect. The experimental dredge was more size selective, catching larger scallops, which compensates for fewer scallops caught. Since the scallops that are caught in the experimental dredge are larger on average, the difference in total scallop meat weight was not significant.

It is beneficial for the fishery to catch larger scallops for both economic and biological reasons. Large scallop meats generally have a higher market value than small meats. Increasing the size of capture would raise the average yield per recruit (DuPaul et al. 1989). Discard mortality is higher for small scallops because they tend to be more susceptible to desiccation and heat on deck (Stokesbury et al. 2011). Therefore, catching fewer small scallops would decrease the discard mortality rate.

The CFTDD experimental dredge catches fewer fish and small scallops than the control dredge, which indicates that it is more selective. By reducing the apron size and twine top hanging ratio, the mechanical sorting ability is increased. The experimental dredge has a higher mechanical sorting ability due to an extended twine top that overhangs the sweep. The 10.5 inch mesh of the twine top with a low hanging ratio sorts the catch more efficiently than the 4 inch steel rings of the bag. Since the short apron does not overhang the sweep, fish and small scallops that are deflected up come into contact with the twine top, permitting the release of fish and small scallops. The dredge is less efficient at catching small scallops because they are less dense and are more susceptible to the mechanical sorting process than large scallops (Bourne 1965).

The 10% loss in scallops in the experimental CFTDD is not due the volume of material in the bag. The difference in scallop catches between the experimental and control CFTDDs in the 30 highest volume tows was minimal (Table 6). Yochum and DuPaul (2008) determined that the volume of trash in the dredge bag did not significantly impact scallop catch. A longer tow time on a commercial tow could influence the volume of material in the bag, but may not impact scallop catch.

Volume of material in the dredge bag appears to influence the efficiency of the gear at catching flatfish. Material accumulates in the bag from clubstick to sweep/twine top. Once the material reaches the twine top the efficiency of the dredge at retaining fish decreases, since the 10.5 inch mesh of the twine top with a low hanging ratio has larger openings than 4 inch steel rings of the bag. When the bag is completely full, the dredge “bulldozes” along the bottom and only the densest of material is retained. Figure 12 illustrates this hypothesis, where fish catch efficiency would be greatest at point A and decrease as material accumulates from point A to C.

In this study it was observed that tows with low volume had a greater proportion of fish in the catch as compared with high volume tows (Table 6). Otter trawl studies have shown that catch volume and the shape of the cod-end influence selectivity (Herrmann 2005, Hodder and May 1964). Future experimentation is needed to determine if and to what extent the shape of a scallop dredge bag influences the overall catch efficiency of the dredge.

This hypothesis could be tested by filming fish behavior and dredge bag shape as it fills over the course of a tow. In the 2013 Gear Project, Coonamessett Farm Foundation used GoPro cameras attached to the gooseneck of the dredge to investigate the behavior of fish ahead of the cutting bar and during the hauling back of the dredge. We plan to continue testing camera placement on future trips to observe fish behavior behind the head bail.

Windows in the bags significantly reduced windowpane flounder catch. CFF has tested windows in the dredge bag in past experiments and the side pieces seem to be the most effective location of windows in reducing bycatch. Further testing of windows in this location on the bag under various fishing conditions is needed to determine whether this may be an effective management tool.

In conclusion, the gear modifications reduced bycatch in two ways. The first is that bycatch is prevented from entering the bag. The low profile dredge has a reduced angle of attack and a head bail that is towed lower to the seafloor, thereby enabling fish to swim over the dredge and avoid capture. Secondly, the gear facilitates the escape of non-target species after capture. Reducing the apron size decreases the distance from the sweep to the twine top, thus facilitating fish escapement. Decreasing the twine top hanging ratio may increase the mesh opening and further facilitate escapement. Understanding the abiotic (accumulation of material) and biotic factors (fish behavior) that impact dredges performance will inform more effective gear modifications to reduce bycatch without significantly impacting the target species catch. Gear modifications in conjunction with other management tools, such as gear restricted areas, represent an economically viable solution for reducing bycatch in the scallop fishery.

PRESENTATIONS

Davis F., Rudders D., and Smolowitz R. Testing of Bag Design Modification to Reduce Flatfish Bycatch in the Northwest Altantic Sea Scallop Fishery. 19th International Pectinid Workshop. Florianopolis, Santa, Catarina, Brazil. April 10-16, 2013.

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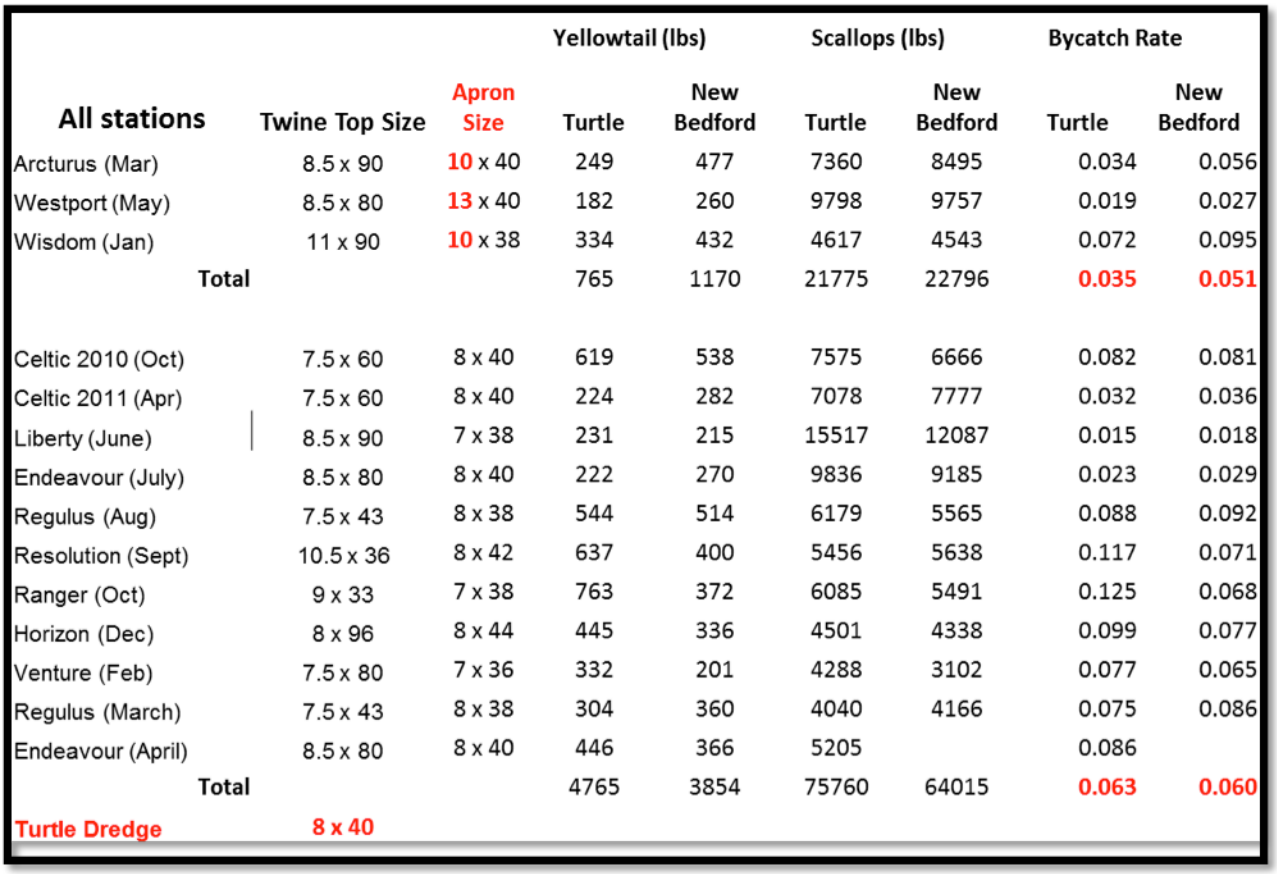
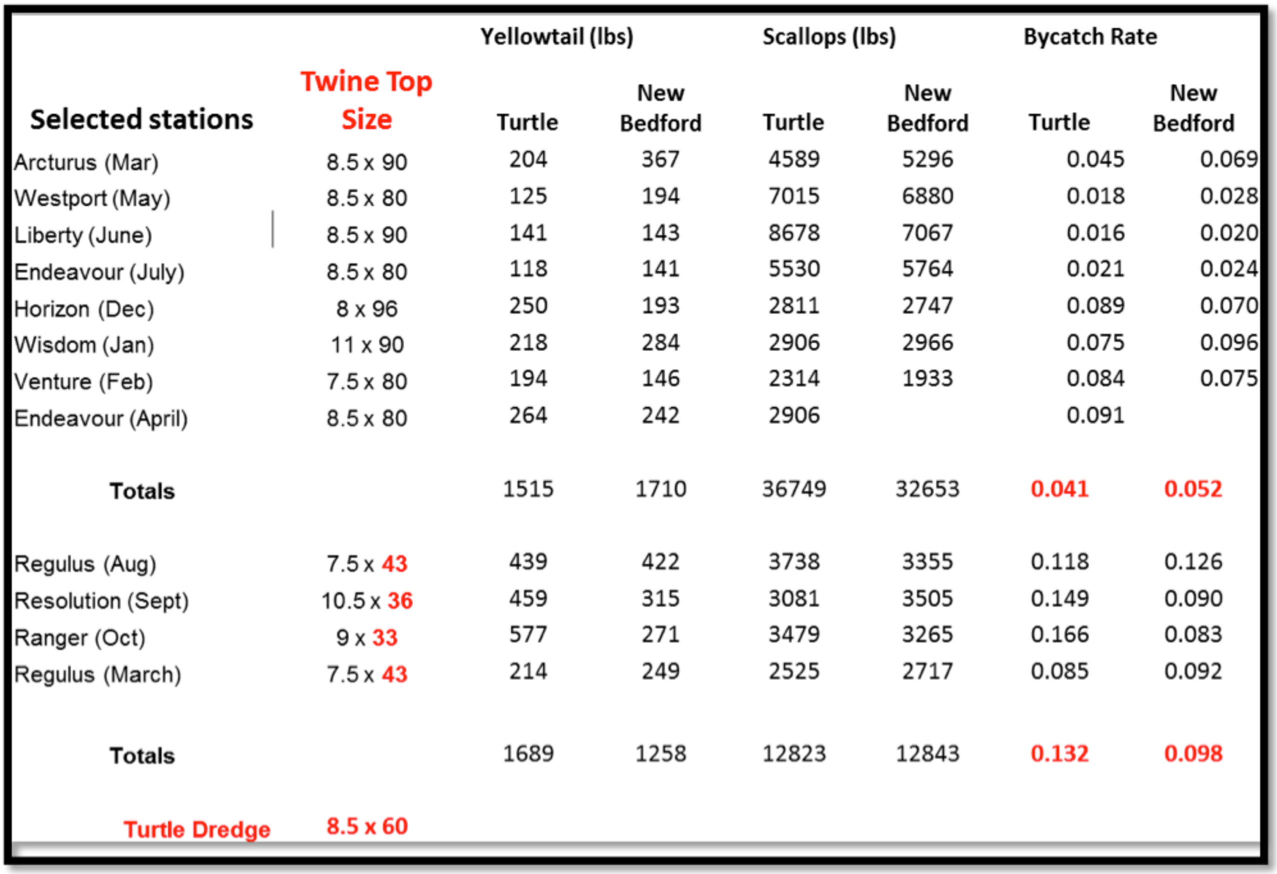
TABLES

Table 1 Impact of Apron Length on Bycatch Rates from the 2011 RSA Bycatch Survey



			Yellowtail (lbs)		Scallops (lbs)		Bycatch Rate	
All stations	**Twine Top Size**	**Apron Size**	**Turtle**	**New Bedford**	**Turtle**	**New Bedford**	**Turtle**	**New Bedford**
Arcturus (Mar)	8.5 x 90	**10** x 40	249	477	7360	8495	0.034	0.056
Westport (May)	8.5 x 80	**13** x 40	182	260	9798	9757	0.019	0.027
Wisdom (Jan)	11 x 90	**10** x 38	334	432	4617	4543	0.072	0.095
Total			765	1170	21775	22796	**0.035**	**0.051**
Celtic 2010 (Oct)	7.5 x 60	8 x 40	619	538	7575	6666	0.082	0.081
Celtic 2011 (Apr)	7.5 x 60	8 x 40	224	282	7078	7777	0.032	0.036
Liberty (June)	8.5 x 90	7 x 38	231	215	15517	12087	0.015	0.018
Endeavour (July)	8.5 x 80	8 x 40	222	270	9836	9185	0.023	0.029
Regulus (Aug)	7.5 x 43	8 x 38	544	514	6179	5565	0.088	0.092
Resolution (Sept)	10.5 x 36	8 x 42	637	400	5456	5638	0.117	0.071
Ranger (Oct)	9 x 33	7 x 38	763	372	6085	5491	0.125	0.068
Horizon (Dec)	8 x 96	8 x 44	445	336	4501	4338	0.099	0.077
Venture (Feb)	7.5 x 80	7 x 36	332	201	4288	3102	0.077	0.065
Regulus (March)	7.5 x 43	8 x 38	304	360	4040	4166	0.075	0.086
Endeavour (April)	8.5 x 80	8 x 40	446	366	5205		0.086	
Total			4765	3854	75760	64015	**0.063**	**0.060**
Turtle Dredge	**8 x 40**							

Table 2 Impact of Twine Top Hanging Ratios on Bycatch Rates from the 2011 RSA Bycatch Survey



		Yellowtail (lbs)		Scallops (lbs)		Bycatch Rate	
Selected stations	**Twine Top Size**	**Turtle**	**New Bedford**	**Turtle**	**New Bedford**	**Turtle**	**New Bedford**
Arcturus (Mar)	8.5 x 90	204	367	4589	5296	0.045	0.069
Westport (May)	8.5 x 80	125	194	7015	6880	0.018	0.028
Liberty (June)	8.5 x 90	141	143	8678	7067	0.016	0.020
Endeavour (July)	8.5 x 80	118	141	5530	5764	0.021	0.024
Horizon (Dec)	8 x 96	250	193	2811	2747	0.089	0.070
Wisdom (Jan)	11 x 90	218	284	2906	2966	0.075	0.096
Venture (Feb)	7.5 x 80	194	146	2314	1933	0.084	0.075
Endeavour (April)	8.5 x 80	264	242	2906		0.091	
Totals		1515	1710	36749	32653	**0.041**	**0.052**
Regulus (Aug)	7.5 x **43**	439	422	3738	3355	0.118	0.126
Resolution (Sept)	10.5 x **36**	459	315	3081	3505	0.149	0.090
Ranger (Oct)	9 x **33**	577	271	3479	3265	0.166	0.083
Regulus (March)	7.5 x **43**	214	249	2525	2717	0.085	0.092
Totals		1689	1258	12823	12843	**0.132**	**0.098**
Turtle Dredge	**8.5 x 60**						

Table 3 Gear Specifications of the Experimental (CFTDD and LPD) and Control Dredges

Dredge Designation	Control	Experimental
Frame	CFTDD	CFTDD and LPD
Type of Chain for Turtle Mat	3/8" Grade 70	3/8" Grade 70
Up and Downs	13	13
Tickler Chain	9	9
Type of Chain for Sweep	Long Link Grade 80	Long Link Grade 80
Number of Links in Sweep	121 long links	121 long links
Chain Sweep Hanging	(6,4,4,2,4...every two links in the bag), 12 link dog chain for the first diamond, 9 link dog chain for the remainder of the rings in the diamond, 11 link dog chain in corners	(6,4,4,2,4...every two links in the bag), 12 link dog chain for the first diamond, 9 link dog chain for the remainder of the rings in the diamond, 11 link dog chain in corners
Twine Top	2:1 with two in the sides (60 Meshes)	1.5:1 with two in the sides (45 Meshes)
Diamonds	14	14
Skirt	2X28 or 2X40	2X28 or 2X40
Sides	6X18 or 6X20	6X18 or 6X20
Apron	8 X 40	5 X 40
Bag	10 X 40	10 X 40
Chaffing Gear	Sewn in three rows down from the sweep for the bag and on the diamonds	Sewn in three rows down from the sweep for the bag and on the diamonds
Club Stick	20 link dog chains	20 link dog chains

Table 4 Species List

Common Name	Scientific Name
Invertebrates	
Sea Scallop	*Placopecten magellanicus*
Flatfish	
Yellowtail Flounder	*Limanda ferruginea*
Winter Flounder	*Pseudopleuronectes americanus*
Windowpane Flounder	*Scophthalmus aquosus*
Summer Flounder (Fluke)	*Paralichthys dentatus*
Skates	
Barndoor Skates	*Dipturus laevis*
Little Skates	*Leucoraja erinacea*
Winter Skates	*Leucoraja ocellata*

Table 5 Total catch of yellowtail, winter, windowpane, and summer flounders, sea scallops and benthos in the experimental (5R-top, LPD-middle, and 5R with windows-bottom) versus control dredges. Benthos and sea scallops are quantified in bushels and flatfish in pounds (lbs).

	Benthos (bu)	Yellowtail	Winter	Windowpane	Summer	Scallops (bu)
Experimental (5R)	278	1061	149	314	75	769
Control	374	1621	223	570	135	822
Difference	-96	-560	-74	-256	-60	-53
% Difference	-25.67%	-34.55%	-33.18%	-44.91%	-44.44%	-6.45%
N	148	110	100	75	45	145

	Benthos (bu)	Yellowtail	Winter	Windowpane	Summer	Scallops (bu)
Experimental (LPD)	205	271	13	556	112	431
Control	251	388	32	1030	193	622
Difference	-46	-117	-19	-474	-81	-191
% Difference	-18.48%	-30.15%	-59.38%	-46.02%	-41.97%	-30.76%
N	150	80	33	127	53	149

	Benthos (bu)	Yellowtail	Winter	Windowpane	Summer	Scallops (bu)
Experimental (5R w/window)	41	302	23	2	3	126
Control	42	501	42	13	3	130
Difference	-1	-199	-19	-11	0	-4
% Difference	-2.38%	-39.72%	-45.24%	-84.62%	0.00%	-3.08%
N	28	20	25	8	6	28

Table 6 Mean and standard deviation scallop, benthos, skate and total fish catch per tow in bushels and proportion of total catch in the experimental CFTDD and Control Dredge in the 30 largest tows (top) and the 30 smallest tows by volume (bottom).

		Scallop	Benthos	Skate	Fish
Experimental	**Mean (SD)**	11.49 (9.28)	3.93 (4.90)	1.11 (0.64)	0.14 (0.16)
	Proportion	68.94%	23.56%	6.67%	0.83%
Control	**Mean (SD)**	11.95 (9.61)	4.38 (3.53)	1.18 (0.67)	0.18 (0.25)
	Proportion	67.54%	24.77%	6.65%	1.04%

		Scallop	Benthos	Skate	Fish
Experimental	**Mean (SD)**	1.93 (0.93)	0.49 (.48)	0.59 (0.52)	0.09 (0.10)
	Proportion	62.18%	15.93%	18.90%	2.99%
Control	**Mean (SD)**	2.61 (1.35)	0.67 (0.82)	0.62 (0.44)	0.20 (0.24)
	Proportion	63.56%	16.29%	15.19%	4.96%

Table 7 Mean weight (lbs) of fish per tow and (standard deviation) for the experimental CFTDD (5R/ 45 meshes) and Control Dredge. P-values were obtained using a Mann-Whitney Rank Sum Test.

	Yellowtail (SD)	**Winter (SD)**	**Windowpane (SD)**	**Summer (SD)**	**Sea Scallops (SD)**
Experimental (5R)	10.73 (17.27)	2.13 (2.73)	1.95 (2.22)	6.39 (7.19)	39.56 (42.13)
Control	15.99 (23.56)	3.55 (4.00)	3.58 (3.92)	7.90 (9.56)	44.12 (44.98)
Difference of Means	-5.26	-1.42	-1.63	-1.50	-4.56
% Difference	-32.89%	-40.05%	-45.57%	-19.05%	-10.34%
N	110	100	75	45	145
U Statistic	5018	3692	2100	935	9279
P-Value	0.029*	0.001*	.007*	0.526	0.084

* Denotes significiant difference ($p < 0.05$)

Table 8 Total yellowtail, winter, windowpane flounder and scallop weights (lbs) and bycatch rates for the experimental CFTDD and Control Dredge.

Gear Type		**Yellowtail**	**Winter**	**Windowpane**	**Summer**	**Scallops**
Experimental (5R)	**Fish Weight (lbs)**	1169.3	212.90	6.43	287.65	5735.84
	Bycatch Rate	0.20	0.04	0.001	0.05	
Control	**Fish Weight (lbs)**	1751.85	355.05	11.70	355.30	6397.05
	Bycatch Rate	0.27	0.06	0.002	0.06	

<u>Table 9</u> Mean weight (lbs) of fish per tow and (standard deviation) for the Low Profile Dredge and Control Dredge. P-values were obtained using a Mann-Whitney Rank Sum Test.

	Yellowtail (SD)	Winter (SD)	Windowpane (SD)	Summer Flounder (SD)	Sea Scallops (SD)
Experimental (LPD)	3.20 (4.24)	0.61 (0.97)	2.08 (3.42)	5.91 (12.03)	22.28 (20.99)
Control	5.31 (6.36)	1.89 (2.14)	3.83 (5.56)	10.18 (12.68)	32.21 (26.92)
Difference	-2.11	-1.28	-1.75	-4.27	-9.99
% Difference	-39.79%	-67.85%	-45.67%	-41.99%	-31.03%
N	80	33	127	53	149
U Statistic	2368	312	8621	824	8156
P-Value	0.004*	0.002*	0.001*	0.001*	<0.001*

* Denotes significiant difference ($p < 0.05$)

<u>Table 10</u> Total yellowtail, winter, windowpane flounder and scallop weights (lbs) and bycatch rates for the Low Profile Dredge and Control Dredge.

Gear Type		Yellowtail	Winter	Windowpane	Summer	Scallops
Experimental (LPD)	**Fish Weight (lbs)**	255.7	20	264.35	312.95	3341.31
	Bycatch Rate	0.08	0.01	0.08	0.09	
Control	**Fish Weight (lbs)**	424.60	62.20	486.40	539.50	4843.03
	Bycatch Rate	0.09	0.01	0.10	0.11	

Table 11 Mean weight (lbs) of fish per tow and (standard deviation) for the experimental CFTDD with windows and the Control Dredge. P-values were obtained using a Mann-Whitney Rank Sum Test or a two-tailed Student's t-test.

	Yellowtail (SD)	Winter (SD)	Windowpane (SD)	Summer (SD)	Scallops (SD)
Experimental (5R window)	16.95 (18.36)	1.35 (1.46)	0.11 (0.215)	2.83 (3.55)	30.61 (13.34)
Control	28.32 (28.16)	2.56 (2.12)	0.93 (0.522)	3.50 (3.97)	32.62 (12.71)
Difference	-11.37	-1.21	-0.81	-0.67	-2.02
% Difference	-40.14%	-47.38%	-87.78%	-19.06%	-6.18%
N	20	25	8	6	28
Test Statistic	3267	207	2	16	-0.6 ”
P-Value	0.151	0.038*	0.001*	0.818	0.282 ”

* Denotes significiant difference ($p < 0.05$)

” P-value obtained from a two-tailed Student's t-test.

Table 12 Total yellowtail, winter and windowpane flounder and sea scallop weights (lbs) and bycatch rates for the experimental CFTDD with windows and the Control Dredge.

Gear Type		Yellowtail	Winter	Windowpane	Summer	Scallops
Experimental (5R window)	**Fish Weight (lbs)**	339.05	33.70	0.90	17.00	856.93
	Bycatch Rate	0.40	0.04	0.00	0.02	
Control	**Fish Weight (lbs)**	566.40	64.05	7.40	21.00	913.40
	Bycatch Rate	0.62	0.07	0.01	0.02	

Table 13 Model building results for each species examined in the analysis. Fixed effects included in the model indicate the specification that resulted in the lowest AIC value for that particular species. Random effects are shown in brackets and were included at the tow level. Species where the model failed to converge are indicated.

Species	**Model Specification**
Barndoor Skate	RE_{5R} ~ intercept +frame+[tow]
Unclassified Skate	RE_{5R} ~ intercept +frame+[tow]
Summer Flounder	RE_{5R} ~ intercept + length + [tow]
Yellowtail Flounder	RE_{5R} ~ intercept +[tow]
Winter Flounder	RE_{5R} ~ intercept +[tow]
Windowpane Flounder	RE_{5R} ~ intercept +[tow]
Monkfish	RE_{5R} ~ intercept +[tow]
Sea Scallops	RE_{5R} ~ intercept + length + frame + [tow]

Table 14 Mixed effects model for sea scallop catch using the unpooled catch data . Results are for from the model that provided the best fit (intercept, length and frame) to the data as supported by model comparison (minimum AIC value). Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale.

Species	**Effect**	**Frame**	**Estimate**	**SE**	**DF**	**t-value**	**p-value**	**LCI**	**UCI**
Sea Scallop	Intercept		-0.770	0.105	3662	-7.326	<0.001	-0.976	-0.564
	Size		0.004	0.001	3662	6.133	<0.001	0.003	0.006
	Frame	LPD	-0.285	0.058	3662	-4.921	<0.001	-0.399	-0.172
	Frame	CFTDD	0.000						

Table 15 Mixed effects model for summer flounder catch using the unpooled catch data. Results are for from the model that provided the best fit (intercept and length) to the data as supported by model comparison (minimum AIC value). Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale.

Species	**Effect**	**Estimate**	**SE**	**DF**	**t-value**	**p-value**	**LCI**	**UCI**
Summer Flounder	Intercept	-2.205	0.520	411	-4.241	<0.001	-3.227	-1.183
	Length	0.033	0.011	411	3.148	0.002	0.013	0.054