Testing of Modifications to the Cfarm Turtle Deflector Dredge For Bycatch Reduction

FINAL REPORT

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Project Summary

The objective of these experiments was to determine if the two different scallop dredges performed differently and how those differences might be affect catch rates and size selection of both scallops and the major finfish bycatch species. Ultimately, 4 experimental cruises were conducted from October 2010 through May 2011, performing roughly 308 paired tows. The testing took place on Georges Bank, in Closed Area I (CAI) and Closed Area II (CAII) access areas (Figure 1), chosen based on relatively high historical yellowtail and winter flounder bycatch. On each trip an 80 station sub-set of 160 pre-identified grid stations were occupied, consisting of 40 stations in each area. Tows were 30 minutes in duration, with an average tow speed of 4.8 knots. All catch was recorded and a subset of species were measured, and then returned to the sea.

To examine the comparative data, we used a Generalized Linear Mixed Model (GLMM) 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. 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 two dredges performed roughly equivalently with respect to sea scallop retention. The Coonamessett Farm Turtle Deflector Dredge (CFTDD) was slightly more efficient (~2.1%), although this difference was not statistically significant. A slight difference in scallop size selectivity of the two dredges was detected, with the CFTDD capturing more small scallops. With respect to finfish bycatch, results were varied. The CFTDD generally reduced the capture of flatfish and some skates, however, these differences were generally not statistically significant. No statistically significant differences in the size selectivity of the finfish bycatch were detected for all trips combined but differences existed on individual trips.

Background

In an effort to reduce the capture of threatened and endangered sea turtles; a modified dredge frame was designed by personnel at Coonamessett Farm. Changes to the dredge were intended to reduce the injuries suffered by turtles by reducing the probability of being captured by the gear. A series of experiments were conducted to determine the efficacy of this dredge with respect to turtles. While the primary goal of these modifications was focused on sea turtles, the impact of the CFTDD with respect to the target species (sea scallops) and finfish bycatch is also critically important for the modified dredge to be considered as an alternative or replacement for existing dredges in the fishery.

From May 2006 until November 2009 a total of thirty-three trips were made on thirteen different commercial scallop vessels to test turtle deflector dredge modifications for impacts on scallop catch, fish bycatch, and frame durability. Five general design modifications were tested by conducting paired tows using the modified dredge design alongside a standard New Bedford dredge as a control. Both the modified deflector dredge and control dredges were fished using identical tow parameters. A total of 4,059 paired tows were conducted in which tow data and scallop catch were recorded; total catch was quantified from 40% of these tows. In addition, flume tank testing was utilized for flow characterization to determine if there were any significant differences in cutting bar and frame hydrodynamics between the various design options.

Overall the experimental dredge design concept (cutting bar forward of depressor plate, 45° cutting bar and strut angle, doubled outer bale, and reduced number of bale bars) increased the catch of scallops while decreasing the retention of important bycatch species. Of the 1,632 observed tows analyzed (student's t-test for paired means a=0.05) relative to the standard New Bedford dredge, the experimental dredges increased scallop catch by 3% (P = 0.0000), while having significant decreases in summer flounder (-11%, P=0.003), yellowtail flounder (-46%, P=0.0000), winter flounder (-69%, P=0.0000), barndoor skate (-18%, P=0.0000), winter skate (-20%, P=0.005), windowpane flounder (-47%, P=0.0000), and fourspot flounder (-20%, P=0.0000). Interestingly there was no significant difference in the catch of little skates (-0.3%, P=0.404) and monkfish (1%, P=0.309).

The final dredge frame design tested in the study (CFTDD) held up to the rigors of commercial fishing on most scallop grounds, maintained commercially acceptable levels of scallop catch, and had significantly lower bycatch of several species, while applying features that could reduce injury to sea turtles. In addition, this dredge design was found to be readily acceptable and applied by fishers with no increase in costs or labor. However, the final dredge design was not tested in areas of high yellowtail bycatch.

The original objective of this project was to continue the focus on twine top design. However, the 2009 dual mesh twine top project found that twine top modifications to the CFTDD did not seem to be effective in changing the bycatch ratios for yellowtail flounder. The NEFMC Sea Scallop Plan Development Team (PDT) requested that additional information be collected on the reductions of yellowtail bycatch using the final deflector dredge design, which then became the focus of this project.

CFTDD Design

There are five overall components of the TDD modification:

1. Cutting bar must be forward of the dredge frame;
2. Angle between the cutting bar and the top of the frame must be less than or equal to 45 degrees;
3. All bale bars must be removed except the outer bale and center support bar, leaving an otherwise unobstructed space between the cutting bar and forward bale wheels;
4. Strut spacing not to exceed 12 inches; and
5. Frame extension or "bump out" required, exceeding 12 inches.

Each element of this dredge is based on direct field research that has been conducted over several years. For example, the first condition (that the cutting bar must be forward of the dredge frame) is intended to direct turtles up and over the dredge, and is based on early field tests conducted in Panama City in (2005 Milliken et al. 2007; Smolowitz et al. 2010). The cutting bar in a standard dredge is behind and under the depressor plate, preventing a turtle from rising above the dredge.

The specification that the angle between the cutting bar and the top of the frame must be less than or equal to 45 degrees is intended to provide a smoother transition for a turtle to get over the dredge, but still maintain the same overall height of the standard dredge. This angle has been directly tested in the field and steeper angles provide a greater barrier. Research is currently being conducted using lower angles, or a lower profile dredge.

Third, the requirement that specifies that all bale bars must be removed except the outer bale and center

support bar has evolved from several trials with different versions of this dredge. This combination of two outside bale bars and one center bar creates an unobstructed space for turtles to escape up and over the dredge, maximizing escapement upward without compromising the structural integrity of the dredge design.

The maximum 12 inch spacing requirement has been directly tested in the field, and it has been found that this modification helps prevent turtles from entering the dredge and while still maintaining the integrity of the dredge design.

Lastly, the requirement of a frame extension or "bump out" that must be at least 12 inches is an element that was designed to address a potential hang up point for turtles. By bumping out the dredge frame, a greater area is created for turtles to escape up and over the dredge and prevents turtles from getting hung up in the corners of the dredge. This element was also tested directly in the field and showed improved escapement without compromising the integrity of the dredge.

The combination of these elements is designed to reduce the likelihood of a turtle passing under the frame when the dredge fishes on the seafloor and subsequently getting injured/crushed. Future adaptations can be developed to further minimize scallop dredging impacts on turtles.

Approach

On directed research trips we compared standard New Bedford style dredges to a CFTDD. The trips occurred in the scallop special access areas within groundfish CAI and CAII. These areas have the highest ratios of bycatch to scallop catch on Georges Bank for yellowtail flounder (CAII), skates (CAI & CAII), winter flounder (CAI) and summer flounder (CAI). They also contain a range of habitat types from flat sand to occasional boulder. The trips were as follows:

F/V Celtic 2010-2	October 12-18, 2010
F/V Arcturus 2011-1	March 09-15, 2011
F/V Celtic 2011-1	April 13-20, 2011
F/V Westport 2011-1	May 11-17, 2011

Two dredges were towed simultaneously during all four trips. The participating vessels provided the standard dredge rigged the way they typically fish their gear. The turtle deflector dredge (Figure 2) was the same on all four trips and served as the control. All gear specifications can be found in Table 1. Towing speeds were maintained at 4.6 -5.0 knots and wire scope was four to one; tow times were 30 minutes.

Experimental Design

Two different approaches were utilized to analyze the data set. The first approach described, the GLMM, groups all the data and gives an overall perspective on how the two gears compare over the entire experiment. Then, a Student t-test was used to compare the separate dredges on each individual trip.

The paired tow experiments were conducted within the context of a bycatch survey of the Georges Bank Closed Areas I and II covering a wide range of fishery conditions. 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. In contrast, the Student t-test approach is trip specific and therefore is not an appropriate methodology for comparing data from two or more different trips.

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 most tows. These subsamples were measured in 5 mm incremental groups to estimate the length frequency of the entire catch. This method allows for the determination of the size frequency of the entire catch by expanding the catch at each shell height by the fraction of total number of baskets sampled. All of the commercially important finfish species and barndoor skates were measured to the nearest centimeter and counts were taken of winter and little skates.

Statistical Models – GLMM

Scallop catch data from the paired tows provided the information to estimate differences in the fishing power of each vessel/gear combination tested and is based on the analytical approach in Cadigan et al. 2006. Assume that each vessel/gear combination tested in this experiment has a unique catchability. Let q_r equal the catchability of the CFTDD and q_f equal the catchability of the standard dredge used in the study. The efficiency of the CFTDD relative to the standard 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 and fish density is minimized, observed differences in scallop catch for each vessel will reflect differences in the catchabilities of the vessel/gear combinations tested. Our analysis of the efficiency of the CFTDD relative to the standard dredge consisted of two levels of examination. The first analysis examined potential differences in the total catch per tow. Subsequent analyses investigated whether size (i.e. length) was a significant factor affecting relative efficiency. Each analysis assumes a hierarchy of random variation and nests tow by tow variation within trip level variation.

Let C_{iv} represent the scallop catch at station i by dredge v, where $v=r$ denotes the CFTDD and $v=f$ denotes the standard New Bedford style dredge. Let λ_{ir} represent the scallop/fish density for the ith station by the CFTDD and λ_{if} the scallop/fish density encountered by the standard 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 patch size and coverage by a paired tow. The probability that a scallop 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 CFTDD is given by:

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

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

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

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

If the dredges encounter the same scallop 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 stations and scallop lengths (Cadigan et al. 2006). The preferred approach is to use the conditional distribution of the catch by the CFTDD 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:

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

where $p=\rho/(1+\rho)$ is the probability that a scallop taken in the survey is captured by the CFTDD. 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:

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

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 scallop catch per tow is pooled over lengths.

Often, modifications can result in changes to the length based relative efficiency of the two gears. In those instances, the potential exists for the catchability of scallops 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 scallop density exist, a binomial logistic regression GLMM for a range of length groups would be:

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

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

The potential exists, however, that there will be variability in both the number as well as the length distributions of scallops 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:

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

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 volume, catches for particular tows were sub-sampled. This is accomplished by randomly selecting a one bushel sample for length frequency analysis. 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 station i for the vessel r. This adjustment results in a modification to the logistic regression model:

$$\log\left(\frac{p_i}{1+p_i}\right) = \beta_0 + \delta_{i0} + (\beta_1 + \delta_{i1})l_i + \log\left(\frac{q_{ir}}{q_{if}}\right), \delta_{ij} \sim N(0, \sigma_j^2), i = 1,...,n, j = 0,1. \qquad (9)$$

The last term in the model represents an offset in the logistic regression (Littell et al. 2006). We used SAS/STAT® PROC GLIMMIX to fit the generalized linear mixed effects models.

Statistical approach – Student T-Test

Paired student t-tests were used for trip by trip comparisons to test for significance between the experimental and control dredges in terms of catch of scallops and ten other species. Significance was evaluated as a difference from zero. The methodology of towing two dredges simultaneously provided for the assumptions necessary to analyze the data using a paired t-test. Zar (1984) states, "the paired-sample t-test does not have the normality and equality of variances assumptions of the two sample t-test, but assumes only that the differences (d(t)) come from a normally distributed population of differences.... Whenever the paired-sample t-test is applicable, the Wilcoxon paired-sample test is also applicable. If, however, the d(t) values are from a normal distribution, then the latter (Wilcoxon) has only a 95% of

detecting differences as the former (paired t-test)." Although Zar seems to suggest the paired student t-test as the better test, there is not universal agreement on this issue. Because of this, we also evaluated comparisons using the non-parametric Wilcoxon matched pairs test (Wilcoxon 1945) and found that the results were consistent with those provided by the paired Student t-tests. Catch ratios for each dredge were calculated in order to compare the total count of each bycatch species per sampled scallop bushel.

Results and Discussion

Overall results, based on using the GLMM, indicate the two dredge designs had similar catches. Roughly 308 paired tows were completed over the course of the experiment. Only a subset was actually sampled for scallop/fish and not all species were present in each of the sampled tows. Total catch for the major species with the number of sampled tows are shown in Table 2. For the intercept only model (gear effect only), a scatterplot of the catches from the paired tows are shown in Figures 3 and 4. Parameter estimates are shown in Table 3. The performance of the two dredges was variable and only in the case of unclassified skates was the estimated relative efficiency values statistically significant.

For the two parameter model (length effects), the only significant difference in the length compositions of catches from each gear appeared in scallops, although there was a general trend for the CFTDD to be less efficient as length increased (negative parameter estimates B_1). Graphs depicting the length based data as well as estimated proportions are shown in Figure 5. Parameter estimates for the 2 parameter length based model are shown in Table 4.

In both model formulations, we attempted to fit a model that included a hierarchical random effect structure (i.e. station within cruise). For some species, that model was too complex and a model that allowed the intercept to vary randomly as a function of only station was used.

The paired Student t-test analyses examined differences in catch from each dredge on a trip-by-trip basis. Overall, when using the paired t-tests there was no significant difference in the number of bushels each dredge caught on any given research cruise, as shown in Table 5. However, when examining yellowtail flounder and winter flounder bycatch amounts, the CFTDD caught significantly less of each of these two species on three of the four trips (Tables 6 and 7).

Although there was a significant difference in the yellowtail and winter flounder bycatch amounts from each dredge, the number of trips conducted for this research is low. Since many factors impact the scallop catch and bycatch amounts, we are hoping to continue to test the gear in order to find a suitable design that consistently and adequately reduces bycatch while maintaining scallop landings. One unexpected but highly useful outcome of this research is increased knowledge of the seasonal distribution of various fish species in the research area. With future work, we hope to create a more comprehensive understanding of the impacts on scallops and fish bycatch within the scallop industry.

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Figure 1. Map of Georges Bank Closed Areas I and II.

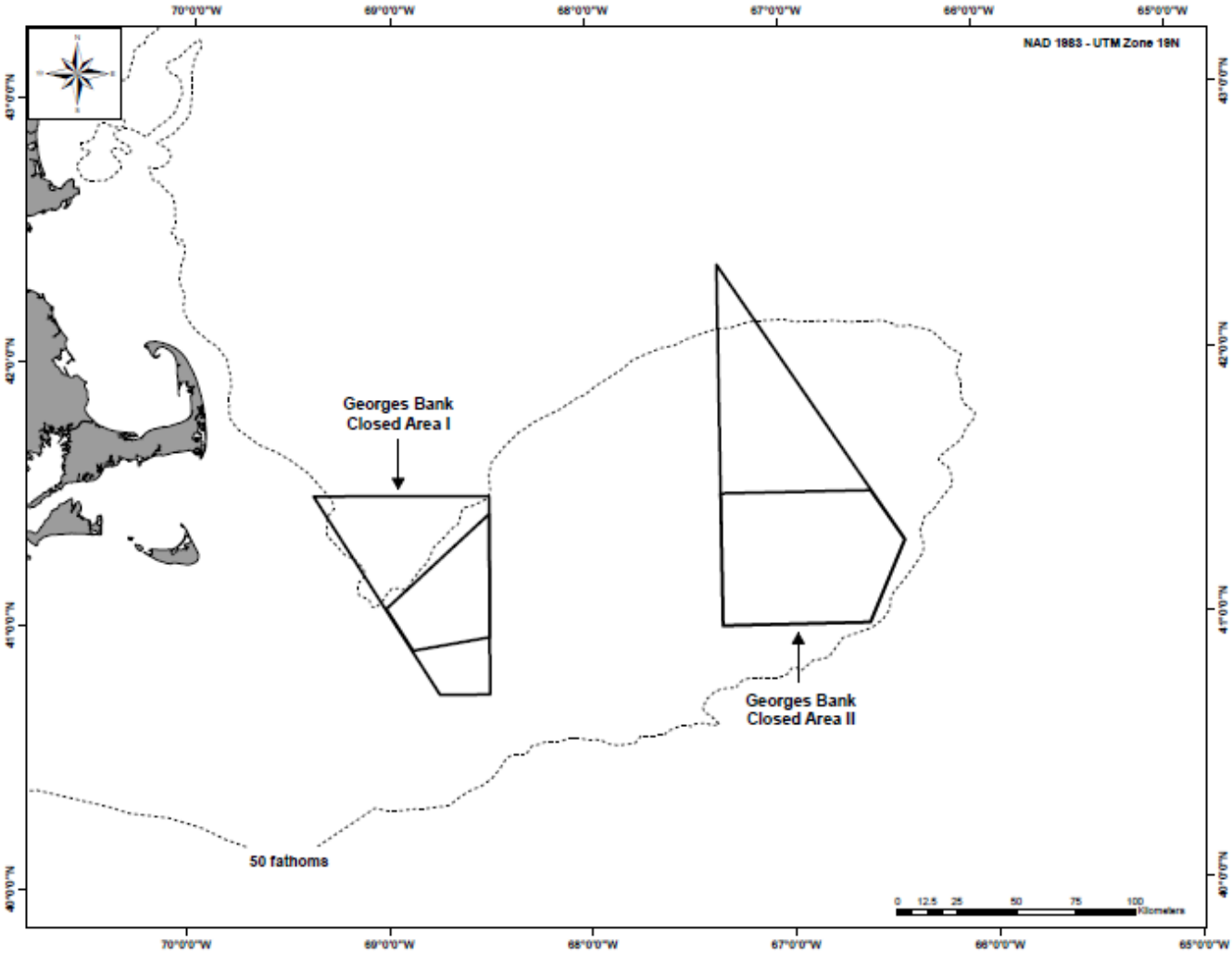
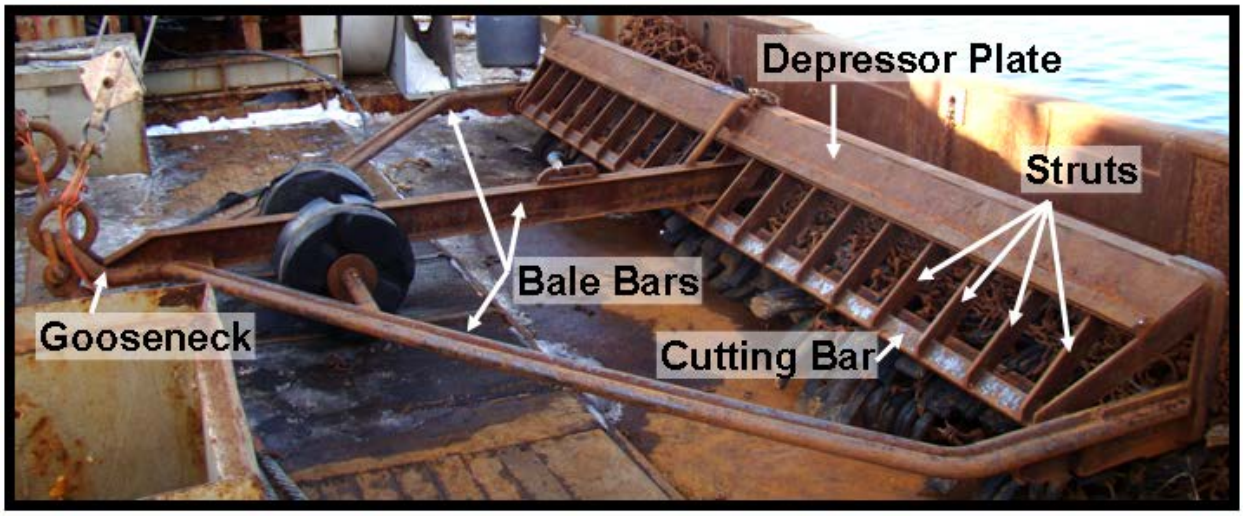


Figure 2. Photo of CF turtle deflector dredge frame (top) and illustration of completely rigged standard scallop dredge (bottom).



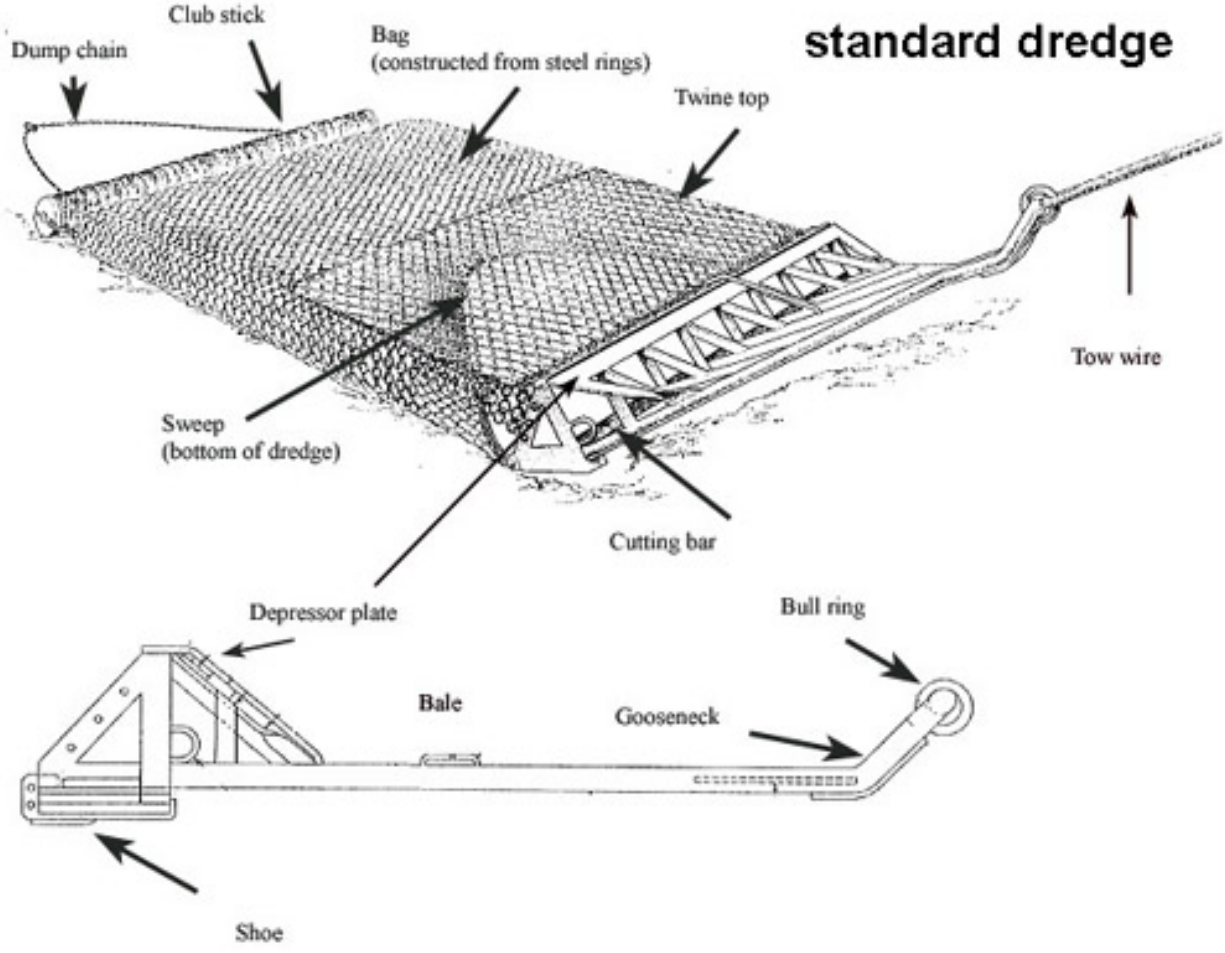


Figure 3. Total scaled pooled scallop catches for CFTDD vs. the standard New Bedford style scallop dredge (top panel). The black line has a slope of one. The dashed line has a slope equal to the estimated relative efficiency (from the one parameter gear effect only model).

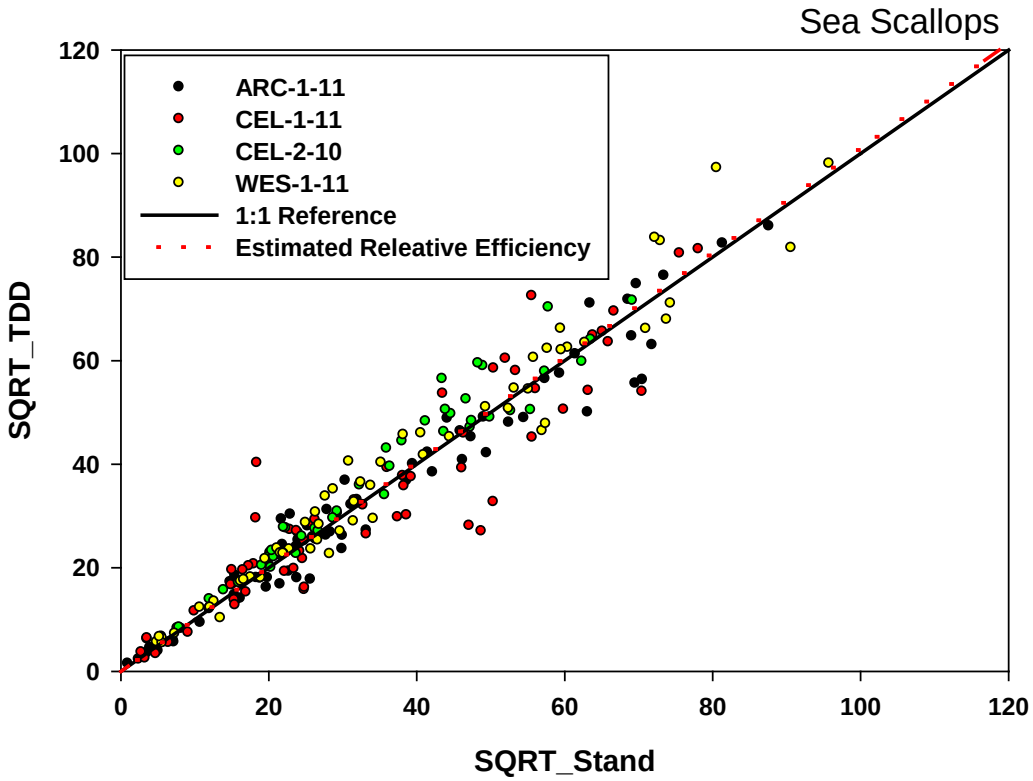
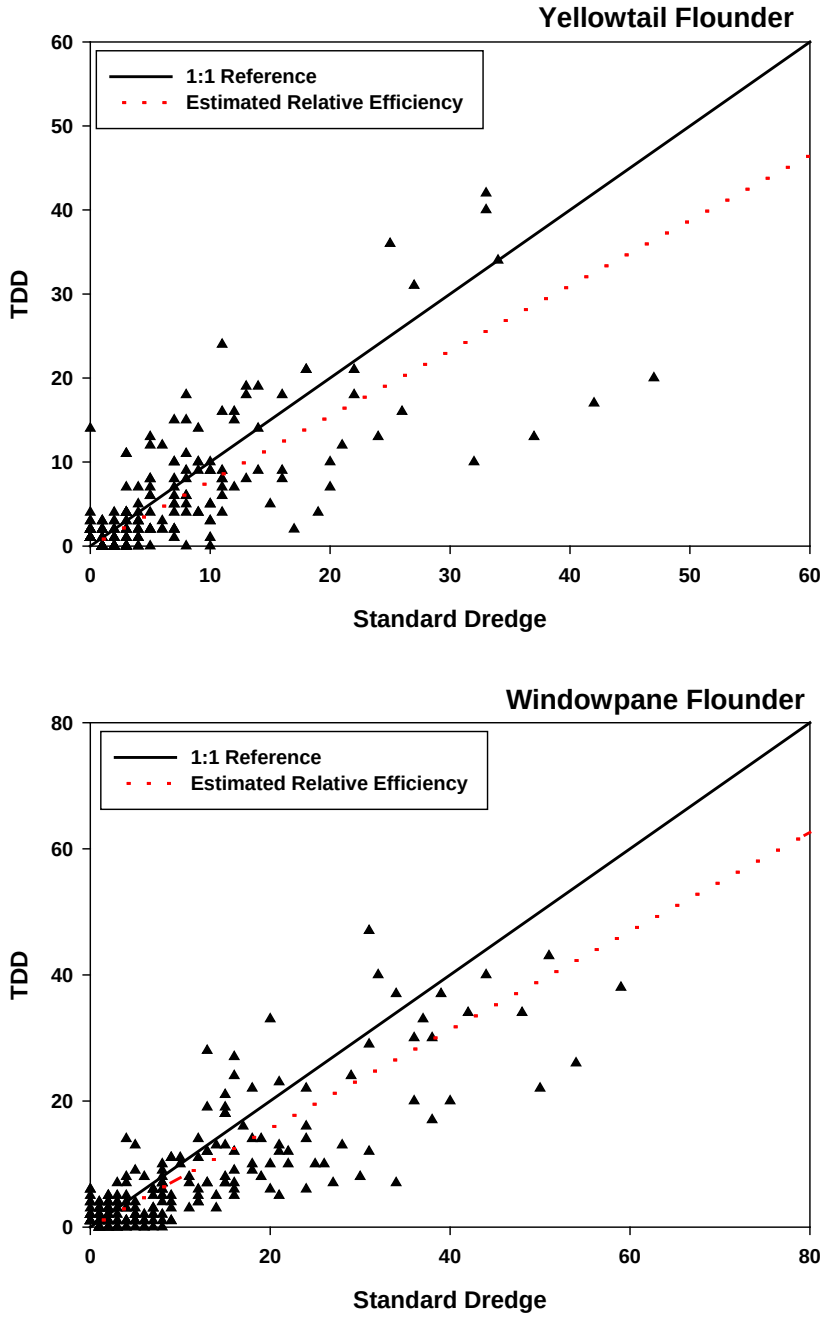
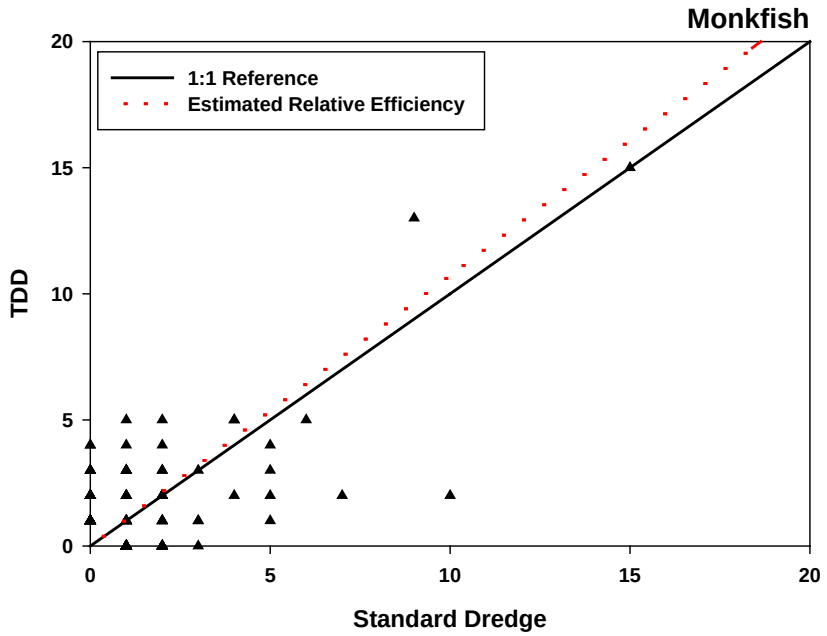
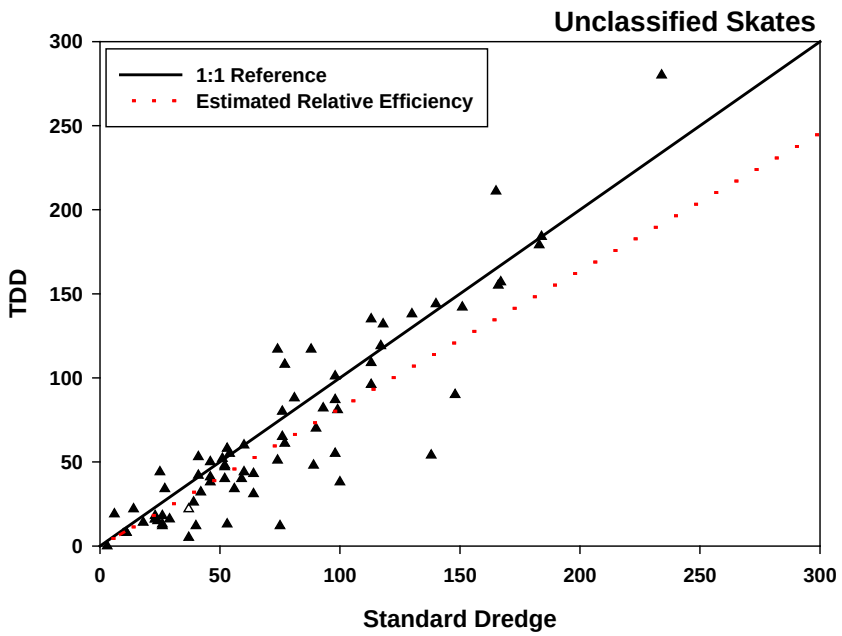


Figure 4. Total scaled pooled finfish catches for CFTDD vs. the standard New Bedford style scallop dredge (top panel). The black line has a slope of one. The dashed line has a slope equal to the estimated relative efficiency (from the one parameter (gear effect only) model.




Monkfish
1:1 Reference
Estimated Relative Efficiency
TDD
Standard Dredge
0
5
10
15
20


Unclassified Skates
1:1 Reference
Estimated Relative Efficiency
TDD
Standard Dredge
0
50
100
150
200
250
300

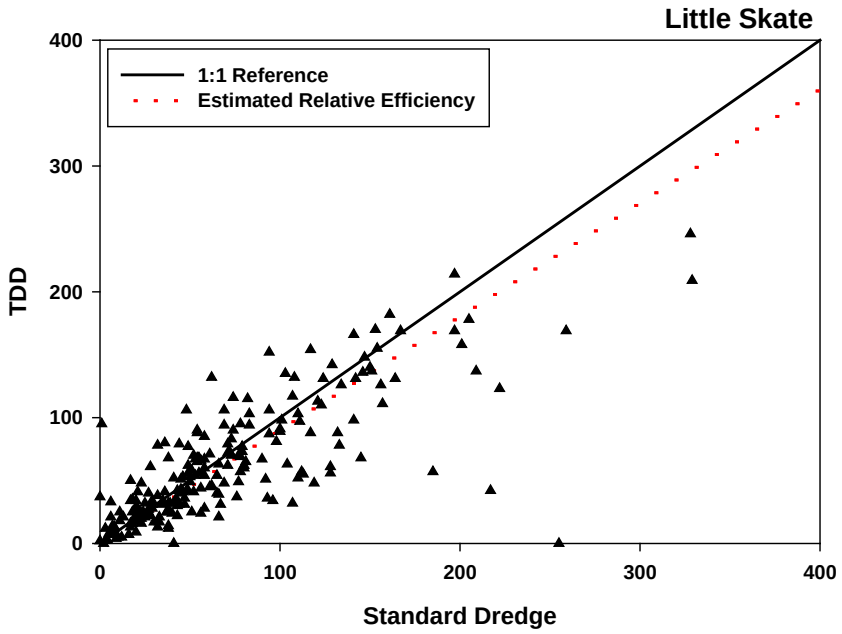
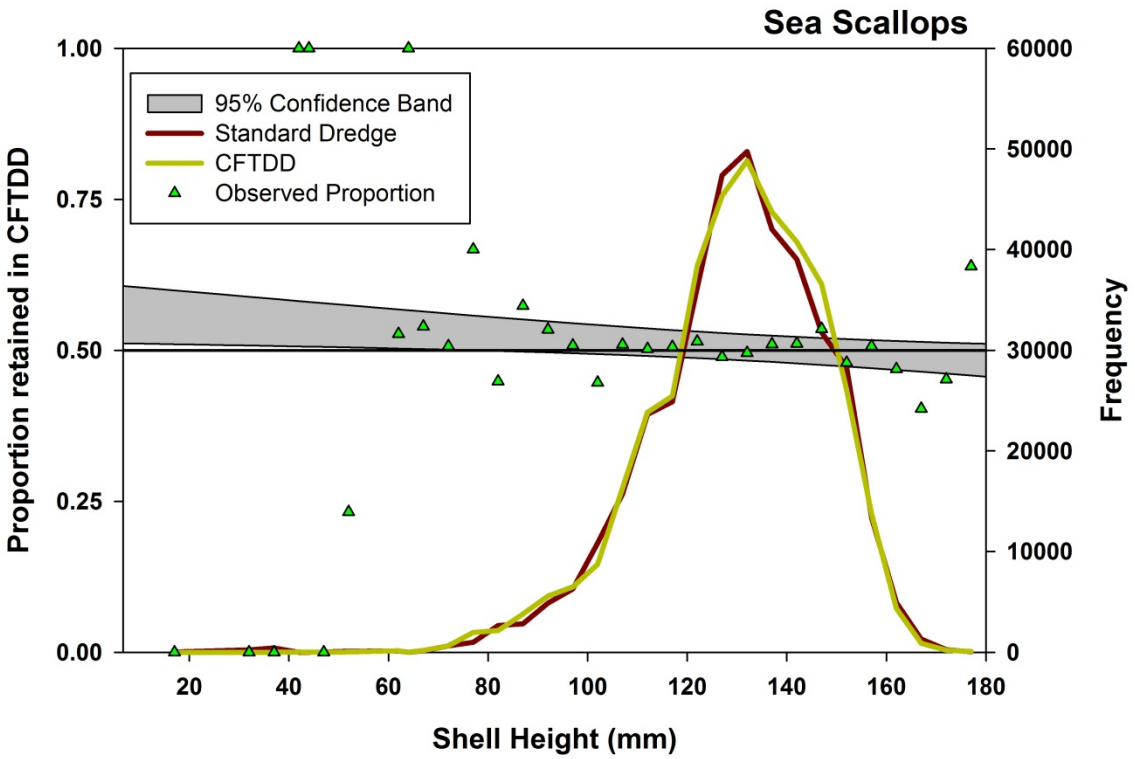
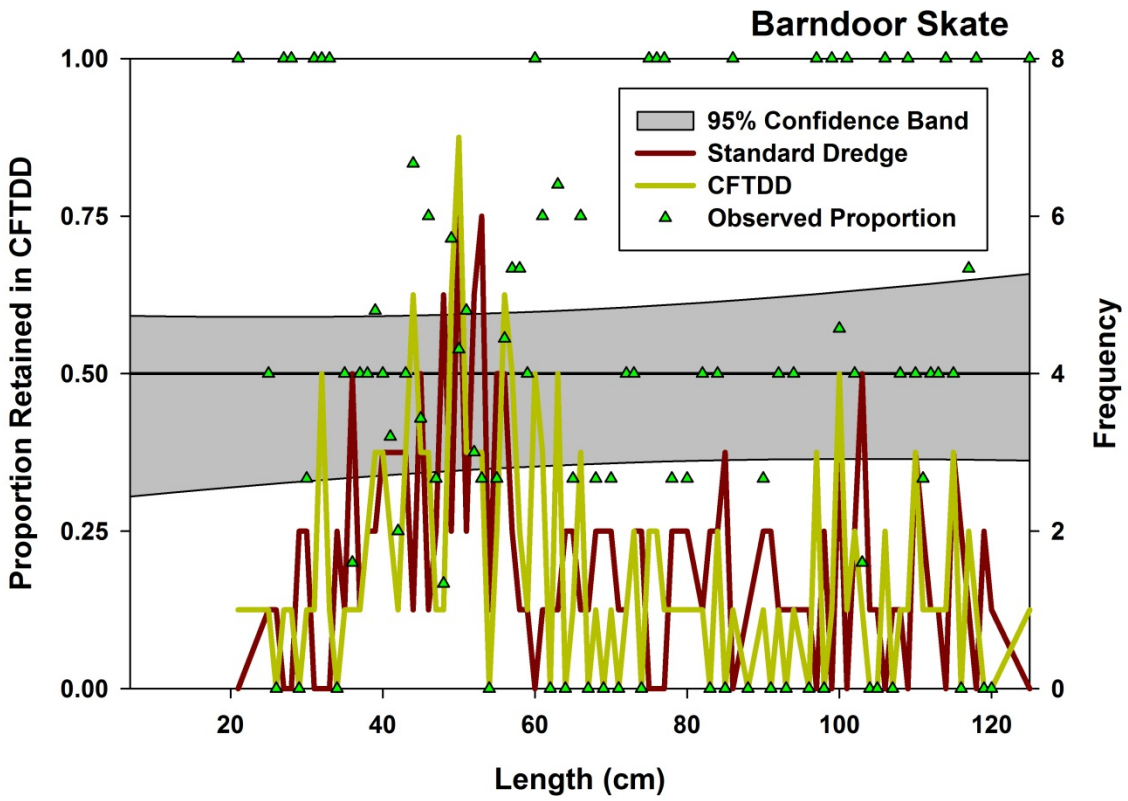
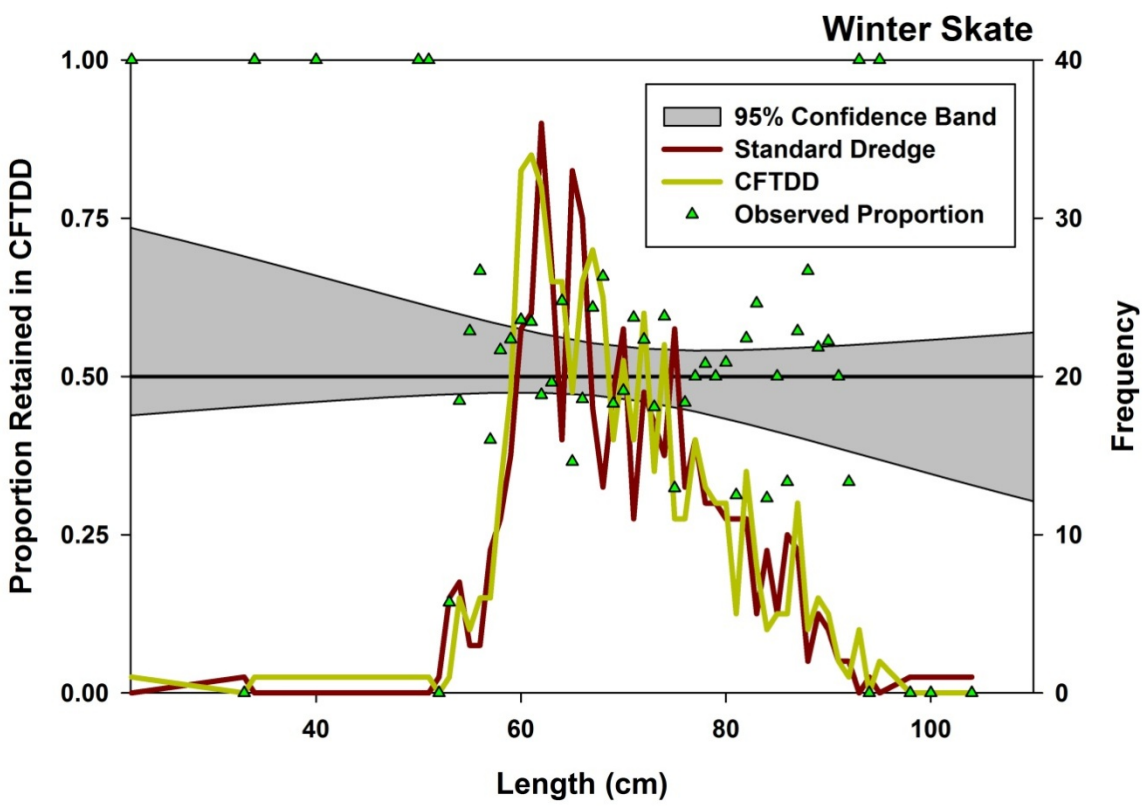
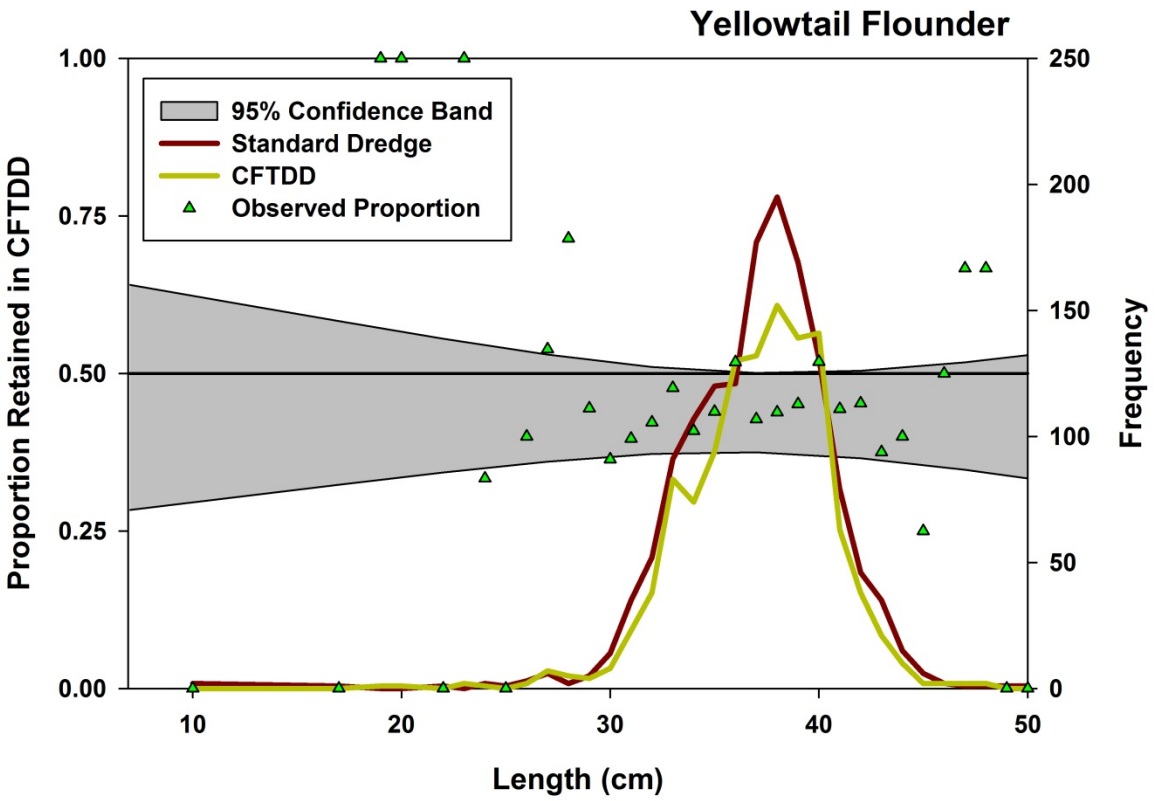

Little Skate
1:1 Reference
Estimated Relative Efficiency
TDD
Standard Dredge
0
100
200
300
400

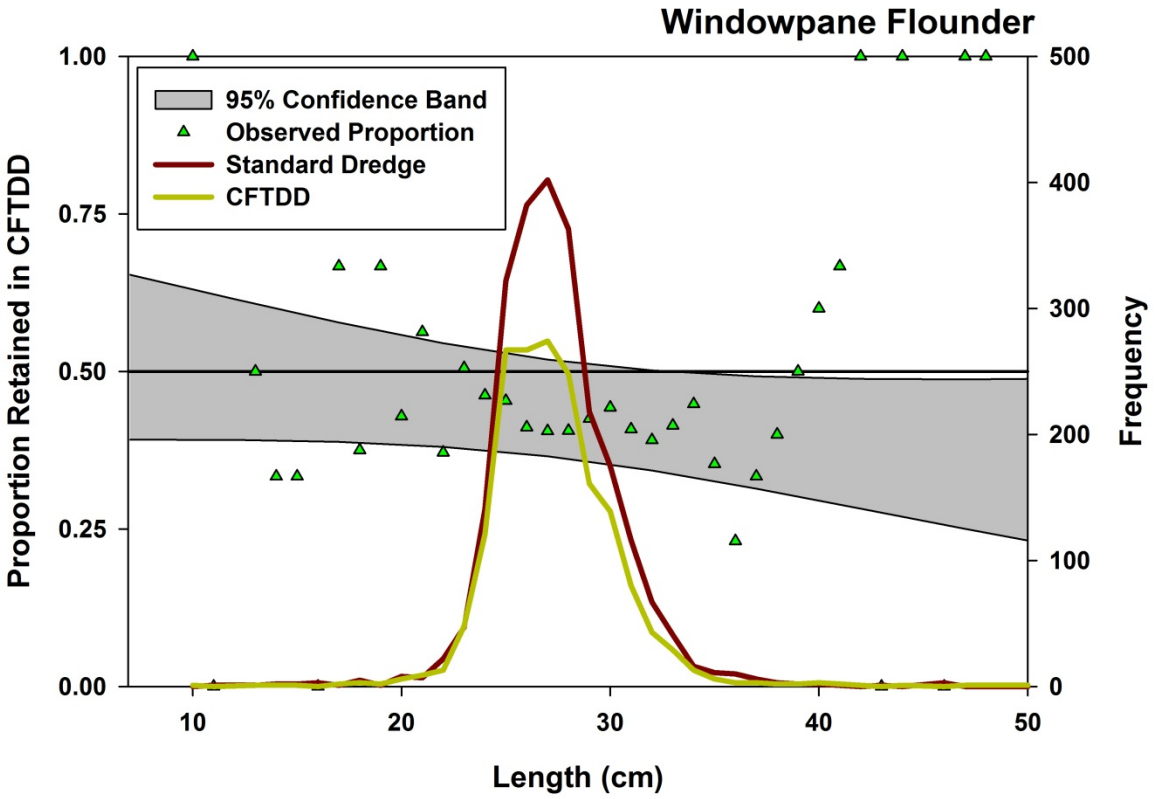
Figure 5. Observed scaled length frequency distributions for the CFTDD and the New Bedford style scallop dredge. The green triangles represent the observed proportions ($Catch_{CFTDD}/(Catch_{STAND} + Catch_{CFTDD})$). The grey shaded area represents the 95% confidence band around the estimated relative efficiency values as estimated by the two parameter (gear and length) effect model.




Barndoor Skate
95% Confidence Band
Standard Dredge
CFTDD
Observed Proportion
Proportion Retained in CFTDD
Frequency
Length (cm)
1.00
0.75
0.50
0.25
0.00
8
6
4
2
0
20
40
60
80
100
120


Winter Skate
95% Confidence Band
Standard Dredge
CFTDD
Observed Proportion
Proportion Retained in CFTDD
Frequency
Length (cm)
1.00
0.75
0.50
0.25
0.00
40
30
20
10
0
40
60
80
100


Yellowtail Flounder
95% Confidence Band
Standard Dredge
CFTDD
Observed Proportion
Proportion Retained in CFTDD
Frequency
Length (cm)
1.00
0.75
0.50
0.25
0.00
250
200
150
100
50
0
10
20
30
40
50


Windowpane Flounder
95% Confidence Band
Observed Proportion
Standard Dredge
CFTDD
Proportion Retained in CFTDD
Frequency
Length (cm)
1.00
0.75
0.50
0.25
0.00
500
400
300
200
100
0
10
20
30
40
50

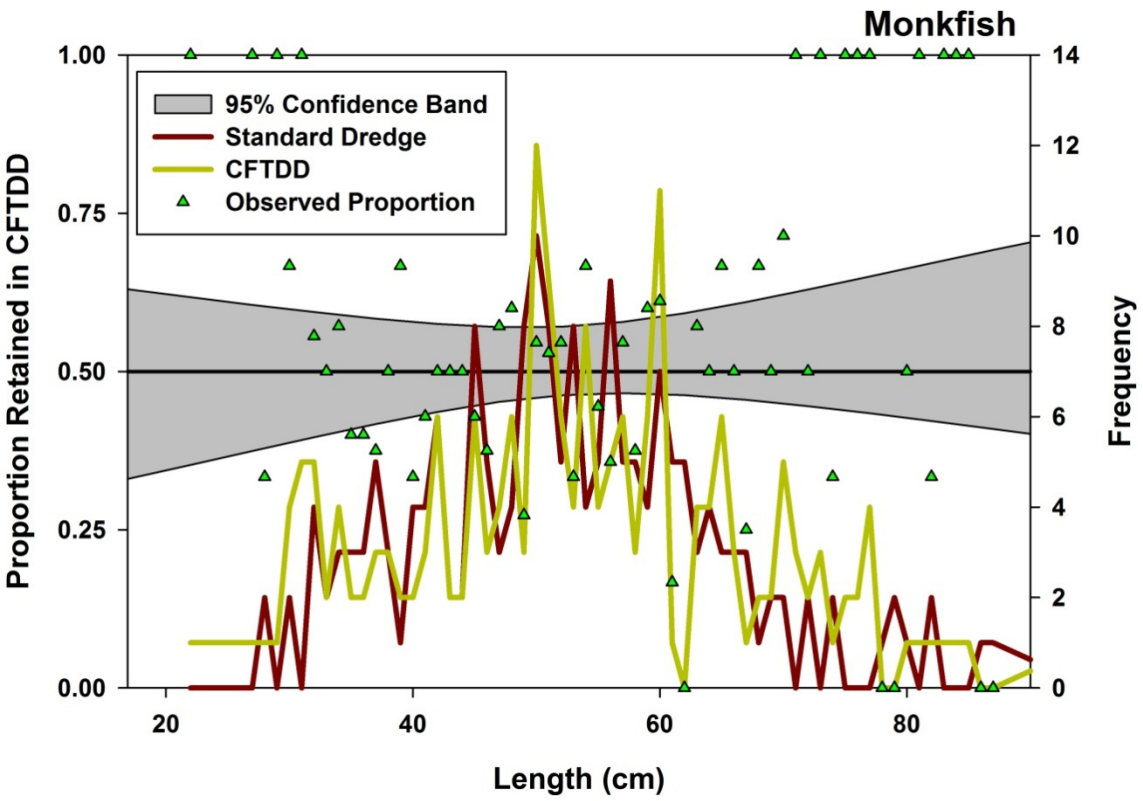

Monkfish
95% Confidence Band
Standard Dredge
CFTDD
Observed Proportion
Proportion Retained in CFTDD
Frequency
Length (cm)
1.00
0.75
0.50
0.25
0.00
14
12
10
8
6
4
2
0
20
40
60
80

Table 1. Gear specifications for each vessel and the CFTDD.

	Celtic	**Westport**	**Arcturus**	**Turtle**
Bag (# of rings)	10 x 40	9 x 40	9 x 40	10 x 40
Apron (# of rings)	8 x 40	13 x 40	10 x 40	8 x 40
Side Piece (# of rings)	6 x 17	5 x 16	5 x 17	6 x 17
Diamond (# of rings)	14	14	13	14
Skirt (# of rings)	3 x 38	2 x 36	dog chains	3 x 38
Sweep (# of links)	125	121 long links	141	125
Twine Top (# of meshes)	7.5 x 60	8.5 x 80	8.5 x 90	8.5 x 60
Mesh size = 292 mm	Ring size = 104 mm			

Table 2. Summary data for the paired tow experiments.

Common Name	Scientific Name	Number of Tows Sampled	Standard Dredge	CFTDD	% Difference
Sea Scallops	*Placopecten magellanicus*	*241*	388,666	394,205	1.43
Unclassified Skates	*Raja spp.*	*72*	5303	4745	-10.52
Winter Skate	*Raja ocellata*	*90*	546	574	5.13
Little skate	*Raja erinacea*	*217*	15074	13420	-10.97
Barndoor skate	*Raja laevis*	*114*	150	141	-6.00
American Plaice	*Hippoglossoides platessoides*	*96*	176	104	-40.91
Summer Flounder	*Paralichtys dentatus*	*44*	34	37	8.82
Fourspot Flounder	*Paralichtys oblongotus*	*76*	170	182	7.06
Yellowtail Flounder	*Limanda ferruginea*	*217*	1422	1177	-17.23
Winter Flounder	*Psuedopleuronectes americana*	*104*	228	173	-24.12
Witch Flounder	*Glyptocephalus cynoglossus*	*41*	36	40	11.11
Windowpane Flounder	*Scophthalmus aquasus*	*224*	2383	1755	-26.35
Monkfish	*Lophius americanus*	*121*	187	199	6.42

Table 3. Mixed effects model (gear effect only) results. Parameter estimates are on the logit scale and significant estimates are shown in bold. An * represents a model formulation with non-nested random effects (i.e. the random effect was station only). DF is degrees of freedom.

Common Name	**Scientific Name**	**Tows Sampled**	**DF**	**Estimate (β_0)**	**Standard Error**	**Lower 95% CI**	**Upper 95% CI**	**t**	**p-value**
Sea Scallops	*Placopecten magellanicus*	*241*	*3*	0.021	0.044	-0.118	0.160	0.480	0.6639
Unclassified Skates*	*Raja Spp.*	*72*	71	**-0.200**	**0.050**	**-0.300**	**-0.099**	**3.971**	**0.0002**
Winter skate*	*Raja ocellata*	*90*	*89*	0.031	0.082	-0.132	0.193	0.374	0.7095
Little skate	*raja erinacea*	*217*	*3*	-0.103	0.129	-0.515	0.309	0.790	0.4849
Barndoor skate	*Raja laevis*	*114*	*3*	-0.096	0.245	-0.874	0.682	0.393	0.7203
American Plaice	*Hippoglossoides platessoides*	*96*	3	-0.469	0.271	-1.332	0.393	1.731	0.1819
Summer Flounder*	*Paralichtys dentatus*	*44*	*43*	0.117	0.268	-0.423	0.658	0.437	0.6640
Fourspot Flounder*	*Paralichtys oblongotus*	*76*	75	0.049	0.136	-0.222	0.320	0.362	0.7186
Yellowtail Flounder	*Limanda ferruginea*	*217*	3	-0.254	0.131	-0.670	0.162	1.946	0.1469
Winter Flounder	*Psuedopleuronectes americana*	*104*	3	-0.662	0.342	-1.749	0.425	1.938	0.1480
Witch Flounder*	*Glyptocephalus cynoglossus*	*41*	40	0.277	0.366	-0.462	1.017	0.758	0.4526
Windowpane Flounder	*Scophthalmus aquasus*	*224*	3	-0.245	0.159	-0.750	0.259	1.547	0.2196
Monkfish*	*Lophius americanus*	*121*	120	0.071	0.112	-0.150	0.292	0.633	0.5278

Table 4. Two parameter mixed effects model results. The comparison models the logit of the proportion of the catch at length from the CFTDD relative to the total catch from both dredges. Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale and significant parameter estimates are shown in bold. An * represents a model formulation with non-nested random effects (i.e. the random effect was station only).

Common Name	Scientific Name	Parameter	Estimate	Standard Error	Lower 95% CI	Upper 95% CI	t	p-value
Sea Scallop	*Placopecten magellanicus*	β_0	0.251	0.103	-0.077	0.579	2.434	0.093
		β_1	**-0.002**	**0.001**	**-0.003**	**0.000**	**-2.507**	**0.012**
Winter skate*	*Raja ocellata*	β_0	0.551	0.464	-0.371	1.474	1.187	0.238
		β_1	-0.008	0.007	-0.021	0.005	-1.140	0.255
Barndoor skate	*Raja laevis*	β_0	-0.243	0.315	-1.244	0.758	-0.772	0.496
		β_1	0.002	0.003	-0.003	0.008	0.794	0.428
Summer Flounder*	Paralichtys dentatus	β_0	0.858	1.024	-1.206	2.923	0.839	0.406
		β_1	-0.015	0.020	-0.055	0.025	-0.755	0.457
American Plaice	*Hippoglossoides platessoides*	β_0	-1.102	1.062	-4.481	2.277	-1.037	0.376
		β_1	0.017	0.027	-0.037	0.071	0.617	0.538
Fourspot Flounder*	*Paralichtys oblongotus*	β_0	0.858	0.844	-0.823	2.538	1.017	0.312
		β_1	-0.025	0.026	-0.077	0.026	-0.971	0.333
Yellowtail Flounder	*Limanda ferruginea*	β_0	-0.157	0.464	-1.634	1.321	-0.338	0.758
		β_1	-0.003	0.012	-0.026	0.021	-0.219	0.827
Winter Flounder	*Psuedopleuronectes americana*	β_0	-1.003	0.912	-3.906	1.901	-1.099	0.352
		β_1	0.008	0.021	-0.033	0.050	0.403	0.687
Witch Flounder*	*Glyptocephalus cynoglossus*	β_0	1.292	3.043	-4.858	7.442	0.425	0.673
		β_1	-0.025	0.073	-0.173	0.124	-0.337	0.739
Windowpane Flounder	*Scophthalmus aquasus*	β_0	0.214	0.339	-0.864	1.292	0.632	0.572
		β_1	-0.017	0.011	-0.038	0.005	-1.539	0.124
Monkfish*	*Lophius americanus*	β_0	-0.163	0.446	-1.046	0.720	-0.365	0.716
		β_1	0.004	0.008	-0.012	0.020	0.540	0.590

Table 5. Scallop catch in bushels for each individual research trip.

	Turtle Dredge	Standard Dredge	Difference	Probability
Celtic 2010	1047.97	946.69	1.1069833	0.1125
Arcturus	1153.16	1268.33	0.9091956	0.2795
Celtic 2011	1101.52	1140.52	0.9658051	0.2132
Westport	1368.78	1241.36	1.1026455	0.3829

Table 6. Total number of Yellowtail Flounder caught on each research trip.

	Turtle Dredge	Standard Dredge	Difference	Probability
Celtic 2010	577	491	1.17515275	0.0625
Arcturus	229	436	0.52522936	0.0239
Celtic 2011	225	292	0.77054795	0.0288
Westport	194	276	0.70289855	0.0354

Table 7. Total number of Winter Flounder caught on each research trip.

	Turtle Dredge	Standard Dredge	Difference	Probability
Celtic 2010	118	106	1.1132075	0.2711
Arcturus	11	41	0.2682927	0.0207
Celtic 2011	15	35	0.4285714	0.011
Westport	38	78	0.4871795	0.0066