Relative Efficiency of a Coonamessett Farm Turtle Excluder Dredge Equipped with Escape Windows

Final Report

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Project Summary

Throughout the duration of this project, March 2014 through May 2015, Coonamessett Farm Foundation, Inc. tested the efficacy of using escape windows to reduce flatfish bycatch. Four designated research trips aboard Limited Access vessels and 24 days of testing took place aboard a Limited Access General Category vessel *F/V Mister G* during the research period. Aboard the first vessel, the *F/V Reliance*, five different seam window configurations were tested but were not pursued further beyond this trip due to an observed reduction in scallop catch utilizing these configurations. A rigid escape window configuration was tested for a limited number of tows during the second trip aboard the *F/V Celtic*. This configuration was abandoned when the headbale crushed the frames. The final configuration, CFFTDD14, utilized chain to maintain the shape of the window and bag and was tested during the remaining two research trips aboard the *F/V Endeavor* and *F/V Concordia*. Unfortunately, escape windows configured in the manner tested during this project are not a viable means of reducing bycatch within the scalloping industry due to an excessive loss in scallop catch.

Vessel	Start Date	End Date	Number of Tows	Experimental Gear Tested
Reliance	8/25/2014	8/31/2014	49	CFFTDD08, CFFTDD09, CFFTDD10, CFFTDD11, CFFTDD12
Celtic	9/16/2014	9/22/2014	42	CFFTDD13, CFFTDD14
Endeavor	9/29/2014	10/05/2014	43	CFFTDD14
Concordia	1/17/2015	1/23/2015	50	CFFTDD14

Introduction

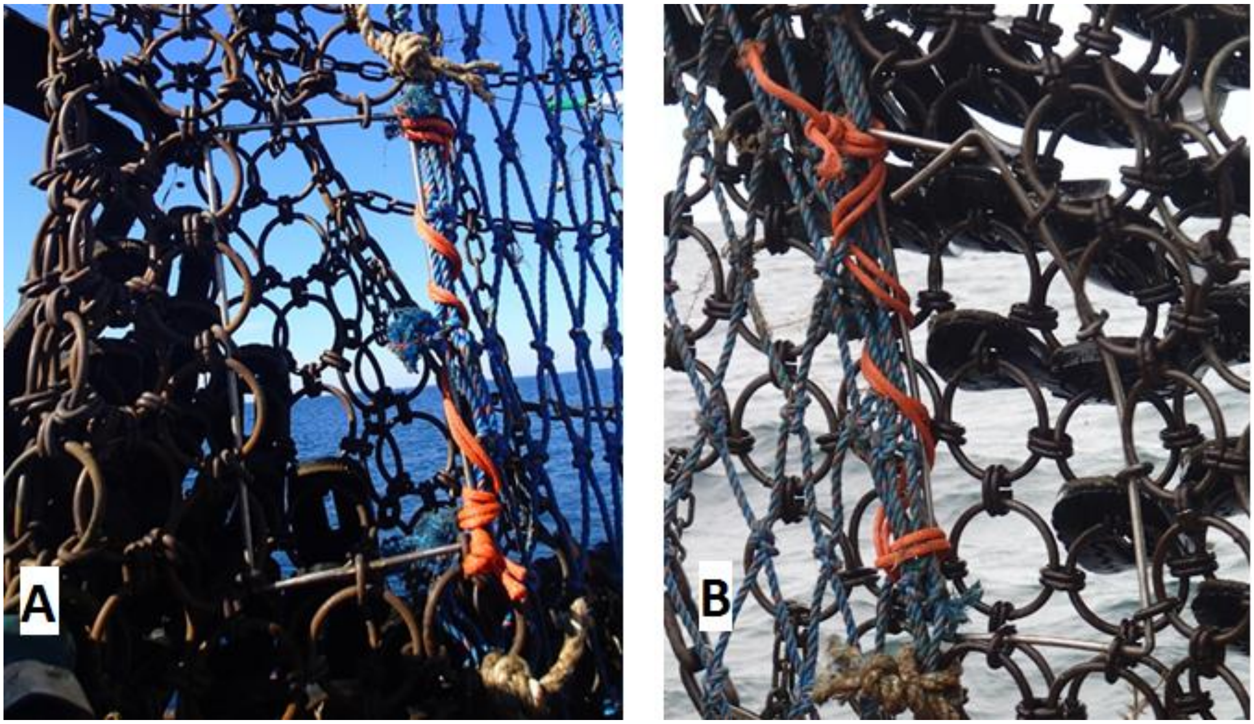
As the environmental impacts of fishing become more easily definable through the use of ecosystem-based models, the research and development of sustainable fishing gear becomes increasingly necessary for the long-term sustainability of fisheries (Jennings and Revill, 2007). Large populations of Atlantic sea scallops (*Placopecten magellanicus*) on Georges Bank and in the Mid-Atlantic region support one of the world's most lucrative fisheries (Hart and Jacobson, 2013). The high level of economic productivity, lasting for almost a decade, is due in part to the successful collaboration of the fishing community, managers and scientists through the sea scallop Research Set Aside (RSA) program (O'Keefe and Stokesbury, 2009; Adams, 2014). Bycatch mitigation and avoidance utilizing current technology and innovative thinking has been one of the main goals of the scallop RSA program.

Gear-based bycatch solutions are often the most effective means to achieving a long-term solution for the reduction of bycatch within a fishery (Jennings and Revill, 2007). Time/area closures can be a successful means of reducing fleet wide bycatch, but seasonal changes in bycatch rates make it difficult to optimize closures. Area closures can also displace fishing effort leading to localized overfishing of productive fishing grounds (Hiddink et al., 2006). Fishing area closures in the late 2000's that were the result of the scallop fleet exceeding the sub-Annual Catch Limit (ACL) of yellowtail flounder (*Limanda ferruginea*) prevented the economic maximization of the resource (O'Keefe and DeCelles, 2013). The use of environmentally responsible fishing gear which has a greater species and size selectivity than current traditional fishing gear can be an effective alternative to area closures and fishing effort reduction. Gear regulations can also be used in conjunction with area closures through the creation of Gear Restricted Areas (GRA). Framework 25 utilizes a GRA as a windowpane flounder Accountability Measure (AM). The benefit of a gear based solution is that fishermen would be allowed to continue fishing while simultaneously reducing their impact on the marine ecosystem.

From 2012 to present Coonamessett Farm Foundation, Inc. has been investigating the efficacy of dredge bag modifications for the reduction of flatfish bycatch. In 2012 and 2013, the focus of our research was to investigate the impacts of a reduced twine top hanging ratio and a short apron (NA12NMF4540041). From those projects we were able to show that simple modifications to the bag design could have a large impact on flatfish bycatch in the scallop dredge fishery. The Northeast Fisheries Management Council (NEFMC) was able to utilize data from both years of research to create and implement Framework 26, which regulated the apron length to a maximum of 7 rows of rings. Bag design modifications serve to facilitate the escapement of flatfish that have already become captured in the dredge bag. The working hypothesis for why the short apron and low twine top hanging ratio reduced bycatch is that the modification increases the mechanical sorting ability of the dredge bag. Less dense material like small scallops and fish are more easily expelled through a longer more open twine top.

On the first cruise of the 2012 project, thirty half-hour tows were completed investigating the use of escape windows cut into the side piece of the dredge, with mild success (Table A1). The windows were located along the seam created by the union of the side piece and diamonds (Figure A1). No further testing of the escape windows occurred in 2012 and 2013 in order to limit the number of modifications that could influence the performance of the dredge. A more robust data set only using a low twine top hanging ratio and a short apron had greater applications for the management of the scallop fishery at the time. Keeping in mind the escape window data from 2012, we decided to thoroughly test the use of escape windows for the reduction of flatfish bycatch in 2014. We hypothesized that the escape windows may better allow animals with a stronger swimming ability to escape while retaining scallops that have limited swimming capabilities. The escape-window research took place on four Limited Access (LA) scallop vessels and one Limited Access General Category (LAGC) vessel, the *F/V Mister G*.

The first LA vessel used for the testing of escape windows as means to reduce flatfish bycatch was the *F/V Reliance*. During this trip a similar window configuration to that of the 2012 Concordia trip was tested for 10 half-hour tows. The only difference between this dredge configuration and the 2012 configuration was the apron length, which was 5 rings in 2012 and 8 rings for this experiment. After these 10 tows it was determined that the loss in scallop catch exceeded an acceptable level. We then moved the windows two rows up along the seam and conducted a series of ten more tows. As with the first configuration, the second configuration exceeded the threshold of acceptability for the loss of target species catch. In total five different window configurations along the seam of the dredge bag were tested during the *F/V Reliance* trip, with each configuration reducing the scallop catch enough to impact the conservation benefit of the modification. The loss in scallop catch may have been due to the location of the window along the seam of bag. As the bag filled, scallops would be deflected by the sweep and spill through the windows intended to facilitate the escape of flatfish from the dredge bag. Figure A2 and Table A2 offer a visual representation and a description of each window configuration tested aboard the *F/V Reliance*. During this trip we also decided to change the standardized tow time of 30 minutes to 60 minutes in order to better represent commercial fishing practices. The standard commercial tow time is often between 55 to 75 minutes. This tow time was also appropriate for the scallop densities encountered in the areas where the study took place.



<u>Figure 1</u> A picture of CFFTDD13, the rigid frame windows tested during the F/V Celtic research trip. **Picture A** is the intact frame and **Picture B** is the crushed frame.

With unsuccessful results using escape windows located along the seams of the bag, we decided to shift the location of the escape windows to the top of the dredge bag adjacent to the twine top (Figure A3). We believed that this location would not cause the loss of scallop catch observed with the seam-escape window configurations tested during the *F/V Reliance* trip. The second cruise aboard the *F/V Celtic* tested an escape configuration that utilized rigid frames made from stainless steel to outline the escape window and maintain the shape of the bag (Figure 1). The frame was linked to a two-ring by four-ring hole This configuration appeared to be working as planned until after ten tows, when the structural integrity of the rigid frames was compromised because the headbale crushed them (Figure 1). The frames were crushed while the catch was being dumped from the bag during standard deck operations. We then removed the crushed frames and lined the escape windows with chain, hoping this configuration would be able to withstand the normal operations of dumping out the scallop catch while at same maintaining the shape of the bag (Figure 2). This window configuration, CFFTDD14, was the final modification to the bag design and was tested on all the remaining LA trips aboard the *F/V Endeavor* and *F/V Concordia.* A similar chain window configuration was also compared to a control bag design during 24 days at sea (DAS) aboard the LAGC scallop vessel the *F/V Mister G*.

Figure 2 A picture of the CFFTDD14, the dog chain windows, this was the final configuration that was tested during the *F/V Celtic, F/V Endeavor and F/V Concordia* trips.

LAGC vessels in the Northeast Atlantic are regulated to a combined dredge width of 10.5 feet, and for this reason the vessels often fish a single dredge between 8 and 10.5 feet. These vessels are often smaller and tow at relatively slower speeds compared to LA vessels that have the capability of towing at higher speeds with greater efficiency. Gear modifications may impact the LAGC fishery in an unintended manner, and therefore it is necessary to test gear modifications aboard these vessels. Twenty four days at sea were divided into 12 two-day trips, alternating between the control and the experimental gear with escape windows. Originally, we had intended to test a dredge bag with escape windows attached to three different headbale designs: the low profile dredge, the turtle deflector dredge, and a Provincetown dredge. Due to the inherent variability associated with using an alternative tow strategy, the low profile dredge and turtle deflector dredge headbales were dropped from the experiment. This was done to gather a more complete understanding of the impacts of escape windows without having to account for the impacts that headbale design may have on the catch efficiency of the gear.

As stated previously, LAGC vessels tend to be smaller than their LA counterparts and typically are rigged to tow a single narrower dredge. This vessel configuration presents some challenges from an experimental design standpoint. The LA vessels can simultaneously fish two dredges in a paired fashion to test a dredge modification against a standardized design. This setup is less impacted by variability introduced by time and space than gear comparison studies on different vessels or experimental treatments separated spatiotemporally.

With a paired experimental design, there exists a body of literature focused on analytical approaches specific to this design (Cadigan et al., 2006; Cadigan and Dowden, 2009; Holst and Revill, 2009; Miller, 2013). These approaches take advantage of the paired nature of the data to draw inference on the relative efficiency of the two gears tested in the experiment. In the case of the current study on LAGC vessels, we did not have the luxury of being able to conduct paired tows, or even make at-sea modifications to the gear to approximate paired tows via an alternate tow design, both of which would have reduced, but not eliminated the variability introduced by separating non-paired tows in both time and space. However, given the constraints imposed by the fishing vessel, the experimental design for this study consisted of testing the control gear (PTD01 – no windows in the dredge bag) relative to the experimental gear (PTD02 – windows in the dredge bag) on alternate days.

Methods

Limited Access Field Sampling Methods

During the four paired tow cruises, control and experimental dredges were towed simultaneously. Towing speeds were maintained at commercially representative speeds (4.8-5.5 knots) with a wire scope of three-to-one plus ten fathoms. On all directed research trip tows, the entire scallop catch was counted in bushel baskets and weighed in to the nearest 0.01 kilograms using a Marel scale. A randomly selected one-basket subsample from each side was measured in five-millimeter increments. A one-bushel subsample has been found to accurately represent the size frequency of scallops in a commercial catch (4-inch ring dredge bag) based on our previous research. The fish catch was counted, weighed to a 0.01 kg resolution, and measured in one-centimeter increments by species. The trash or benthos was also counted into bushels and weighed to the nearest 0.01 kilograms. Tow parameter data was recorded using CFF's OLRAC Electronic Monitoring System, which records the vessel's position, heading, and speed in 15-second intervals using the vessel's onboard GPS system. Environmental data was also recorded using the OLRAC system, and this included a Beaufort value, wind direction, wind speed, and sea conditions. Tows were considered to be invalid if the towing parameters were not followed or if there was a gear malfunction with one of the dredges (e.g. tangled twine top or the dredge flipping during setting out). In cases where there were large catches of fish, a subsample was collected for size frequency data.

Data collected for each paired Limited Access tow included:

- Scallop catch rates (bushel(s)/tow/side)
- Scallop catch weight (sum of bushel(s) weight/tow/side)
- Scallop shell height frequency (one bushel/tow/side)
- Finfish catch rates (# of individuals/tow/side)

- Finfish weight (species weight/tow/side)
- Finfish and invertebrate length frequency (by species and species groups (i.e. controlled groundfish species, other groundfish species, pelagic species, and shellfish))
- Skate catch rates (# of individuals/tow/side)
- Skate weight (total weight/tow/side)
- Weight, volumetric and composition assessment of trash (i.e. sea star and crab species)

Limited Access General Category Field Sampling Methods

The *F/V Mister G.* utilized the vessel's dredge and with a standard bag configuration as the control. The experimental bag configuration was identical to the control bag with the exception of the escape windows placed on the top of the bag adjacent to the twine top (Table A3). The vessel was asked to fish the control bag and experimental bag configurations, alternating the dredge bag every other day. The control and experimental bag configurations were tested for a total of twelve paired days or 24 DAS. Towing speed and scope (~4.2 knots and 3:1 +/- 10 fathoms) were held constant and based on the vessel's operating parameters. For each tow a standard tow time of approximately 50 minutes per tow was chosen based on catch rates. Latitude and longitude, vessel speed, and tow distance were recorded for each tow using a handheld GPS. All relevant atmospheric data was recorded on the bridge logs. The Beaufort scale was used as a proxy for sea state and wind intensity because it's a standard measurement that can be objectively recorded at sea. Catch and bycatch were sampled from each tow on LAGC trips. The amount of scallops in the catch was evaluated by the number of baskets. Bycatch species were weighed for total weight and individually measured to the nearest centimeter. The research trips all occurred on "open bottom" in Southern New England, southeast of Block Island, RI.

Data collected for each LAGC tow included:

- Scallop catch rates (bushel(s)/tow)
- Scallop shell height frequency (one bushel/tow)
- Finfish catch rates (# of individuals/tow)
- Finfish and invertebrate length frequency (by species and species groups (i.e. controlled groundfish species, other groundfish species, pelagic species, and shellfish))
- Skate catch rates (# of individuals/tow)
- Skate weight (total weight/tow)

Statistical Models – LA Analysis (GLMM)

Catch data from the paired tows provided the information to estimate differences in the relative efficiency between the two gear combinations tested. This analysis is based on the analytical approach in Cadigan et al. 2006. Our analysis of the efficiency of the CFFTDD07 relative to the CFFTDD14 consisted of multiple levels of examination. Additional details about the derivation of the model can be found in Appendix B.

The model assumes that each gear combination has a unique catchability and differences in scallop or fish catch between paired dredges will be reflected in the ratio of the catchability of the CFFTDD14 (q_r) to the catchability of the CFFTDD07 (q_f). The probability that a scallop or fish is captured by the CFFTDD14 is $p=\rho/(1+\rho)$, where $\rho = q_r/ q_f$.

If binomial regression is used to compare tows, a common practice because fishing catch data is typically over dispersed, and spatial heterogeneity of animal densities is incorporated, the logit (log of the odds) function of the binomial probability p is:

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

After additional terms are added to account for catchability at length (l) and sub-sampling of the catch, the full initial model using unpooled by length catch data becomes:

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

The Alkaike Information Criteria (AIC) was used to select the best model configuration (Akaike 1973). If AIC and factor significance indicated that length was not a significant factor in predicting relative efficiency, the data was pooled over length and the random intercept model was evaluated to assess relative differences in total catch (Equation 1).

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

Statistical Models - LAGC Analysis

This experimental design imposed a number of analytical challenges. Given the non-paired nature of the observations, we were unable to utilize the analytical approaches considered to be the current standard approaches (Cadigan et al., 2006; Cadigan and Dowden, 2009; Holst and Revill, 2009; Miller, 2013). Given these constraints, our overarching objective was to construct a model that would predict the catch of either the target or bycatch species as a function of a suite of predictor variables collected during the trials. The candidate explanatory variables included gear configuration, animal size, water depth, and sea conditions. In addition to being non-paired, the scaling of the catch data was variable as a function of differential tow durations and resulting differences in the areal coverage for a given tow. Catch data from these trials was typical for this type of experiment and consisted of count data. Appropriate distributions to describe count data are the Poisson distribution that describes the probability of an event occurring during a discrete time or space. With respect to fisheries data in general and our data specifically, variance typically exceed the mean and results in overdispersion. The relaxation of the requirement of equal mean and variance imposed by the Poisson distribution is typically characterized by the negative binomial distribution. Given the nature of the data to be analyzed here (overdispersed count data), a family of regression approaches based on the Poisson and negative binomial distributions were explored to create a predictive model to describe the catch data.

Poisson and negative binomial regression were used to examine the catch data and describe the important factors influencing observed differences in catch. As mentioned above, the explanatory variables included categorical variables of gear and Beaufort scale, as well as continuous variables of water depth and animal size. Descriptive statistics for each of these variables are shown in Tables C1-C2. Due to the differences in areal coverage for each tow, the catch data was adjusted within the modeling framework to allow for equal scaling of the catch data. This was accomplished by the inclusion of an offset term in the regression that accounted for the differences in the tow length of the individual tows and as a result, tow distance was not included as an explanatory variable in the model. The determination of whether the data was best described by either the Poisson or negative binomial distributions was assessed by examining the significance of an estimated dispersion parameter in the negative binomial model run. A parameter estimate significantly different from 0 was deemed to be indicative of an overdispersed situation, best described by the negative binomial distribution. For each species of interest (unclassified skates, barndoor skates, summer flounder, fourspot flounder, yellowtail flounder, winter flounder, windowpane flounder, monkfish, and sea scallops), the distributional characteristics were evaluated and the factors included in the model that best fit the data was determined via the AIC. For each species, an estimate of mean catch for the most parsimonious model was calculated to provide a realistic mean catch value.

Results

Limited Access (LA) Catch Data

The data from the four survey cruises were treated as a single data set for the purposes of this analysis. As stated in previous sections, the first trip of the series (*F/V Reliance*) and a portion of the second trip (*F/V Celtic*) were used to test possible configurations of gear modifications within the general context of the experimental approach. These tows were not included in the GLMM analysis. Instead we focused on the final modification, CFFTDD14, as described in Table A2. Tables B1-B6 provide a brief comparison of the five different configurations tested during the *F/V Reliance* trip.

Table 1 The pooled catch weight (kilograms) data from the paired tows testing the final window configuration, CFFTDD14. Scallops were weighed live and whole (shell attached).

Pooled Data	Scallops	Yellowtail Flounder	Winter Flounder	Windowpane Flounder	Fourspot Flounder	Summer Flounder	Barndoor Skate	Monkfish
CFFTDD14	17882.78	289.81	57.70	426.59	50.86	59.88	70.82	1109.79
Control	21861.02	372.68	58.27	489.87	69.52	67.79	71.27	1328.24
Difference	-3978.24	-82.87	-0.57	-63.28	-18.66	-7.91	-0.45	-218.45
% difference	-10.01%	-12.51%	-0.49%	-6.90%	-15.50%	-6.20%	-0.32%	-8.96%

The dredge bag configuration and frames for the control dredge, CFFTDD07, and the experimental dredge, CFFTDD14, were identical with the exception of escape windows cut into the side piece of the CFFTDD14 dredge bag. For all cruises the control dredge configuration (CFFTDD07) was consistent. Overall, the CFFTDD14 data set consisted of 101 valid tow pairs that were examined in the analysis. Pooled catch data of the testing of CFFTDD14 from the *F/V Celtic*, *F/V Endeavor* and *F/V Concordia* can be found in Table 1. Not all species were present in all tow pairs and for the species examined, individual tows with zero total catch for a given species were uninformative and excluded from the analysis. Figure 3 shows the pooled scallop size frequency distribution. Tables B7-B9 provide a trip by trip summary of the catch data collected during the testing of CFFTDD14 window.

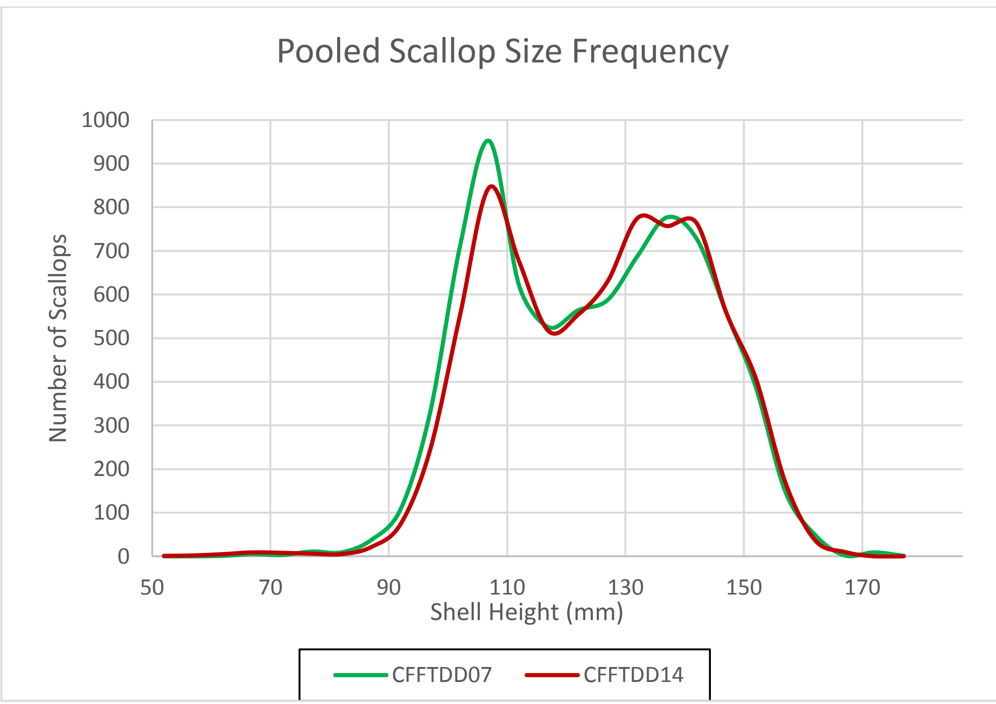


Figure 3 Pooled scallop size frequency data from the three trips that tested the CFFTDD14 (F/V Celtic, F/V Endeavor and F/V Concordia.

LA Statistical Models

This analysis attempted to construct a model that would predict the relative efficiency of the CFFTDD14 dredge relative to the CFFTDD07 dredge tested in the experiment based on a variety of covariates. In many instances, especially with gear modifications that can possibly alter the relative size composition of the catch, using the unpooled catch data and exploring the length based relative efficiency becomes informative. This analysis utilizing the unpooled catch data predicts the changes that the CFFTDD14 dredge had on the relative catch at length for the two gears. For many species, however, length was not a significant predictor of relative efficiency. In these cases, an overall change in the relative total catch was possible and tested via a model specification using the pooled catch data.

LA 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 in these cases. Table 2 shows the best model fit as determined by AIC for the various species in the analysis. Parameter estimates associated with each model specification are shown in Table B10-11. 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 B1-18.

Table 2 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. AIC values that were within two units of each other were considered indistinguishable and the simpler model was chosen. Random effects are shown in brackets and were included at the station level. Species where the model failed to converge are indicated.

Species	Model Specification
Spiny Dogfish	Did Not Converge
Barndoor Skate	Did Not Converge]
Unclassified Skates	RE_{TDD} ~ intercept +[station]
Haddock	RE_{TDD} ~ intercept +[station]
Summer Flounder	RE_{TDD} ~ intercept +[station]
Fourspot Flounder	RE_{TDD} ~ intercept +[station]
Yellowtail Flounder	RE_{TDD} ~ intercept +[station]
Winter Flounder	Did Not Converge
Windowpane Flounder	RE_{TDD} ~ intercept + [station]
Monkfish	RE_{TDD} ~ intercept +[station]
Sea Scallops	RE_{TDD}~ intercept + length + [station]

For the length-based model, the sea scallop was the only species where this model provided the best fit to the data. Figures 5-10 show the graphical results for each species as a function of length. Even though these length-based models may not have provided the best fit to the data for most of the species, they provide insight into how the gear modification affected catch at length. Across species, there was no clear directionality in relative efficiency using the CFFTDD14 dredge configuration relative to the CFFTDD07 as length increased. For windowpane and yellowtail flounder, the reduction in relative efficiency with respect to size was slight especially when viewed in the context of the portion of the length distribution where most of the observed animals were present. For monkfish and fourspot flounder, the relative efficiency increased as a function of length but only slightly, and the effect was not statistically significant. Only for scallops, the increase in relative efficiency for the CFFTDD14 with respect to length was statistically significant, suggesting that as scallop length increased the relative efficiency of the CFFTDD14 increased. Overall, however, the total catch for the CFFTDD14 was lower across all size classes as can be seen by the estimated proportion being <0.5 across the range of lengths modeled.

Animal length was not a significant predictor of relative efficiency for many of the species analyzed, and the catch data was pooled over length. There was a significant difference in total catch between the CFFTDD14 and CFFTDD07 dredges for most of the tested species (unclassified skates, haddock, fourspot flounder, yellowtail flounder, windowpane flounder, monkfish, and sea scallops). Across all species, there was a reduction of catch of the CFFTDD14 relative to the CFFTDD07. In general these reductions were 15-30% (Table B11). Notable flatfish results indicated that for yellowtail flounder and windowpane flounder there were decreases of 23.0% and 16.3%, respectively. For summer flounder, there was no statistically significant difference in the overall catches between the two gears, but looking at trends in the coefficients, there was an overall reduction of summer flounder bycatch in the CFFTDD14 relative to the CFFTDD07. Care must be taken when interpreting the results from haddock. The data for this species consisted of a small number of tow pairs, and the point estimates are highly uncertain with broad confidence intervals around them.

Total pooled scallop catch was also reduced by the CFFTDD14 relative to the CFFTDD07 by roughly 22%. The reduction of target catch must be weighed with respect to the possible implementation of a gear modification.

LAGC Model Results

Scaled length frequency distributions that reflect the differential areal coverage per tow are shown in Figures C1-C8. The model formulation as well as distribution that best fit the data obtained for each species of interest is shown in Table C3. Parameter estimates for each species are shown in Tables C4-C8 and estimated mean catch calculated from those parameters are shown in Table C9. The estimated mean catches are presented as a function of the scaling by the offset variable and represent the catch for a given species per nautical mile towed.

The regression results of the LAGC data suggest that for most bycatch species, the windows had little effect on catch rate. This was the case for all of the flatfish species that could be included in the analysis (those with a reasonable amount of observations). Windows appeared to reduce the relative catch for only unclassified skates and monkfish. While gear modifications endeavor to maintain target catch levels, sea scallops were reduced overall as a function of the window modification. Sea scallops were the only species where length was identified as a significant factor. The parameter estimate associated with scallop size was positive, suggesting an increase in the catch (on the log scale) as scallop size increased. Parameter estimates for the categorical factor of gear indicate that the PTD01 caught significantly more scallops than the PTD02. This result is suggestive of scallop loss as a result the windows in the dredge bag.

Discussion

The use of the escape window configurations tested during this experiment as a means to reduce flatfish bycatch in the sea scallop fishery of the Northwest Atlantic appears to be ineffective due to a significant decrease in catch efficiency of sea scallops (Table B11 and Figure B13). The goal of gear testing and development is to produce environmentally responsible fishing gear that has greater species and size selectivity and reduces habitat impact (Jennings and Revill, 2007). Gear modifications that significantly reduce target species catch increase environmental impact by leading to more fishing effort. The model predicted the reduction in scallop catch efficiency for the CFFTDD14 to be 22.3% and the reduction in yellowtail and windowpane flounder bycatch to be 23.0% and 16.3% (Table B11). This means that 22.3% more effort would be required to catch the equivalent scallop landings of the control dredge bag; which, matches observed commercial scallop dredge bag configurations. In the case of windowpane flounder, the predicted reduction in scallop catch exceeds the predicted reduction in windowpane catch. For yellowtail flounder the predicted reduction in catch is marginally greater than the decrease in scallop catch. In light of these findings the use of escape windows as configured in the ways tested during the course of this experiment would provide no conservation benefit to the scalloping industry.

During the trip aboard the *F/V Reliance* many different window configurations were tested along the seam of the dredge bag. Each of these configurations was tested for only a limited number of tows providing only descriptive statistics (Tables B1-6). Observed reductions in scallop catch for these configurations was too great to warrant further testing. This may have been a result of scallops being kicked up by the sweep and spilling through the escape windows intended to allow fish to escape. Normally, an intact side piece would deflect these scallops to the back of the dredge bag. The windows had an opening that is greater than the regulated four inch rings and because of their larger size, the escape windows were likely allowing retainable scallops to escape. Another possible reason for the loss of scallop catch may have been a result of the escape windows preventing catch from fully accumulating in the dredge bag. Once the catch reached the windows along the seam it was likely spilling out through the escape windows while the control dredge continued to accumulate catch. Videography may provide further information and insight about how the different components of the dredge bag interact. However, the low light conditions and the suspension of sediments caused by the scallop dredge made filming inside the dredge bag itself difficult and no usable footage was obtained during this experiment.

Prior to the departure of the second trip aboard the *F/V Celtic*, the decision was made to no longer test the window configurations along the seam of the dredge bag. Instead the location of the escape windows was shifted to the top of the bag, adjacent to the twine top (Figure 2). A rigid frame was used to maintain the shape of the escape windows and twine top (Figure 1). Ten tows were conducted utilizing this configuration before the rigid frames were no longer structurally intact and began altering the shape of the bag. The frames were broken during normal deck operations. Gear handling and deck operations are an important consideration for gear modifications. Time and effort are wasted when fishing gear has to be replaced. By using chain to outline the windows we were able to maintain the shape of the window and twine top without it being crushed during normal deck operations. This final configuration, CFFTDD14, was utilized on the remainder of the research trips because of the need to gather a more robust data set. As with the seam windows, the CFFTDD14 configuration may have been allowing scallops that would normally have been deflected to the back of the dredge bag to instead pass through the escape windows. Figure 5 shows a picture of scallops caught in the location of the windows and was taken during the testing of the dog chain aboard the *F/V Mister G*. Despite the negative results, testing of the seam window configurations during the *F/V Reliance* trip and the testing of CFFTDD14 did provide insights into the how the different components of the dredge bag interact to maximize the efficiency of the gear. By incorporating the knowledge gained from this project into future projects, we hope to further develop environmentally responsible scallop dredges.

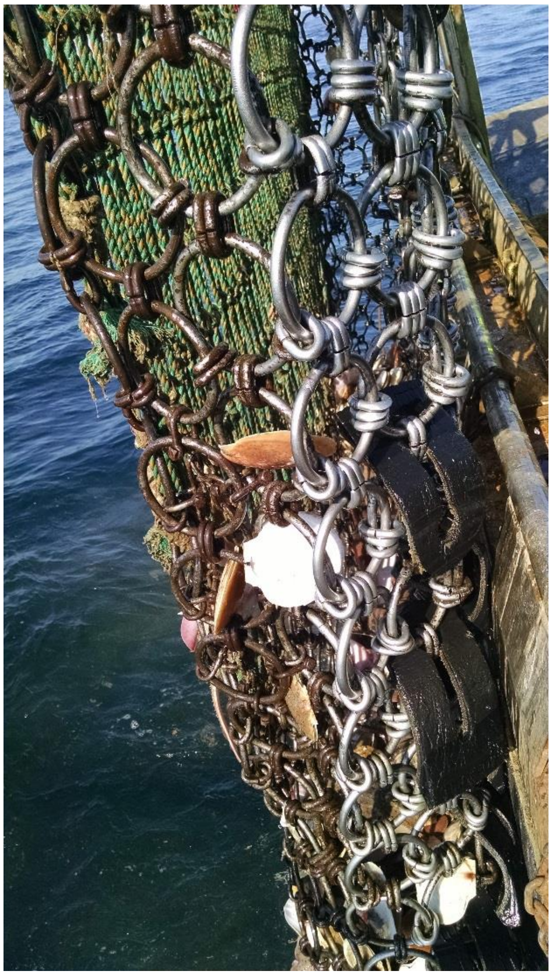


Figure 5 Scallops caught in the window area of the bag indicative that scallops may have been escaping through the opening.

The width of the side pieces for both CFFTDD07 and CFFTDD14 is six rings and the twine top hanging ratio is 2 meshes to a ring or 2:1. As observed during this experiment both the side pieces and the twine top serve to deflect scallops kicked up by the sweep to the back of the dredge bag. The steel rings and twine top however have different selective properties. The 4 inch rings have greater scallop and finfish retention than the regulated 10.5 inch stretched mesh twine top. With the information gained from this experiment it may be worthwhile to experiment with altering the width of the side piece in combination with the twine top hanging ratio. The interconnected nature of the different elements of the dredge bag means that the altering of one aspect of the dredge bag inevitably alters another element of the bag. Reducing the width of the side piece increases the width of the twine top. By lowering the twine top hanging ratio, the meshes of the twine top become more open possibly increasing the likelihood of flatfish escape.

Our results indicate that in many cases, the modifications to the dredge bag by introducing windows (modification CFFTDD14) resulted in a reduction of finfish bycatch in the LA fishery. For a number of species the modeling efforts resulted in significant reductions in overall catch between the two gears while only in scallops did an effect of scallop size prove to be significant. In most cases, however the modification only resulted in a reduction of the overall efficiency of the CFFTDD14 dredge relative to the CFFTDD07. It is also important to realize the effect that dredge bag modifications have with respect to scallop catch and deck operation as these are significant factors for any gear modification. These results however are informative in that it provides insight into how dredge bag modifications affect individual species or similar groups of fish. With this insight, further modifications can be made in an attempt to facilitate additional reductions in bycatch without loss of scallop catch.

The bycatch rates observed in the LAGC experiment were quite low. With the exception of unclassified skates and scallops, most species were captured at an average rate of less than 1 animal per nautical mile towed. Overall, the windows tested in the dredge bag had minimal impact on the reduction of finfish bycatch and resulted in the loss of scallops. Only in the cases of barndoor skate and monkfish did the windows reduce the relative catch between the gears. In all other cases the windows were not a significant factor in predicting catch. While the experimental design of this experiment introduced variability as a function of differences in time and space between the gear configurations the family of regression models used here provided a means to examine the catch data that consisted of, in most cases, overdispersed count data. Perhaps a larger sample size (i.e. more tows) would shed light on the efficacy of the use of escape windows to reduce bycatch within the LAGC fishery.

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Appendix A: Introductory Tables and Figures

<u>Table A1</u> The total yellowtail, winter and windowpane flounder and sea scallop weights (lbs) and bycatch rates for the experimental CFTDD with windows and the Control Dredge from the 2012 RSA Gear Testing Project (NA12NMF4540041).

Gear Type		Yellowtail	Winter	Windowpane	Summer	Scallops
2012 Escape Windows	**Fish Weight (lbs)**	339.05	33.70	0.90	17.00	856.93
	Bycatch Rate	0.40	0.04	0.00	0.02	
Control (CFFTDD07)	**Fish Weight (lbs)**	566.40	64.05	7.40	21.00	913.40
	Bycatch Rate	0.62	0.07	0.01	0.02	

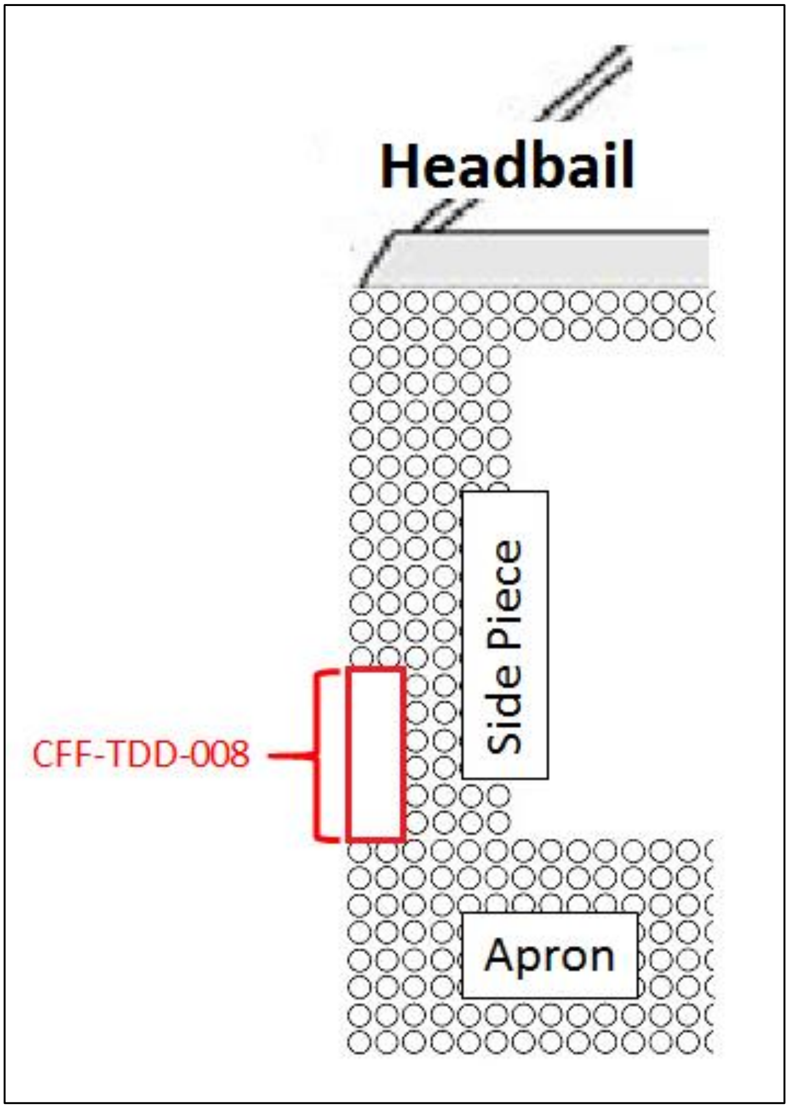
<u>Table A2</u> A brief description of the different window configurations tested during this project. The final configuration, CFFTDD14, is the only configuration for which a sufficient amount was collected to analyze using a GLMM.

Gear ID	Designation	Description of Modification
CFFTDD07	Control	CFF Standardized TDD
CFFTDD08	Experimental	**2 Ring by 6 Ring window** in the side piece where the side piece ends and the apron starts, along the seam created by the union of the diamond and side piece.
CFFTDD09	Experimental	**2 Ring by 4 Ring window** in the side piece where the side piece ends and the apron starts, along the seam created by the union of the diamond and side piece.
CFFTDD10	Experimental	**2 Ring by 4 Ring window** in the side piece **2 rings** up from where the side piece ends and the apron starts, along the seam created by the union of the diamond and side piece.
CFFTDD11	Experimental	**2 Ring by 4 Ring window** in the side piece **4 rings up** from where the side piece ends and the apron starts, along the seam created by the union of the diamond and side piece.
CFFTDD12	Experimental	**2 Ring by 4 Ring window** in the side piece **6 rings up** from where the side piece ends and the apron starts, along the seam created by the union of the diamond and side piece.
CFFTDD13	Experimental	**2 Ring by 4 Ring window** in the side piece where the side piece connects to the twine top, 6 rings up from the apron. **Windows lined with rigid stainless steel frames**.
CFFTDD14	Experimental	**2 Ring by 4 Ring window** in the side piece where the side piece connects to the twine top, 6 rings up from the apron. **Windows lined with dog chain**.

Table A3 The gear specifications of the control and experimental LAGC dredges.

GearID	PTD01	PTD02
Gear Type	Provincetown Dredge	Provincetown Dredge
Gear Description	9 foot Provicetown Dredge	9 foot Provicetown Dredge with (1X4 Ring) windows
Dredge Size	9	9
Bag Width	24	24
Bag Height	8	8
Apron Width	24	24
Apron Height	8	8
Side Width	4	4
Side Height	12	12
Diamond Size	8	8
Skirt Size	2	2
Skirt Style	Rings	Rings
Sweep Length	49	49
Sweep Link Size	0.625	0.625
Twine Top Size	5X46	5X46
ChafingGear	Rubber Tire	Rubber Tire

Figure A1 A diagram of the location of the seam window tested during on the first trip of the 2012 RSA Gear Testing Project (NA12NMF4540041). This configuration is designated as CFFTDD08 in future diagrams (Not Drawn to Scale).



<u>Figure A2</u> A diagram of the location of the seam windows tested during the *F/V Reliance* trip. Starting with configuration CFFTDD08, the location of the window was shifted up two rows of rings on four occasions with the final configuration location being CFFTDD12 (Not Drawn to Scale).

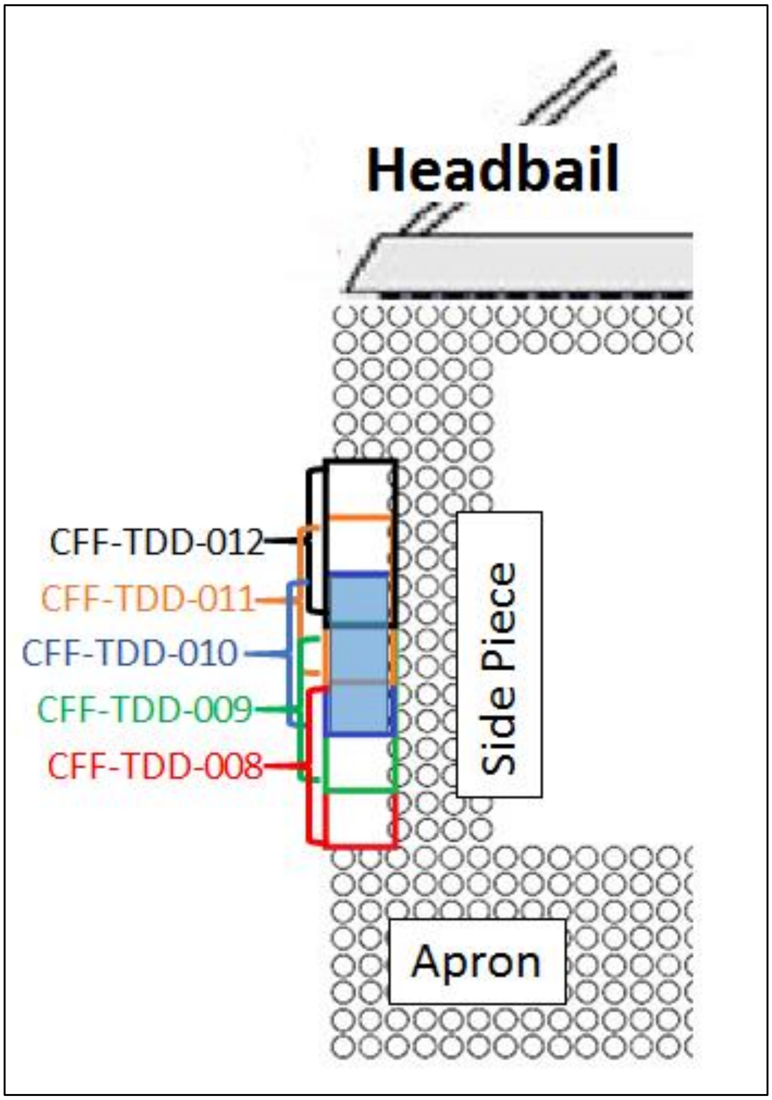
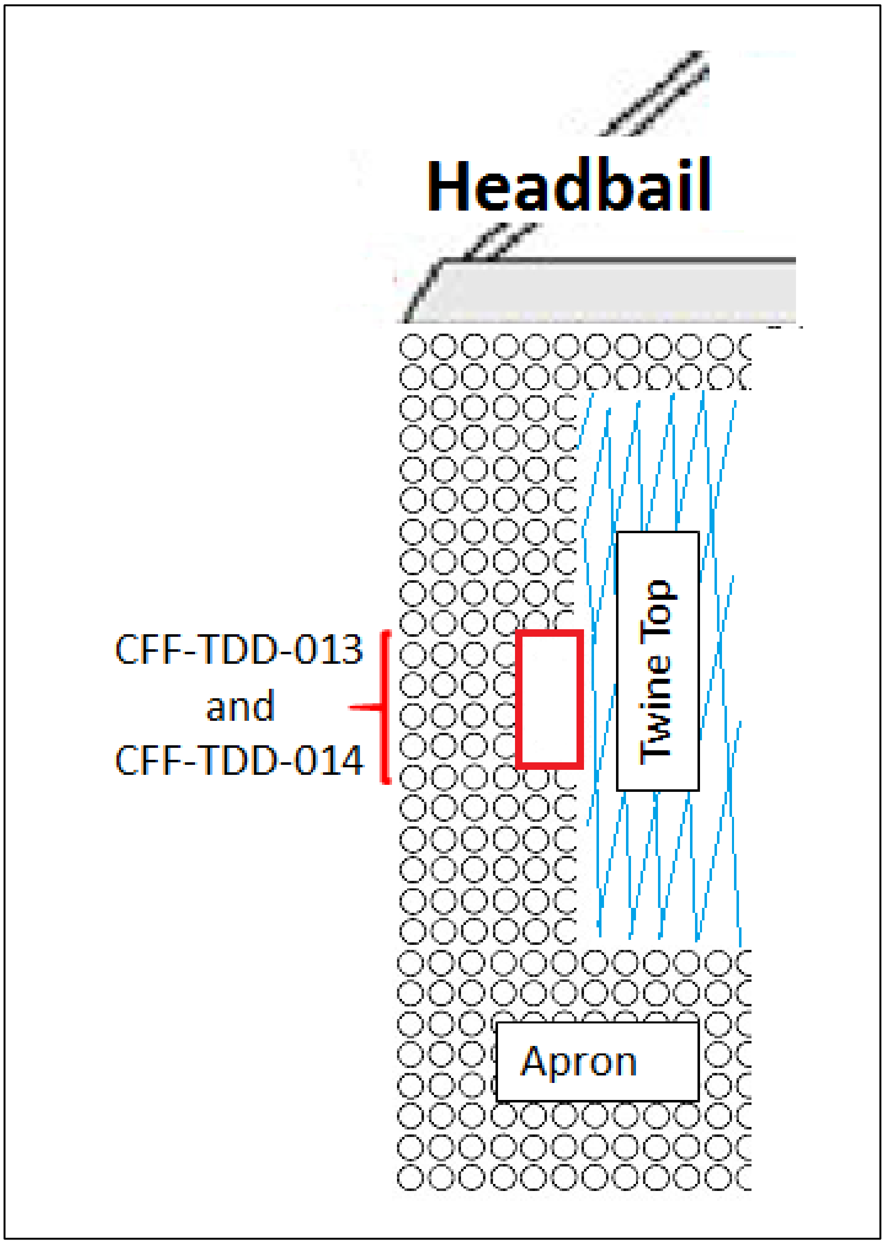


Figure A3 A diagram of the location of the windows adjacent to the twine top. Both the rigid (CFFTDD13) and the dog chain (CFFTDD14) windows were in this location (Not Drawn to Scale).



Appendix B: GLMM Model Details, LA Tables and Figures

Statistical Models – GLMM

Catch data from the paired tows provided the information to estimate differences in the relative efficiency for the gear combinations tested. 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 CFFTDD14 dredge and q_f equals the catchability of the CFFTDD07 dredge used in the study. The efficiency of the CFFTDD14 dredge relative to the CFFTDD07 dredge will be equivalent to the ratio of the two catchabilities:

$$\rho_l = \frac{q_r}{q_f} \qquad (1)$$

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 station i by dredge v, where v=r denotes the CFFTDD14 dredge and v=f denotes the CFFTDD07 dredge. Let λ_{ir} represent the scallop/fish density for the i^{th} station by the CFFTDD14 dredge and λ_{if} the scallop/fish density encountered by the CFFTDD07 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 stations. Assuming that capture is a Poisson process with mean equal to variance, then the expected catch by the CFFTDD14 dredge is given by:

$$E(C_{if}) = q_f \lambda_{if} = \mu_i \qquad (2)$$

The catch by the CFFTDD07 dredge is also a Poisson random variable with:

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

where δ_i =log (λ_{ir}/ λ_{if}). For each station, if the standardized density of scallops /fish encountered by both dredges is the same, then δ_i=0.

If the dredges encounter the same scallop/fish density for a given tow, (i.e. λ_{ir}= λ_{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 stations and scallop/fish lengths (Cadigan et al. 2006). The preferred approach is to use the conditional distribution of the catch by the

CFFTDD14 at station *i*, given the total non-zero catch of both vessels at that station. 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:

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

where $p=\rho/(1+\rho)$ is the probability that a scallop/fish captured by the CFFTDD14 dredge. In this approach, the only unknown parameter is ρ and the requirement to estimate μ for each station is eliminated as would be required in the direct GLM approach (equations 2 & 3). For the binomial distribution $E(C_{ir})=c_i p$ and $Var(C_i r)=c_i p/(1-p)$. Therefore:

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

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:

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

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:

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

In this model, the intercept (β_0) is allowed to vary randomly with respect to station.
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:

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

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. Most finfish were sampled completely without subsampling but there were some tows with large catches of windowpane flounder and the catch was subsampled. In these cases the model caught the tows that were subsampled and treated them accordingly. 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. The subsampling offset adjusts the linear predictor of the model to account for differential scaling in the data (i.e. tow length, subsampling), in the case of windowpane flounder the subsampling rate was 1 on both sides. Since the offset is the log of the quotient of the sampling rate of both sides and the log(1/1) = 0, nothing is added to the linear predictor for windowpane flounder.

Let q_{ir} equal the sub-sampling fraction at station 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 CFFTDD14 dredge relative to the CFFTDD07 dredge consisted of multiple levels of examination. For all species, the full model consisted of unpooled (by length) catch data:

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

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 was evaluated to assess 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.

<u>Table B1</u> A comparison of the control dredge CFFTDD07 and the combined catch number data from all the window configurations tested during the *F/V Reliance* Trip (n = 50).

	Scallops (BU)	Skate	Yellowtail Flounder	Winter Flounder	Windowpane Flounder	Fourspot Flounder	Summer Flounder	Barndoor Skate	Monkfish
Aggregate Exp.	238.7	5142	141	13	17	119	1	133	179
Control	332.35	5237	179	14	24	176	2	147	219
Difference	-93.65	-95.00	-38.00	-1.00	-7.00	-57.00	-1.00	-14.00	-40.00
% difference	-16.40%	-0.92%	-11.88%	-3.70%	-17.07%	-19.32%	-33.33%	-5.00%	-10.05%

<u>Table B2</u> A comparison of the catch numbers from CFFTDD07 and CFFTDD08; which, had a 2 Ring by 6 Ring window along the seam of the dredge bag (n=10).

	Scallops (BU)	Skate	Yellowtail Flounder	Winter Flounder	Windowpane Flounder	Fourspot Flounder	Summer Flounder	Barndoor Skate	Monkfish
CFFTDD08	40.8	1248	5	2	0	21	0	75	7
Control	62.35	1339	2	3	0	36	0	90	8
Difference	-21.55	-91.00	3.00	-1.00	0.00	-15.00	0.00	-15.00	-1.00
% difference	-20.89%	-3.52%	42.86%	-20.00%	#DIV/0!	-26.32%	#DIV/0!	-9.09%	-6.67%

<u>Table B3</u> A comparison of the catch numbers from CFFTDD07 and CFFTDD09; which, had a 2 Ring by 4 Ring window along the seam of the dredge bag (n=10).

	Scallops (BU)	Skate	Yellowtail Flounder	Winter Flounder	Windowpane Flounder	Fourspot Flounder	Summer Flounder	Barndoor Skate	Monkfish
CFFTDD09	38.25	1535	69	6	0	41	0	17	32
Control	45.4	1409	90	5	1	52	0	17	47
Difference	-7.15	126	-21	1	-1	-11	0	0	-15
% difference	-8.55%	4.28%	-13.21%	9.09%	-100.00%	-11.83%	#DIV/0!	0.00%	-18.99%

Table B4 A comparison of the catch numbers from CFFTDD07 and CFFTDD10; which, had a 2 Ring by 4 Ring window in the side piece 2 rings up from where the side piece ends and the apron starts, along the seam created by the union of the diamond and side piece (n=23).

	Scallops (BU)	Skate	Yellowtail Flounder	Winter Flounder	Windowpane Flounder	Fourspot Flounder	Summer Flounder	Barndoor Skate	Monkfish
CFFTDD10	81.15	1873	57	5	6	39	1	36	136
Control	126.85	1885	79	5	14	69	1	37	156
Difference	-45.7	-12	-22	0	-8	-30	0	-1	-20
% difference	-21.97%	-0.32%	-16.18%	0.00%	-40.00%	-27.78%	0.00%	-1.37%	-6.85%

Table B5 A comparison of the catch numbers from CFFTDD07 and CFFTDD11; which, had a 4 Ring by 4 Ring window in the side piece 4 rings up from where the side piece ends and the apron starts, along the seam created by the union of the diamond and side piece (n=1).

	Scallops (BU)	Skate	Yellowtail Flounder	Winter Flounder	Windowpane Flounder	Fourspot Flounder	Summer Flounder	Barndoor Skate	Monkfish
CFFTDD11	11.5	49	1	0	0	1	0	2	1
Control	19	29	1	0	0	1	0	0	0
Difference	-7.5	20	0	0	0	0	0	2	1
% difference	-24.59%	25.64%	0.00%	#DIV/0!	#DIV/0!	0.00%	#DIV/0!	100.00%	100.00%

Table B6 A comparison of the catch numbers from CFFTDD07 and CFFTDD12; which, had a 6 Ring by 4 Ring window in the side piece 4 rings up from where the side piece ends and the apron starts, along the seam created by the union of the diamond and side piece (n=6).

	Scallops (BU)	Skate	Yellowtail Flounder	Winter Flounder	Windowpane Flounder	Fourspot Flounder	Summer Flounder	Barndoor Skate	Monkfish
CFFTDD12	67	437	9	0	11	17	0	3	3
Control	78.75	575	7	1	9	18	1	3	8
Difference	-11.75	-138	2	-1	2	-1	-1	0	-5
% difference	-8.06%	-13.64%	12.50%	-100.00%	10.00%	-2.86%	-100.00%	0.00%	-45.45%

Table B7 The summarized catch weight (kilograms) data from the paired tows conducted aboard the *F/V Celtic*. Scallops were weighed live and whole (shell attached).

F/V Celtic	Scallops	Skate	Yellowtail Flounder	Winter Flounder	Windowpane Flounder	Fourspot Flounder	Summer Flounder	Barndoor Skate	Monkfish	Benthos
CFFTDD14	3984.12	1463.61	85.30	3.68	0.48	22.95	2.66	11.66	437.69	491.26
Control	5688.88	1733.18	128.44	6.18	2.05	39.30	12.37	6.23	455.33	1432.91
Difference	-1704.76	-269.57	-43.14	-2.50	-1.57	-16.35	-9.71	5.43	-17.64	-941.65
% difference	-17.62%	-8.43%	-20.18%	-25.35%	-62.06%	-26.27%	-64.60%	30.35%	-1.98%	-48.94%

Table B8 The summarized catch weight (kilograms) data from the paired tows conducted aboard the *F/V Endeavor*. Scallops were weighed live and whole (shell attached).

F/V Endeavor	Scallops	Skate	Yellowtail Flounder	Winter Flounder	Windowpane Flounder	Fourspot Flounder	Summer Flounder	Barndoor Skate	Monkfish	Benthos
CFFTDD14	7074.13	780.51	52.48	28.68	0.74	21.68	44.76	54.11	578.06	1228.63
Control	8893.07	2717.82	76.38	26.04	1.58	27.14	43.88	62.12	763.02	1477.43
Difference	-1818.94	-1937.31	-23.90	2.64	-0.84	-5.46	0.88	-8.01	-184.96	-248.80
% difference	-11.39%	-55.38%	-18.55%	4.82%	-36.21%	-11.18%	0.99%	-6.89%	-13.79%	-9.19%

Table B9 The summarized catch weight (kilograms) data from the paired tows conducted aboard the *F/V Concordia*. Scallops were weighed live and whole (shell attached).

F/V Concordia	Scallops	Skate	Yellowtail Flounder	Winter Flounder	Windowpane Flounder	Fourspot Flounder	Summer Flounder	Barndoor Skate	Monkfish	Benthos
CFFTDD14	6824.53	7685.70	152.03	25.34	425.37	6.23	12.46	5.05	94.04	2179.84
Control	7279.07	7460.20	167.86	26.05	486.24	3.08	11.54	2.92	109.89	1889.95
Difference	-454.54	225.50	-15.83	-0.71	-60.87	3.15	0.92	2.13	-15.85	289.89
% difference	-3.22%	1.49%	-4.95%	-1.38%	-6.68%	33.83%	3.83%	26.73%	-7.77%	7.12%

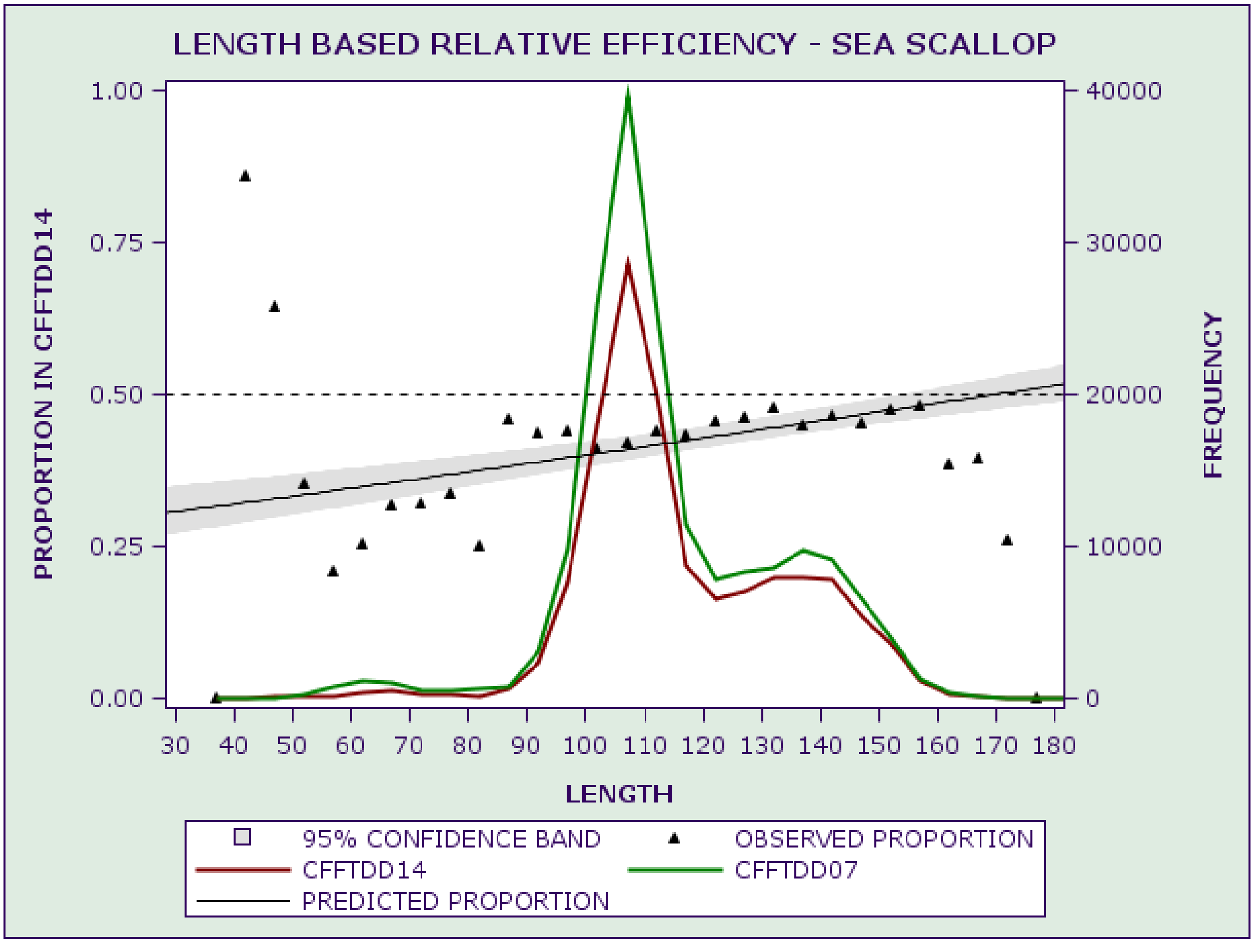
Table B10 Mixed effects model using the unpooled catch data . Results are for all species where the length based model (intercept and length) converged and provided informative results. Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale.

Species	**Effect**	**Estimate**	**SE**	**DF**	**t-value**	**p-value**	**LCI**	**UCI**
Fourspot Flounder	Intercept	-0.799	0.590	379	-1.354	0.177	-1.960	0.362
	Size	0.015	0.019	379	0.775	0.439	-0.023	0.052
Yellowtail Flounder	Intercept	0.147	0.509	620	0.288	0.773	-0.852	1.145
	Size	-0.011	0.014	620	-0.808	0.419	-0.038	0.016
Windowpane Flounder	Intercept	0.331	0.442	428	0.748	0.455	-0.538	1.199
	Size	-0.018	0.017	428	-1.069	0.286	-0.050	0.015
Monkfish	Intercept	-0.084	0.323	654	-0.259	0.796	-0.718	0.551
	Size	-0.002	0.006	654	-0.258	0.796	-0.013	0.010
Sea Scallop	**Intercept**	**-0.983**	**0.119**	**1425**	**-8.275**	**<0.0001**	**-1.216**	**-0.750**
	Size	**0.006**	**0.001**	**1425**	**6.476**	**<0.0001**	**0.004**	**0.008**

<u>Table B11</u> Mixed effects model (random intercept) using the pooled catch data . Results are for all species where the length based model (intercept and length) converged and provided informative results. Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale and the exp(Estimate) is the estimated relative efficiency on the probability scale. Percent change represents the average percentage change in the catch of the CFFTDD14 relative to the CFFTDD07. Significant parameters are shown in bold.

Species	Estimate	SE	DF	t-value	p-value	LCI	UCI	exp(Est)	% Change
Unclassified Skates	**-0.234**	**0.041**	**98**	**-5.669**	**>.0001**	**-0.316**	**-0.152**	**0.791**	**-20.9%**
Haddock	**-1.244**	**0.475**	**17**	**-2.622**	**0.018**	**-2.246**	**-0.243**	**0.288**	**-71.2%**
Summer Flounder	0.054	0.239	33	0.224	0.824	-0.433	0.541	1.055	5.5%
Fourspot Flounder	**-0.347**	**0.140**	**68**	**-2.469**	**0.016**	**-0.627**	**-0.067**	**0.707**	**-29.3%**
Yellowtail Flounder	**-0.262**	**0.059**	**87**	**-4.434**	**>.0001**	**-0.379**	**-0.144**	**0.770**	**-23.0%**
Windowpane Flounder	**-0.178**	**0.054**	**51**	**-3.294**	**0.002**	**-0.287**	**-0.070**	**0.837**	**-16.3%**
Monkfish	**-0.165**	**0.069**	**83**	**-2.392**	**0.019**	**-0.302**	**-0.028**	**0.848**	**-15.2%**
Sea Scallop	**-0.253**	**0.038**	**98**	**-6.573**	**>.0001**	**-0.329**	**-0.176**	**0.777**	**-22.3%**

Figure B1 Relative Sea Scallop catch by the two dredge configurations. The triangles represent the observed proportion at length ($Catch_{TDD14}/(Catch_{TDD14} + Catch_{TDD07})$), with a proportion >0.5 representing more animals at length captured by the TDD dredge. The grey area represents the 95% confidence band for the modeled proportion (solid black line).



<u>Figure B2</u> Relative monkfish catch by the two dredge configurations. The triangles represent the observed proportion at length ($Catch_{TDD14}$/($Catch_{TDD14}$ + $Catch_{TDD07}$), with a proportion >0.5 representing more animals at length captured by the TDD dredge. The grey area represents the 95% confidence band for the modeled proportion (solid black line).

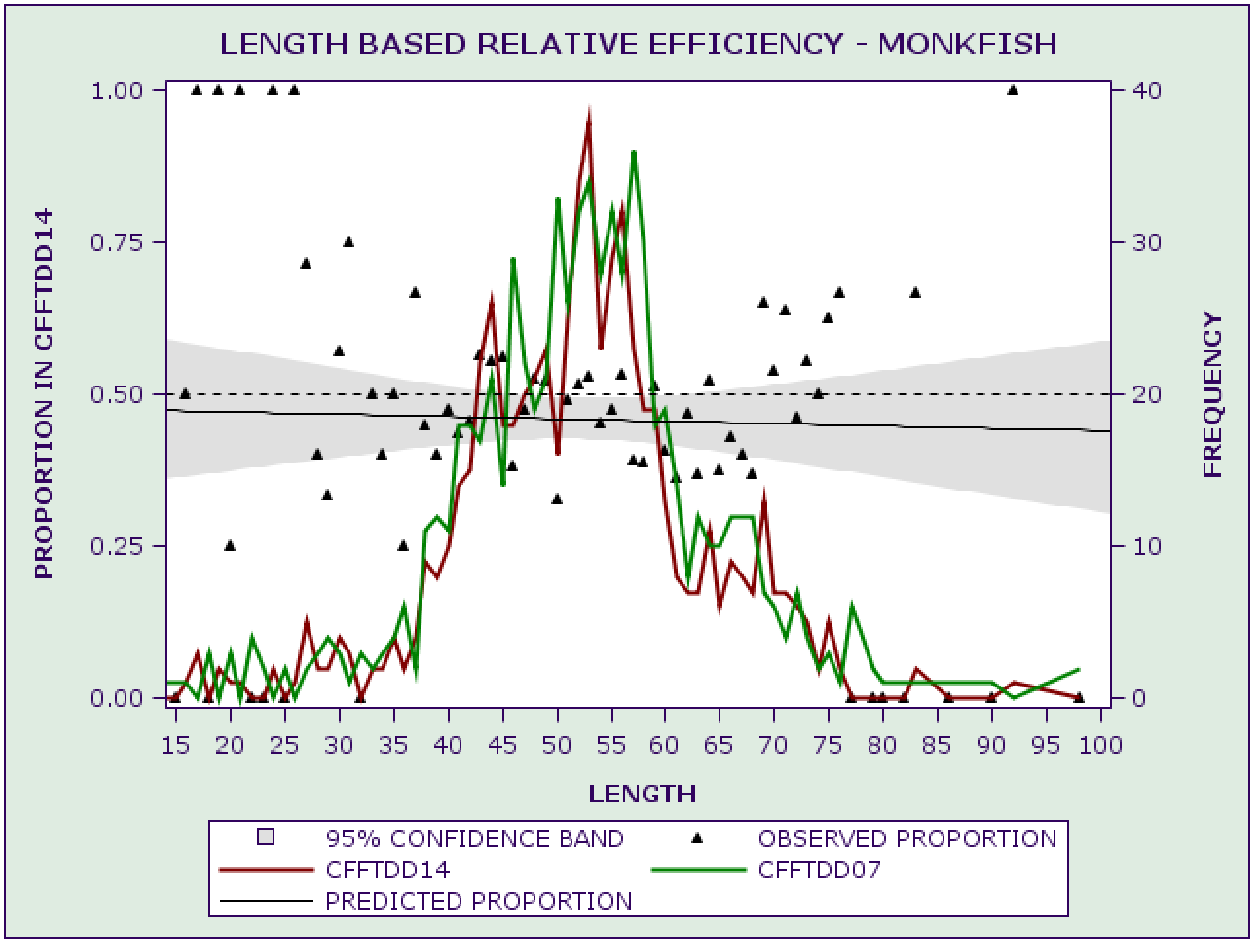


Figure B3 Relative windowpane flounder catch by the two dredge configurations. The triangles represent the observed proportion at length ($Catch_{TDD14}/(Catch_{TDD14} + Catch_{TDD07})$, with a proportion >0.5 representing more animals at length captured by the TDD dredge. The grey area represents the 95% confidence band for the modeled proportion (solid black line).

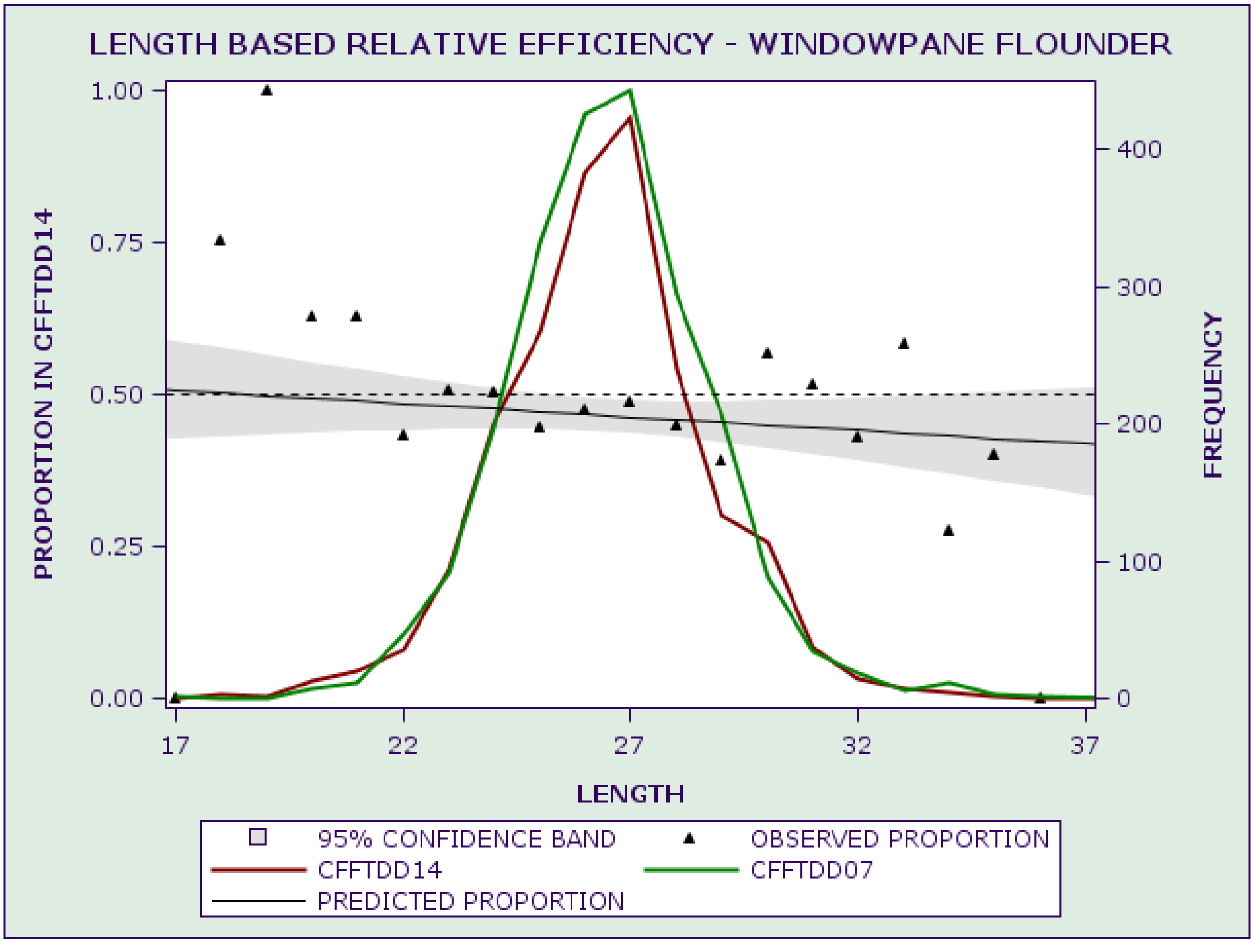
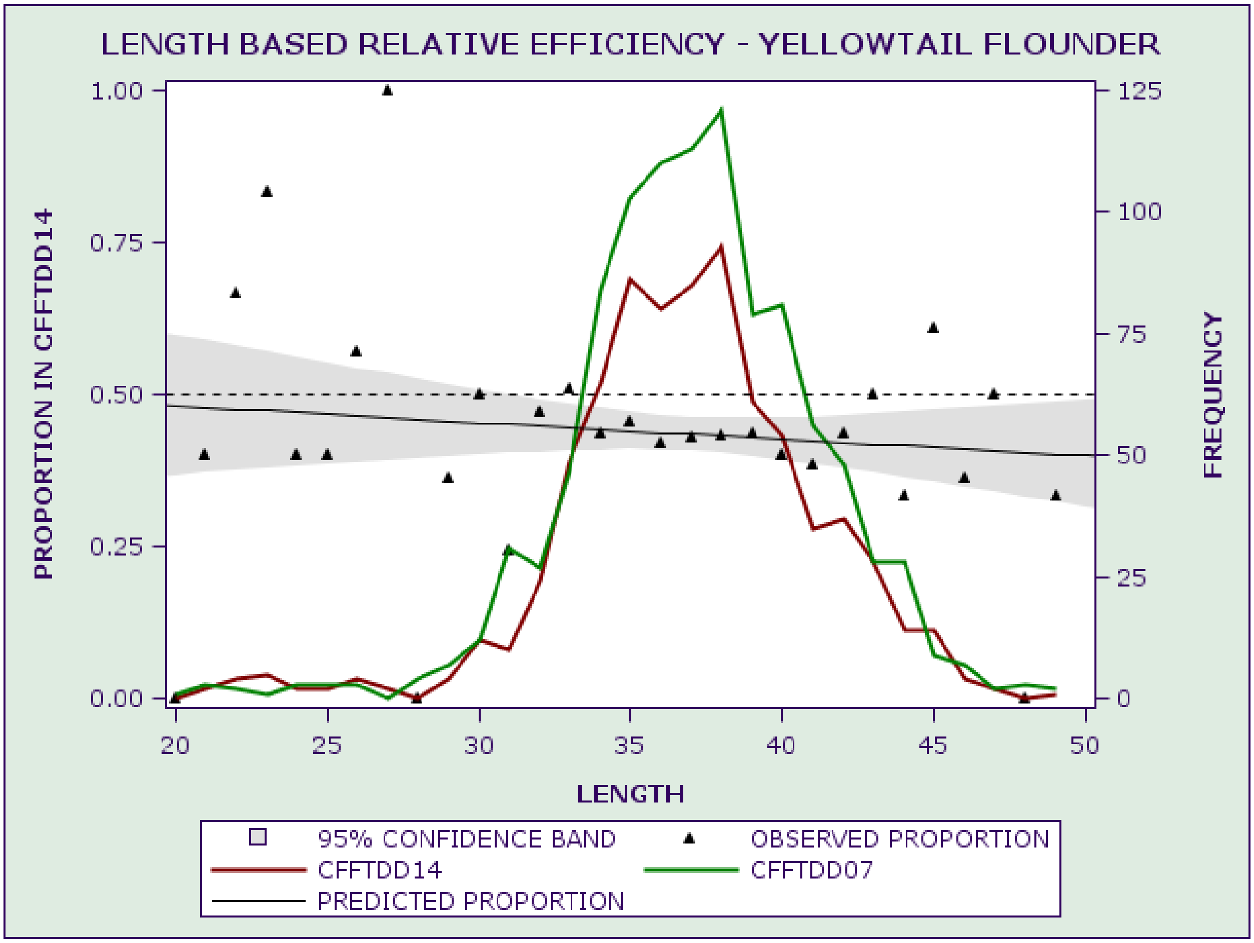


Figure B4 Relative yellowtail flounder catch by the two dredge configurations. The triangles represent the observed proportion at length ($Catch_{TDD14}/(Catch_{TDD14} + Catch_{TDD07})$, with a proportion >0.5 representing more animals at length captured by the TDD dredge. The grey area represents the 95% confidence band for the modeled proportion (solid black line).



<u>Figure B5</u> Relative fourspot flounder catch by the two dredge configurations. The triangles represent the observed proportion at length ($Catch_{TDD14}/(Catch_{TDD14} + Catch_{TDD07})$, with a proportion >0.5 representing more animals at length captured by the TDD dredge. The grey area represents the 95% confidence band for the modeled proportion (solid black line).

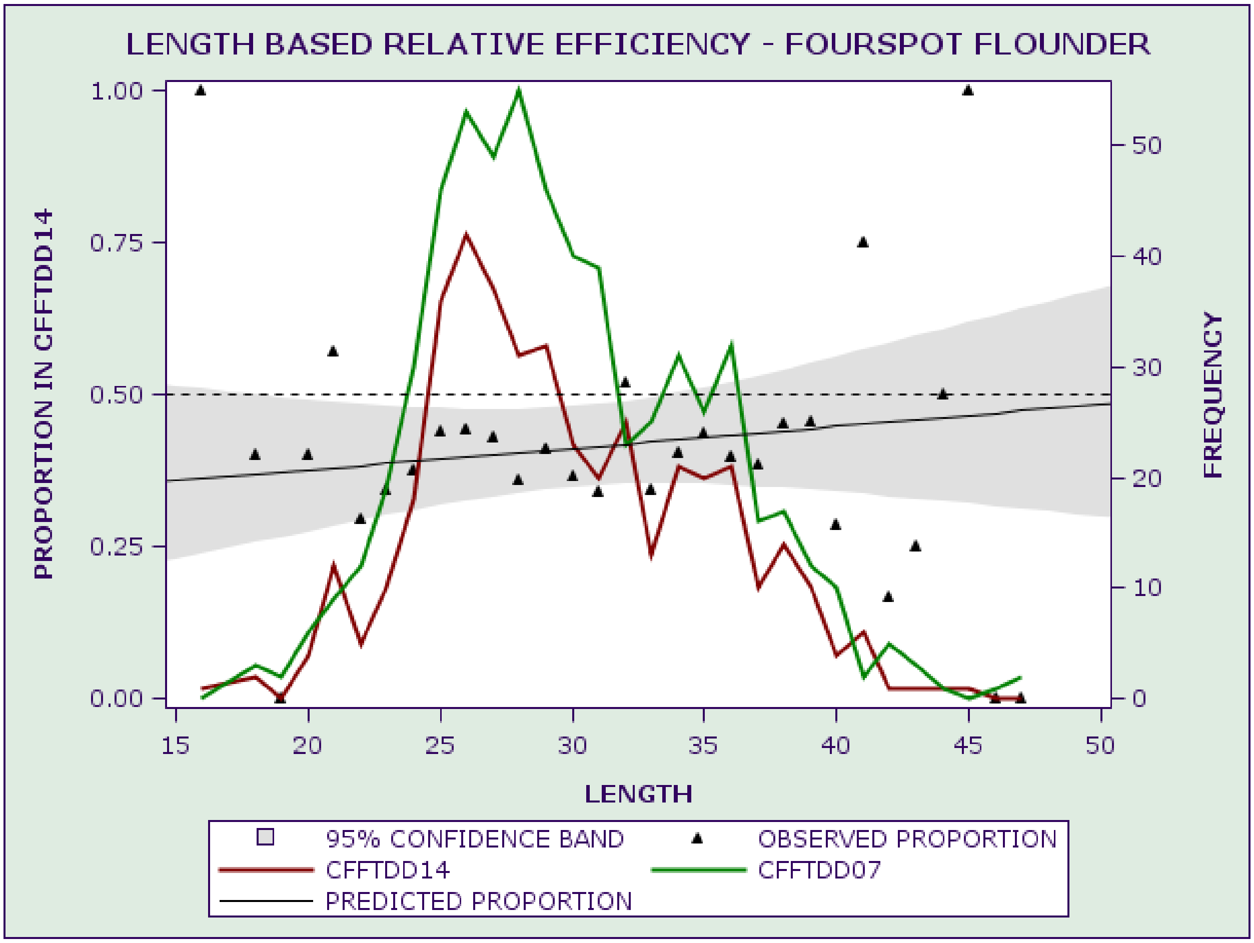


Figure B6 Total pooled catches of unclassified skates for the CFFTDD14 vs. the CFFTDD07. Model output from the analysis of the pooled data. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

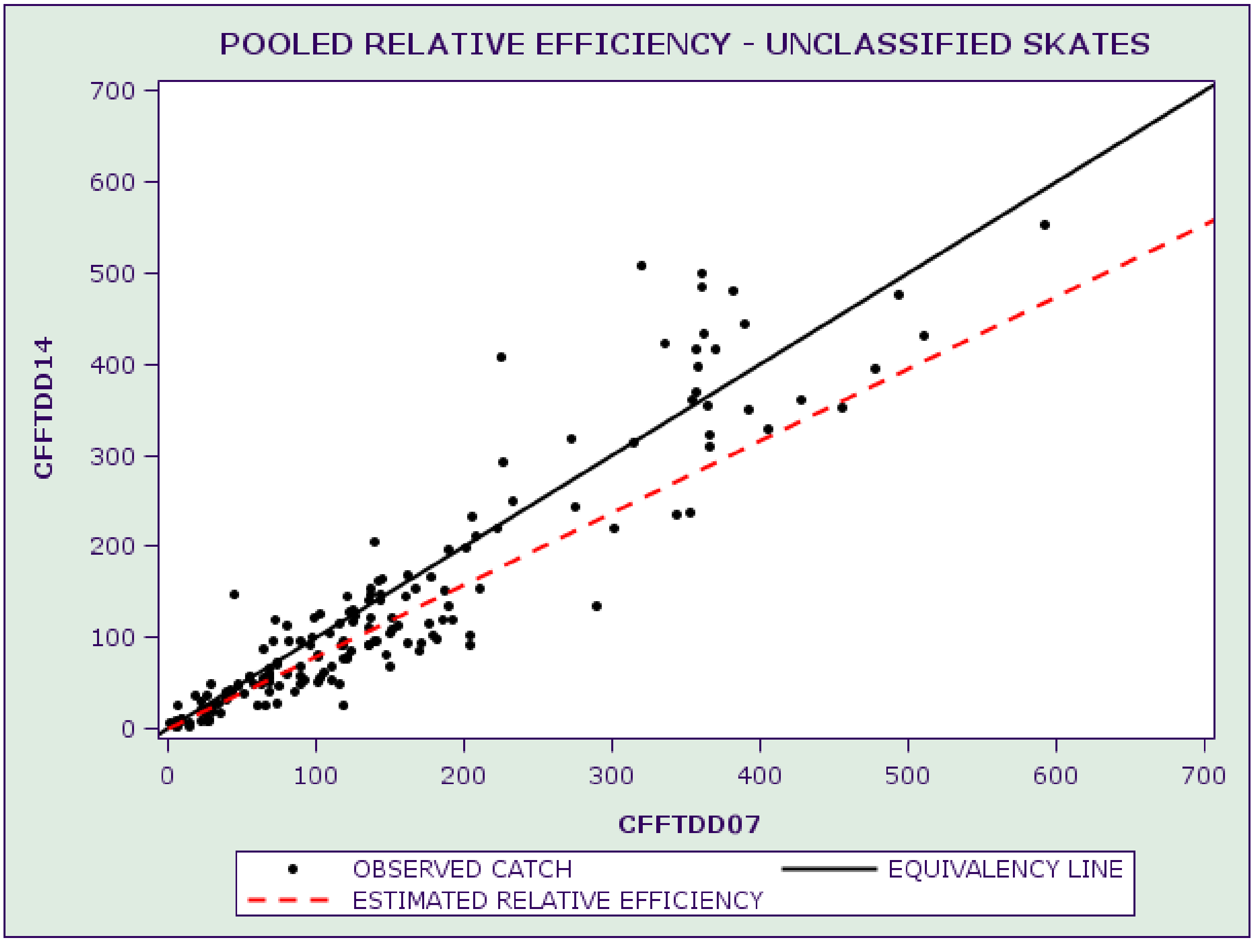


Figure B7 Total pooled catches of haddock for the CFFTDD14 vs. the CFFTDD07. Model output from the analysis of the pooled data. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

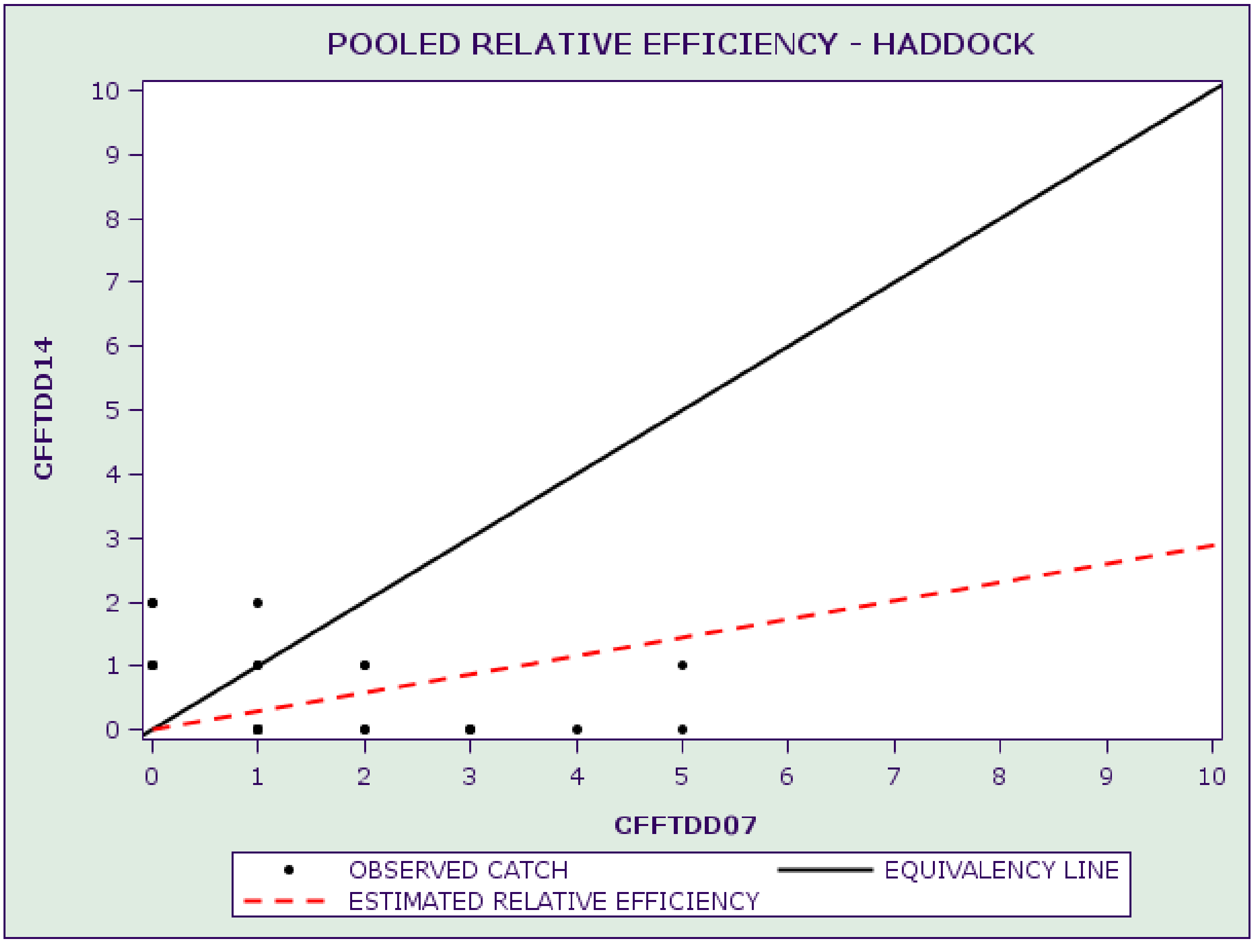


Figure B8 Total pooled catches of summer flounder for the CFFTDD14 vs. the CFFTDD07. Model output from the analysis of the pooled data. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

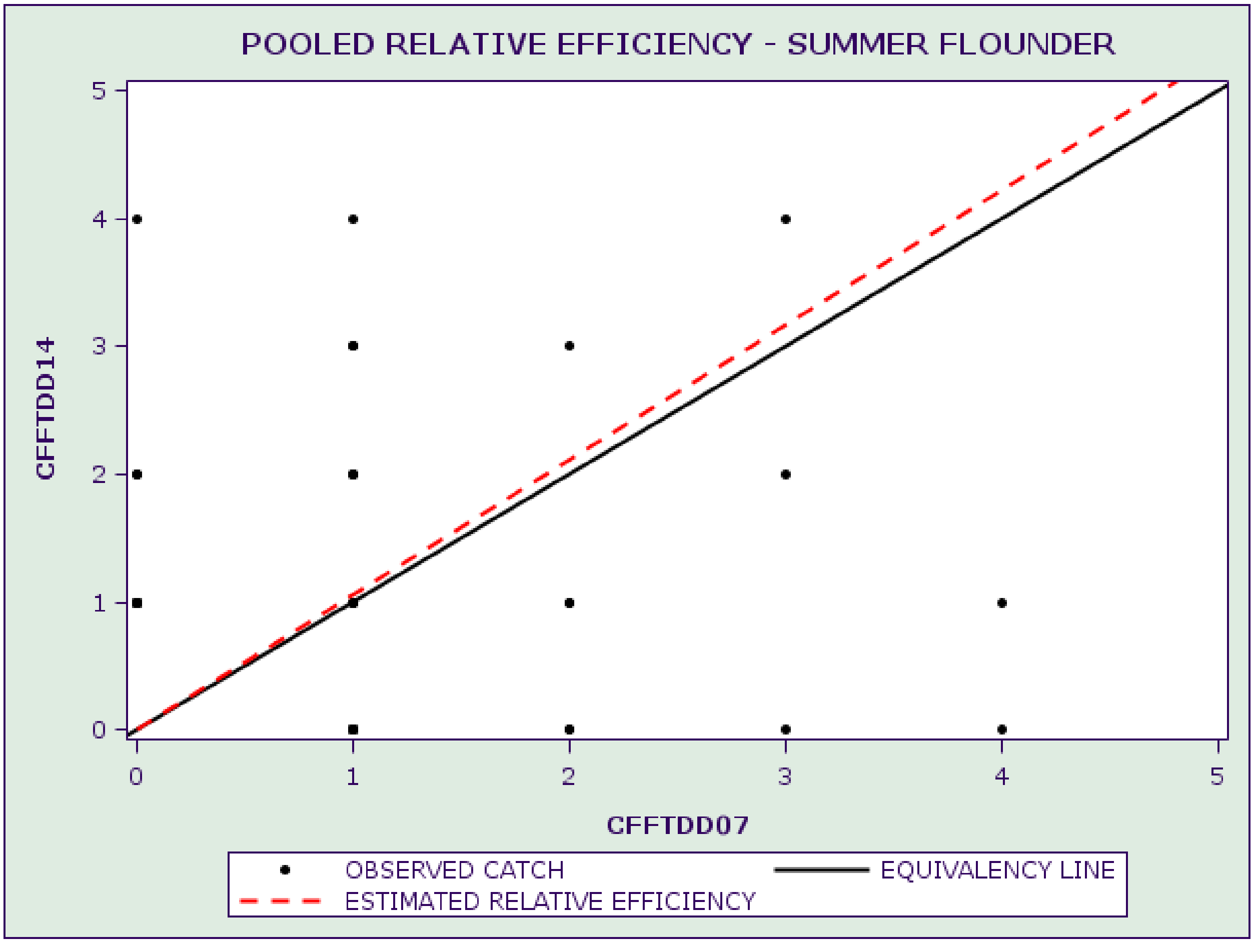


Figure B9 Total pooled catches of fourspot flounder for the CFFTDD14 vs. the CFFTDD07. Model output from the analysis of the pooled data. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

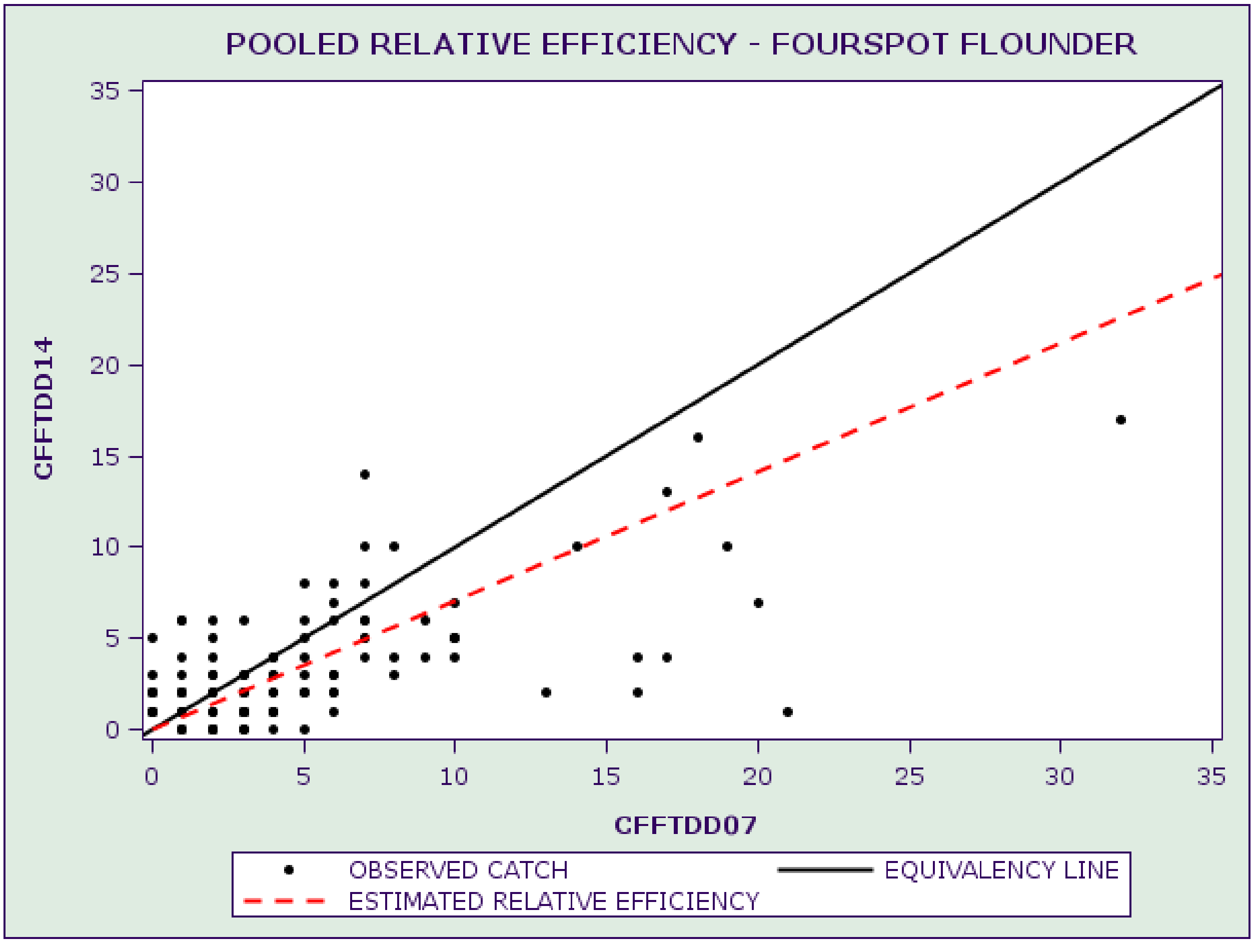


Figure B10 Total pooled catches of yellowtail flounder for the CFFTDD14 vs. the CFFTDD07. Model output from the analysis of the pooled data. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

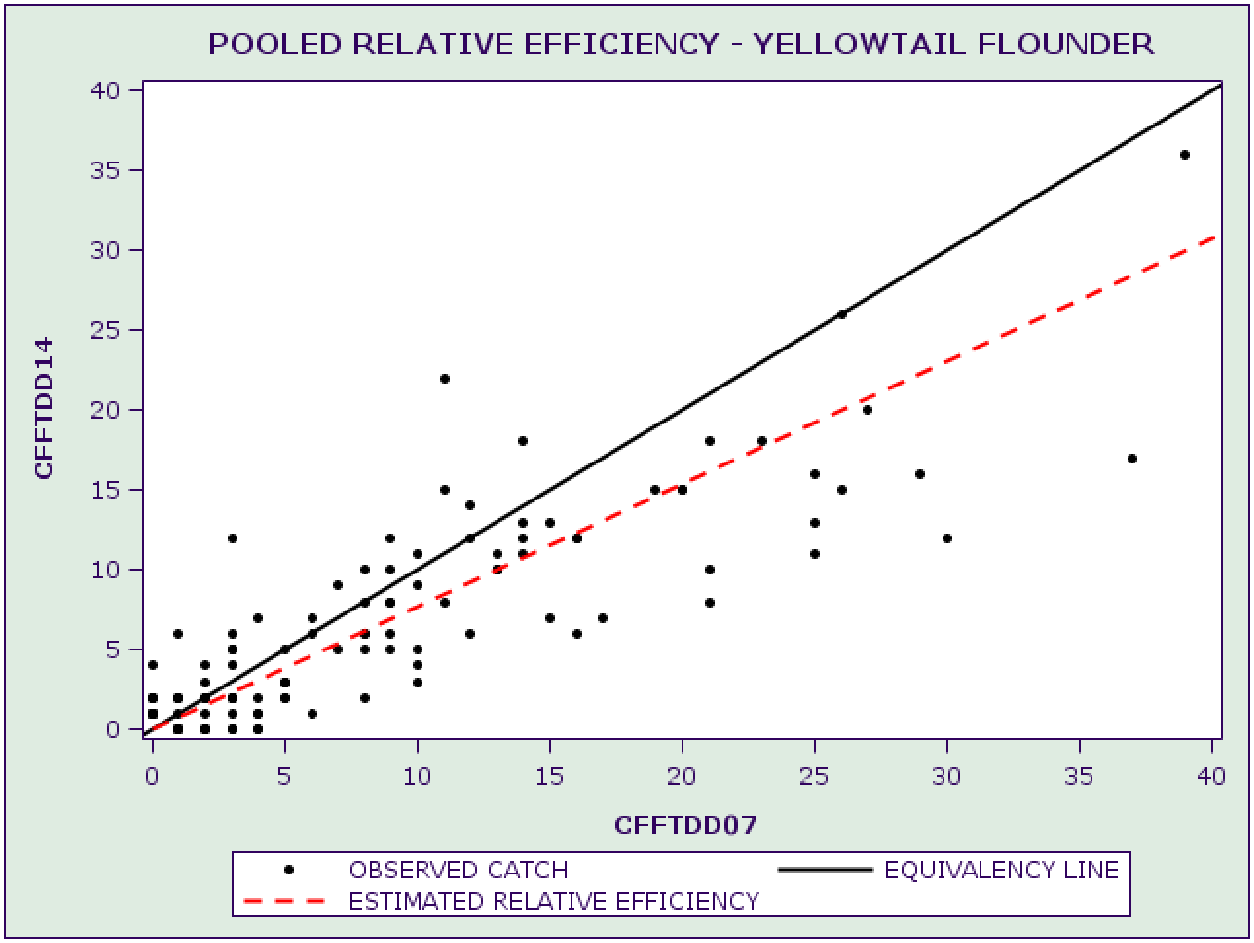


Figure B11 Total pooled catches of windowpane flounder for the CFFTDD14 vs. the CFFTDD07. Model output from the analysis of the pooled data. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

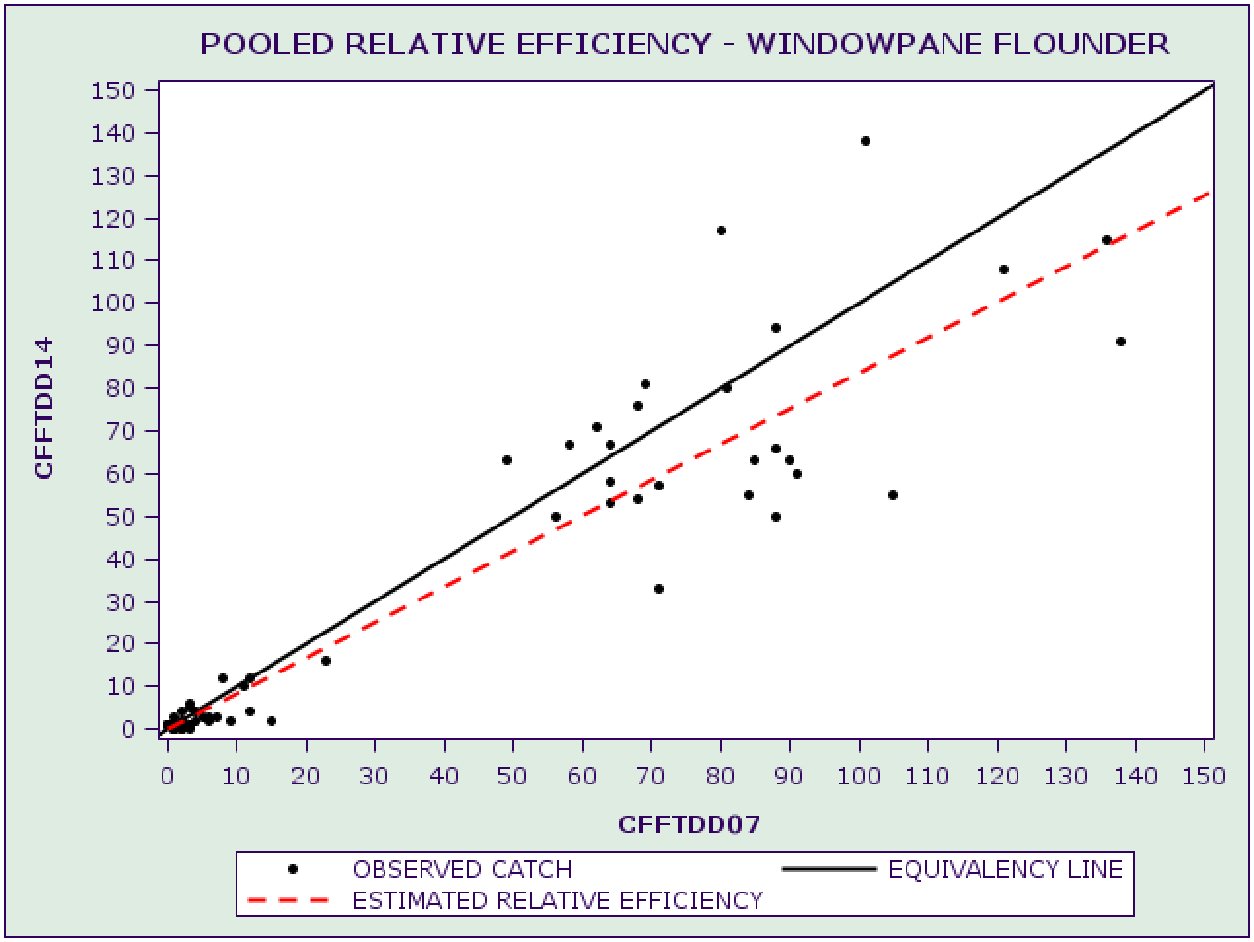


Figure B12 Total pooled catches of monkfish for the CFFTDD14 vs. the CFFTDD07. Model output from the analysis of the pooled data. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

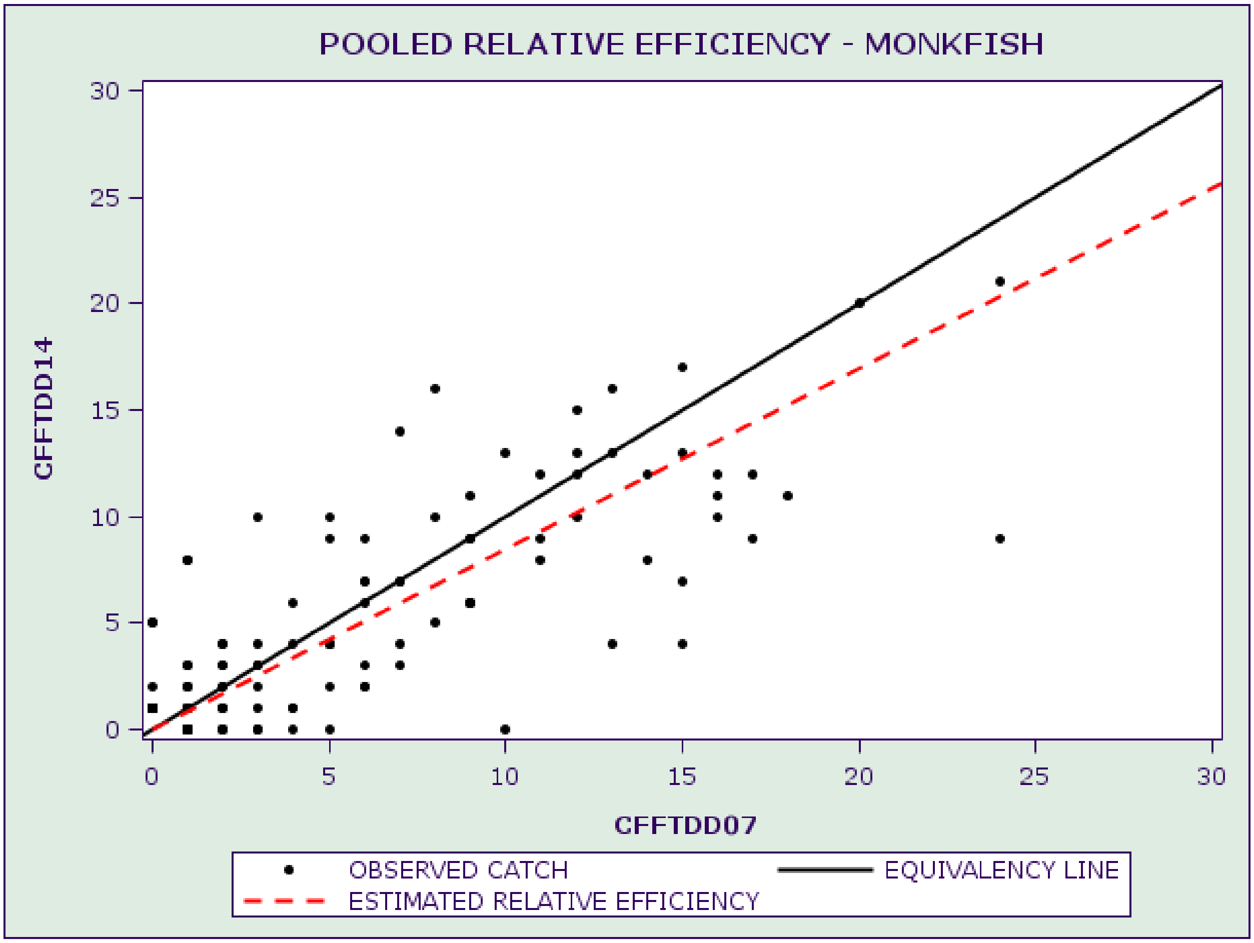
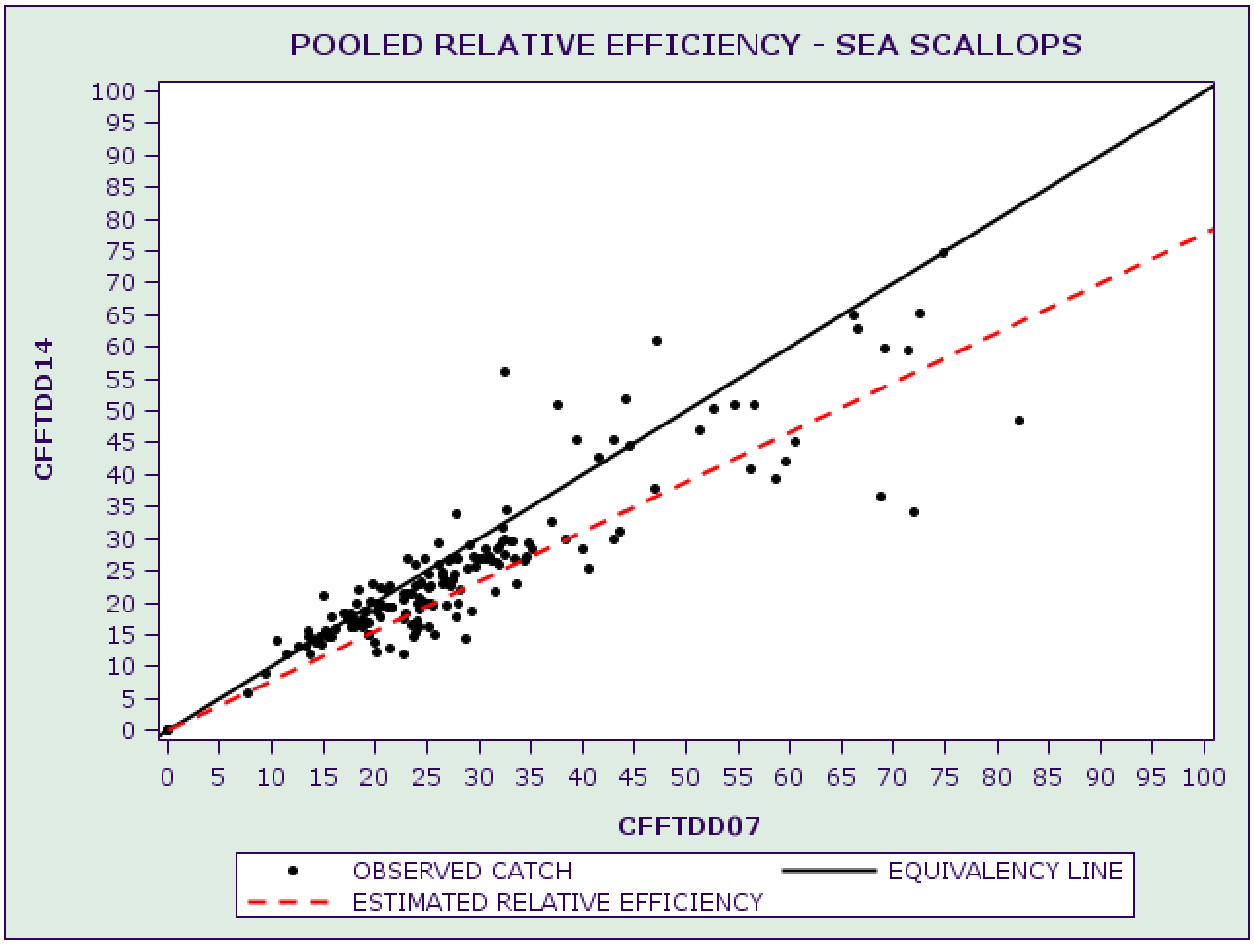


Figure B13 Total pooled catches of sea scallops for the CFFTDD14 vs. the CFFTDD07. Model output from the analysis of the pooled data. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one. The x and y axes represent the square root of catch, which preserves the relative scale and improves the visual representation of the structure of the data.



Appendix C: LAGC Tables and Figures

Table C1 Descriptive statistics for the LAGC data set. The overall number of tows included for each level of the variable gear and the corresponding attributes of the continuous variables tow distance and depth. Tow distance was used in the regression analysis as an offset term to scale the catches to a common scale.

	PDT01 (no windows)	PTD02 (windows)
Tows included in analysis	82	57
Tow Distance (nm)		
Mean tow distance	4.74	4.73
Standard deviation	1.12	0.85
Minimum tow distance	1.30	1.45
Maximum tow distance	9.35	6.76
Depth (m)		
Mean depth	49.53	50.76
Standard deviation	8.54	9.58
Minmum depth	72.88	72.88
Maximum depth	38.26	38.26

Table C2 Descriptive statistics for the variable describing wind and sea conditions encountered for each tow by each gear tested (Beaufort scale).

	Beaufort Scale	Frequency	Percent	Cumulative Frequency	Cumulative Percent
PDT01 (no windows)	0	16	17.98	16	17.98
	1	40	44.94	56	62.92
	2	15	16.85	71	79.78
	3	8	8.99	79	88.76
	4	10	11.24	89	100
PTD02 (windows)	0	6	10.17	6	10.17
	1	20	33.9	26	44.07
	2	21	35.59	47	79.66
	3	6	10.17	53	89.83
	4	4	6.78	57	96.61
	5	2	3.39	59	100

Table C3 Model building for each species. The distribution and explanatory variables that best fit the catch data for each species.

Species	Distribution	Model
Unclassified Skates	Negative Binomial	Catch~Depth
Barndoor Skates	Negative Binomial	Catch~Gear
Summer Flounder	Poisson	Catch~Depth
Fourspot Flounder	Negative Binomial	Catch~Gear,Depth
Yellowtail Flounder	Negative Binomial	Catch~
Winter Flounder	Poisson	Catch~Depth
Windowpane Flounder	Negative Binomial	Catch~
Monkfish	Negative Binomial	Catch~Gear
Sea Scallop	Negative Binomial	Catch~Gear,Size,Depth

Table C4 Parameter estimates for the species where the intercept only model resulted in the best fit to the data.

Species	Parameter	DF	Estimate	Std Err	Lower 95% CI	Upper 95% CI	ChiSq	Prob Chi Sq
Yellowtail Flounder	Intercept	1	-0.815	0.093	-0.998	-0.632	76.162	<0.0001
	Dispersion	1	0.606	0.150	0.373	0.984		
Windowpane Flounder	Intercept	1	0.152	0.064	0.026	0.278	5.62	0.017
	Dispersion	1	0.293	0.069	0.183	0.467		

Table C5 Parameter estimates for the species where the model that included depth resulted in the best fit to the data.

Species	Parameter	DF	Estimate	Std Err	Lower 95% CI	Upper 95% CI	ChiSq	Prob Chi Sq
Uncl. Skates	Intercept	1	1.368	0.337	0.708	2.028	16.504	<0.0001
	Depth	1	0.036	0.007	0.023	0.049	29.556	<0.0001
	Dispersion	1	0.323	0.039	0.255	0.410		
Summer Flounder	Intercept	1	1.604	0.995	-0.346	3.554	2.598	0.107
	Depth	1	-0.080	0.022	-0.122	-0.038	13.758	<0.0001
	Scale	0	1.092	0.000	1.092	1.092		
Winter Flounder	Intercept	1	0.067	0.856	-1.612	1.745	0.006	0.938
	Depth	1	-0.050	0.018	-0.085	-0.014	7.562	0.006
	Scale	0	0.967	0.000	0.967	0.967		

Table C6 Parameter estimates for the species where the model that included gear resulted in the best fit to the data.

Species	Parameter	Level	DF	Estimate	Std Err	Lower 95% CI	Upper 95% CI	ChiSq	Prob Chi Sq
Barndoor Skate	Intercept		1	-3.503	0.302	-4.095	-2.911	134.573	<0.0001
	Gear	PTD01	1	0.862	0.362	0.153	1.572	5.674	0.017
	Gear	PTD02	0	0.000	0.000	0.000	0.000		
	Dispersion		1	4.380	1.246	2.508	7.650		
Monkfish	Intercept		1	-2.663	0.266	-3.185	-2.141	100.035	<0.0001
	Gear	PTD01	1	1.545	0.309	0.939	2.151	24.951	<0.0001
	Gear	PTD02	0	0.000	0.000	0.000	0.000		
	Dispersion		1	1.798	0.420	1.137	2.843		

Table C7 Parameter estimates for the species where the model that included gear and depth resulted in the best fit to the data.

Species	Parameter	Level	DF	Estimate	Std Err	Lower 95% CI	Upper 95% CI	Chi Sq	Prob Chi Sq
Fourspot Flounder	Intercept		1	1.689	1.050	-0.370	3.748	2.586	0.108
	Gear	PTD01	1	0.823	0.291	0.253	1.394	8.000	0.005
	Gear	PTD02	0	0.000	0.000	0.000	0.000		
	Depth		1	-0.094	0.022	-0.138	-0.051	17.877	<0.0001
	Dispersion		1	0.908	0.373	0.406	2.030		

Table C8 Parameter estimates for the species where the model that included gear, depth and animal size resulted in the best fit to the data.

Species	Parameter	Level	DF	Estimate	Std Err	Lower 95% CI	Upper 95% CI	ChiSq	Prob Chi Sq
Sea Scallop	Intercept		1.000	3.151	0.184	2.791	3.511	294.361	<0.0001
	Gear	PTD01	1.000	0.298	0.052	0.196	0.400	32.788	<0.0001
	Gear	PTD02	0.000	0.000	0.000	0.000	0.000		
	Size		1.000	0.005	0.001	0.002	0.007	13.866	<0.0001
	Depth		1.000	-0.033	0.002	-0.038	-0.028	187.963	<0.0001
	Dispersion		1.000	1.118	0.036	1.050	1.190		

Table C9 Model generated estimates as a function of gear configuration. While gear may not have been included in the best model specification for each individual species, since it was the factor of primary interest it is informative to be able to compare the catch rates between the levels of that factor. In cases where other factors were significant (i.e. depth) the average value for each level of gear was used to estimate the value for gear. Scallops included a significant size factor and 125 mm was selected as the value for that factor. Mean catch rates are depicted as the mean catch per nautical mile towed. Statistical significance refers to the estimated mean value, not relative to other levels of the factor.

Species	Level	Mean Estimate	Lower 95% CI	Upper 95% CI	Chi Sq	Prob Chi Sq
Barndoor Skates	PTD01	0.071	0.048	0.105	174.910	<0.001
	PTD02	0.030	0.017	0.054	134.573	<0.001
Fourspot Flounder	PTD01	0.116	0.084	0.161	166.735	<0.001
	PTD02	0.045	0.027	0.077	131.614	<0.001
Yellowtail Flounder	PTD01	0.484	0.383	0.612	36.787	<0.001
	PTD02	0.385	0.287	0.515	41.163	<0.001
Windowpane Flounder	PTD01	1.112	0.941	1.313	1.556	0.212
	PTD02	1.240	1.022	1.506	4.738	0.030
Monkfish	PTD01	0.327	0.240	0.445	50.419	<0.001
	PTD02	0.070	0.041	0.118	100.035	<0.001
Sea Scallops	PTD01	11.337	10.451	12.299	3420.607	<0.001
	PTD02	8.081	7.378	8.850	2028.119	<0.001
Winter Flounder	PDT01	0.093	0.072	0.120	325.648	<0.001
	PTD02	0.078	0.051	0.119	140.343	<0.001
Summer Flounder	PTD01	0.100	0.070	0.144	154.266	<0.001
	PTD02	0.126	0.086	0.186	108.989	<0.001
Unclassified Skates	PTD01	25.873	22.414	29.865	1974.572	<0.001
	PTD02	23.770	20.008	28.238	1299.602	<0.001

Figure C1 Length frequency distributions for the scaled catch data at size for Barndoor Skate.

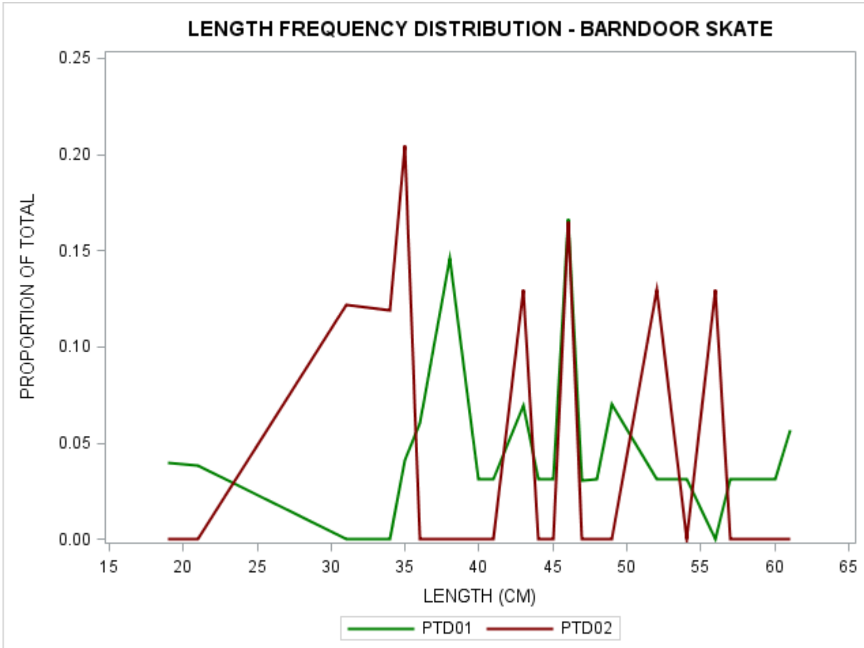


Figure C2 Length frequency distributions for the scaled catch data at size for Summer Flounder.

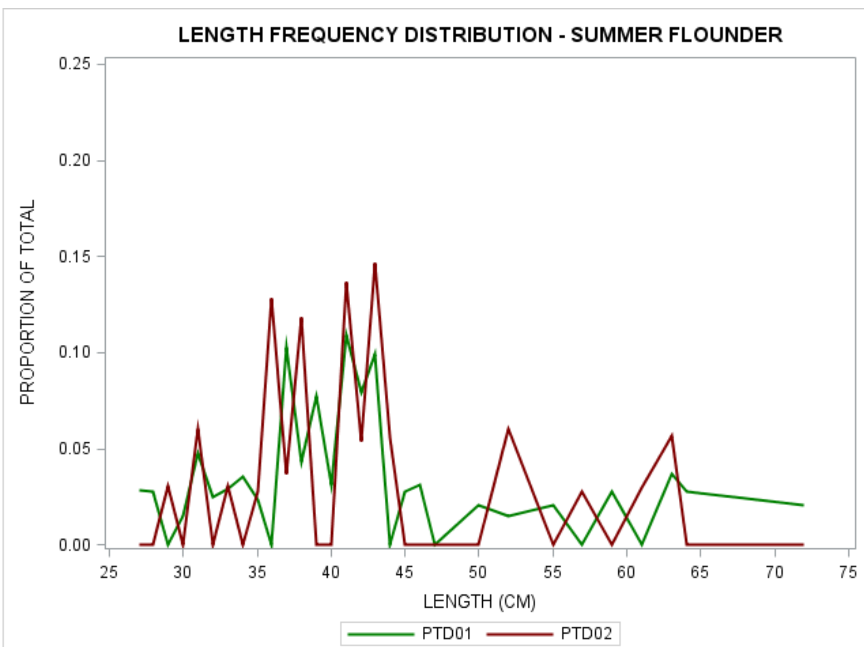


Figure C3 Length frequency distributions for the scaled catch data at size for fourspot flounder.

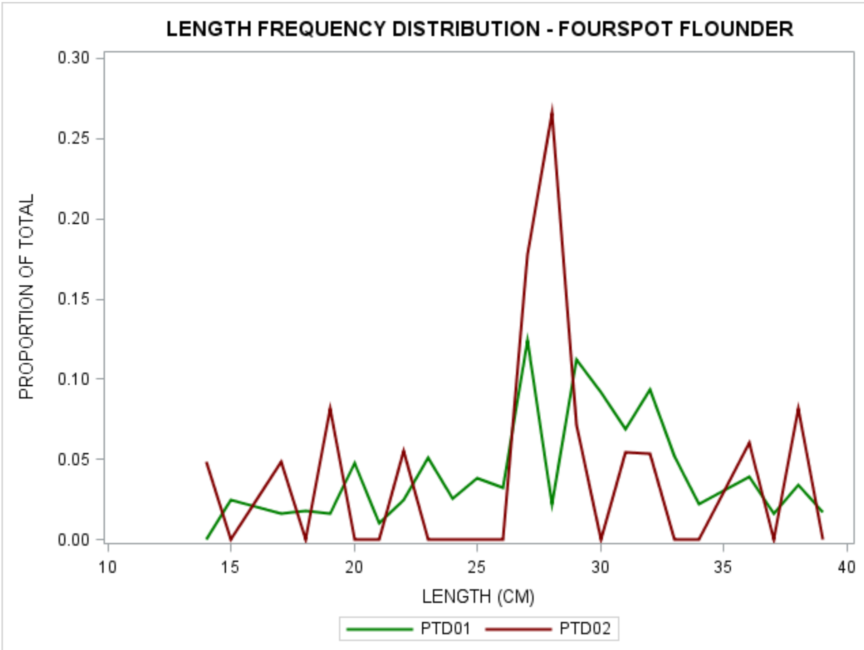


Figure C4 Length frequency distributions for the scaled catch data at size for yellowtail flounder.

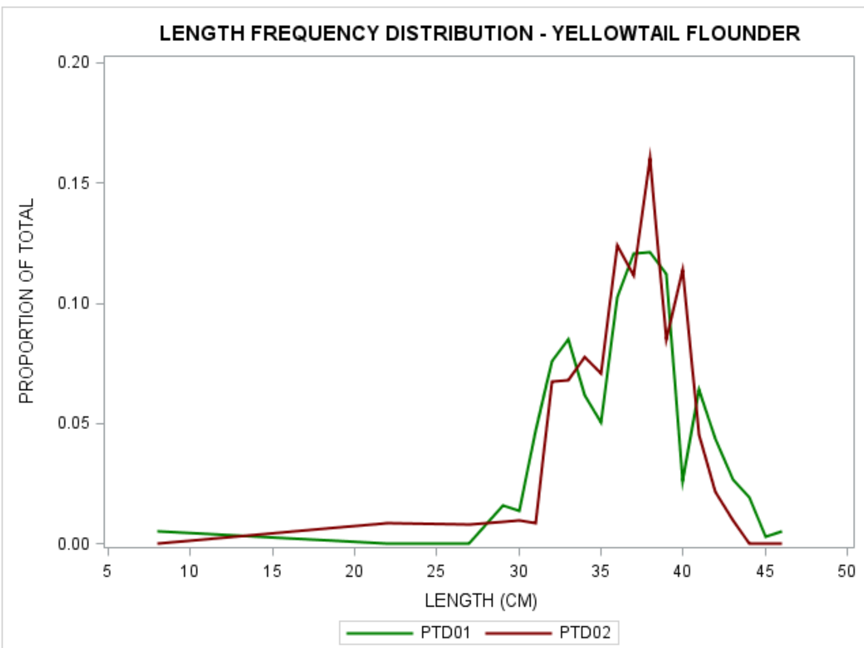


Figure C5 Length frequency distributions for the scaled catch data at size for winter flounder.

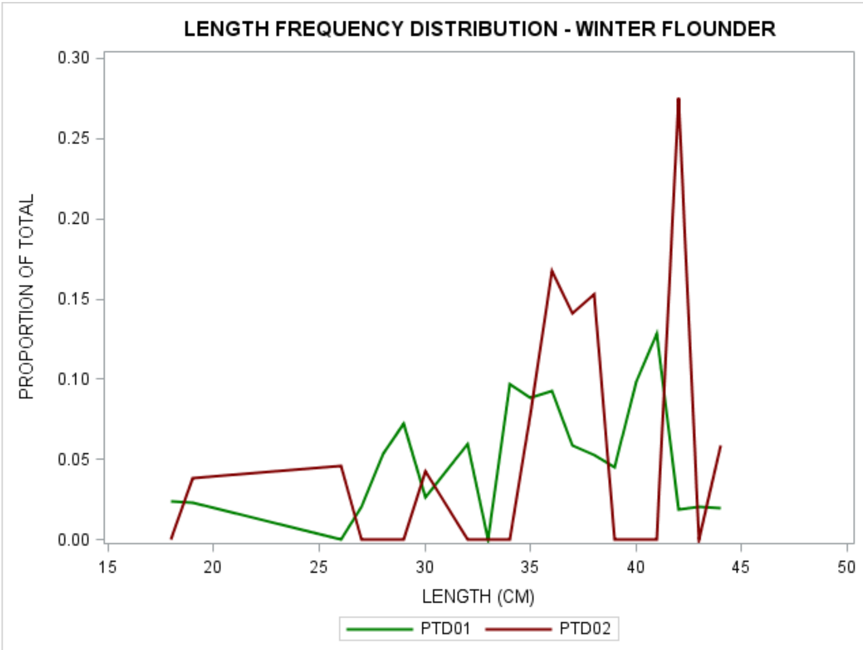


Figure C6 Length frequency distributions for the scaled catch data at size for windowpane flounder.

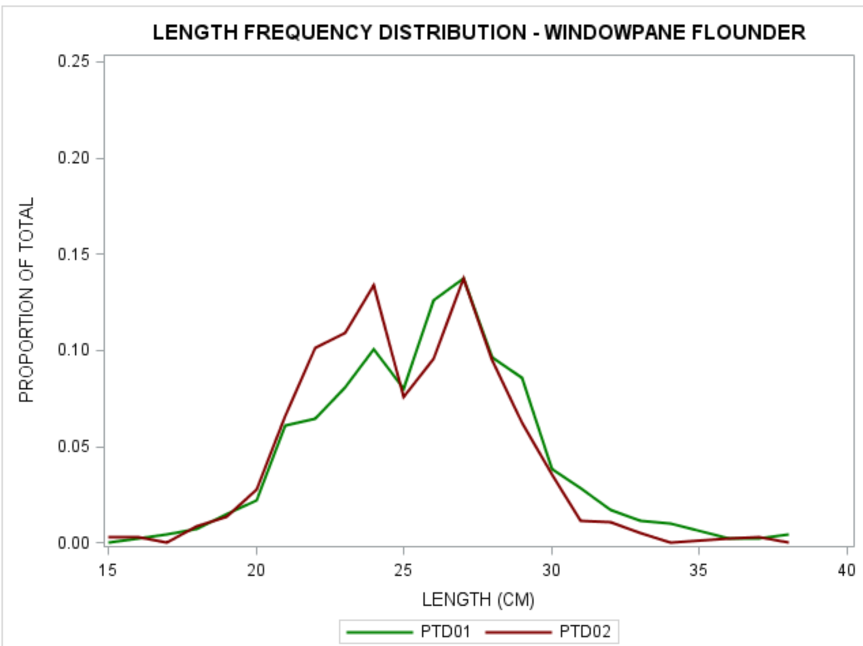


Figure C7 Length frequency distributions for the scaled catch data at size for monkfish.

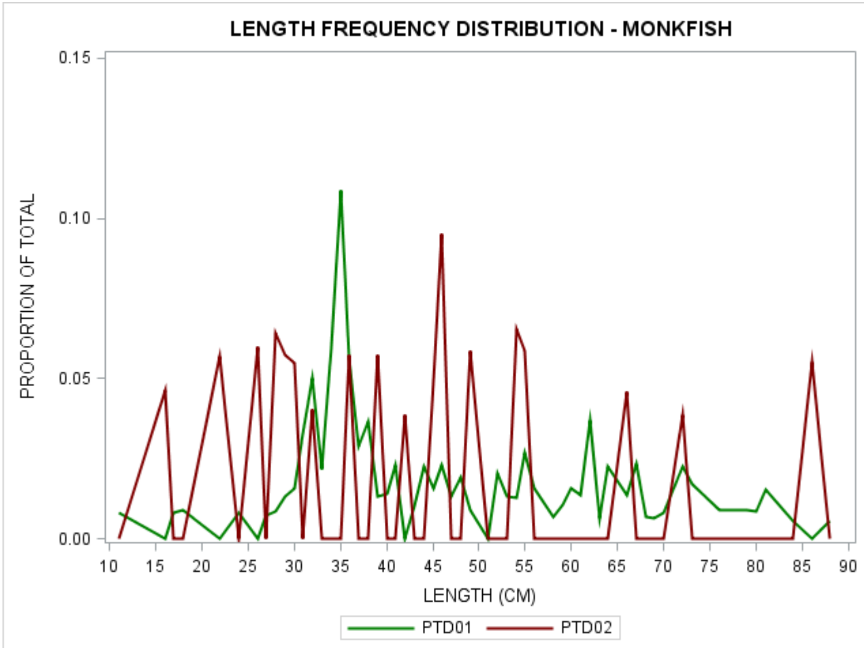


Figure C8 Length frequency distributions for the scaled catch data at size for sea scallops.