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 whether the gear performance characteristics of the two dredges differed and how those differences might be reflected in differential 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 CAI and CAII access areas; areas with relatively high yellowtail and winter flounder bycatch. On each trip an 80 station sub-set of 160 pre-identified grid stations were occupied; 40 in each area. Tows were 30 minutes in duration. All catch was 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 over 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.

Overall, the two dredges performed roughly equivalently with respect to sea scallops. The Coonamessett Farm turtle Deflector Dredge (CFTDD) was slightly more efficient (~2.1%), although this difference was not statistically significant. A slight difference in the size selectivity of the two dredges were detected for scallops, with the CFTDD being slightly more efficient in capturing 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 reduce the capture of threatened and endangered sea turtles; a modified dredge frame was designed by personnel at Coonamessett Farm. Modifications 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 were focused on sea turtles, the impact of the CFTDD with respect to the target species (sea scallops) and finfish bycatch is also critically important if the modified dredge be considered for implementation into 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 along side 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%, $P_t=0.0000$), winter flounder (-69%, $P=0.0000$), barndoor skate (-18%, $P= 0.0000$), winter skate (-20%, $P_t = 0.005$), sand dab (-47%, $P=0.0000$), and fourspot flounder (-20%, $P=0.0000$). Interestingly there were no significant difference in the catch of little skate (-0.3%, $P_t = 0.404$) 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, 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 Cfarm Turtle Deflector dredge do 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 and that 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 element that the cutting bar must be forward of the dredge frame is intended to direct turtle up and over 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 to test the impacts of a lower angle.

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 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; it maximizes escapement upward without compromising the structural integrity of the dredge design.

The requirement that strut spacing not exceed 12 inches has been directly tested in the field, and it has been found that 12 inch spacing is a good compromise that prevents turtles from entering the dredge and does not compromise 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 a dredge and not get 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 getting injured/crushed. It is possible that these elements could be modified by future actions if additional components or modifications are developed to further minimize impacts on turtles.

Approach

On directed research trips we compared standard New Bedford style dredges to a Cfarm Turtle Deflector Dredge (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 (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 1) was the same on all four trips and was 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

The paired tow experiments were conducted within the context of a bycatch survey of the Georges Bank Closed Areas I and II. As a result the experimental protocol varied, ranging from actual commercial conditions to more defined protocols as determined by the gear comparison or survey experimental designs. This approach has the advantage of being realistic relative to the actual biotic and abiotic conditions that the dredge will be operated in. In addition, varied species assemblages were sampled, to accurately represent the how the potential gear will be used. Multiple vessels and slight variation in gear handling and design were included in the experimental design and while this variability exists, the modeling approach detailed in the next section accounts for this variability and allows for a more broad inference (relative to vessels) to be made.

For each paired tow, the entire scallop catch was placed in baskets. A fraction of these baskets were measured to estimate length frequency for the entire catch. The shell height of each scallop in the sampled fraction was measured in 5 mm intervals. This protocol allowed 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. Finfish and invertebrate bycatch was quantified, with finfish being sorted by species and measured to the nearest 1 cm.

Statistical Models

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 the 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 consisted of an examination of potential differences in the total catch per tow. Subsequent analyses investigate 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 i^{th} 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:

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

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:

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

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:

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

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:

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

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 model for a range of length groups would be:

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

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:

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

Adjustments for sub-sampling of the catch

Additional adjustments to the models were required to account for sub-sampling of the catch. In some instances, due to high volume, catches for particular tows were sub-sampled. Often this is accomplished by randomly selecting a subset of the total catch (in baskets) 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 artificially 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 consistent throughout each tow and did not vary with respect to scallop length. 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:

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

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.

Table 1: Gear specifications

	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			

After an observed tow, the catch from each dredge was separated by species and individually counted; scallop catches were recorded as bushels (bu = 35.2 liters). A one-bushel subsample of scallops was picked at random from most tows, and those collected were measured in 5 mm incremental groups. All the important commercial finfish species and barndoor skates were measured to the nearest centimeter and counts taken of little and winter skates.

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 later (Wilcoxon) has only a 95% of detecting differences as the former (paired t test)." Although Zar seems to suggest the paired Students t-test as the better test, there is not universal agreement on this issue so, 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 a sampled scallop bushel.

Results and Discussion

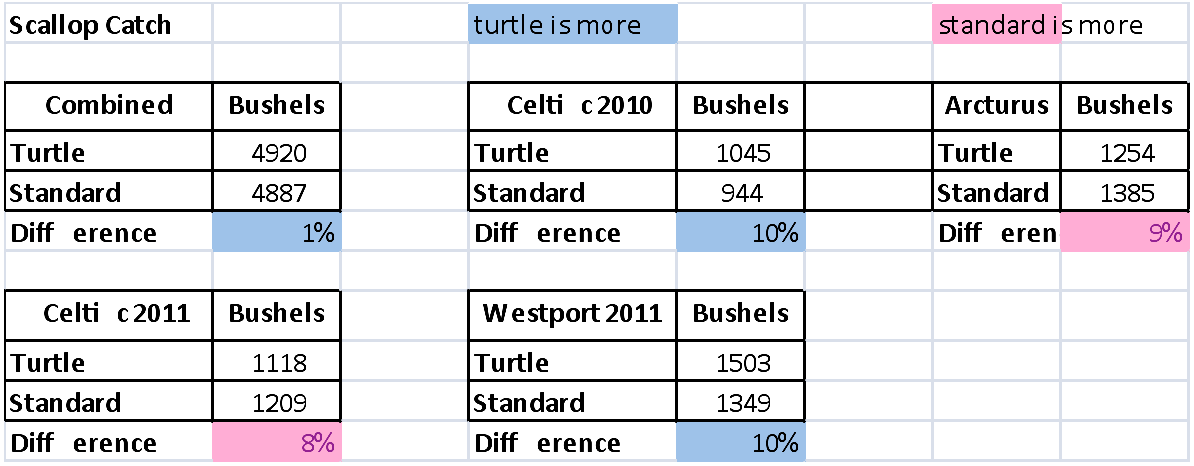
Overall, roughly 308 paired tows were completed over the course of the experiment. Only a subset was actually sampled for scallop/fish and not all species were present in each of the sampled tows. Total catch for the major species with the number of sampled tows are shown in Appendix Table 1. For the intercept only model (gear effect only) a scatterplot of the catches from the paired tows are shown in Appendix Figures 1 and 2. Parameter estimates are shown in Appendix Table 2. 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) only sea scallops resulted in a significant difference in the length compositions of the catches of the two gears, although a 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 Appendix Figure 3. Parameter estimates for the 2 parameter length based model are shown in Appendix Table 3.

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.

<u>Scallops</u>: Overall, when using the paired t-tests there was no significant difference in the scallop catch between trips as shown in Table 2.

Table 2: Scallop catch in bushels.

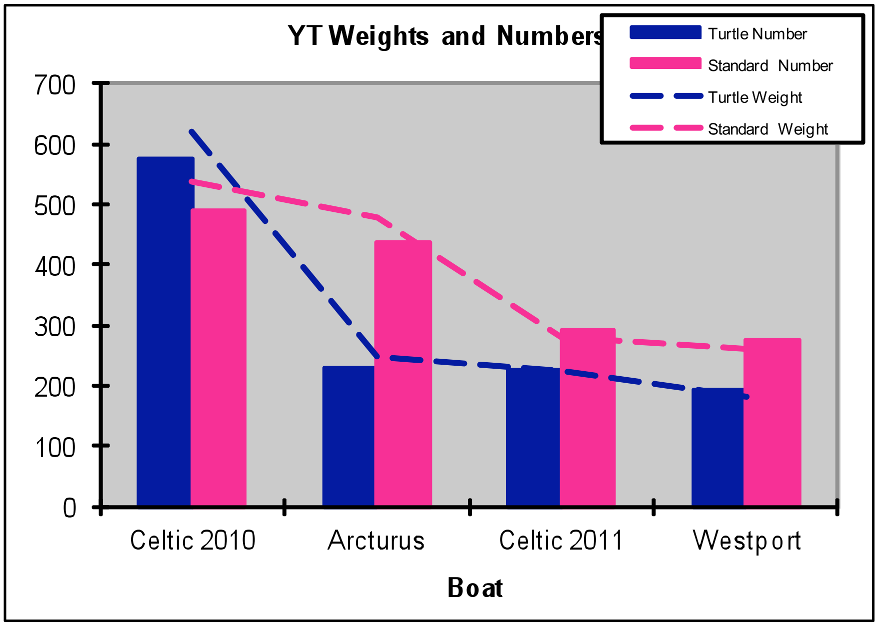


Scallop Catch			turtle is more			standard is more	
Combined	**Bushels**		**Celtic 2010**	**Bushels**		**Arcturus**	**Bushels**
Turtle	4920		**Turtle**	1045		**Turtle**	1254
Standard	4887		**Standard**	944		**Standard**	1385
Difference	1%		**Difference**	10%		**Differen**	9%
Celtic 2011	**Bushels**		**Westport 2011**	**Bushels**			
Turtle	1118		**Turtle**	1503			
Standard	1209		**Standard**	1349			
Difference	8%		**Difference**	10%			

Yellowtail flounder: While there were no major statistical differences overall, on three of the trips the CFTDD caught less yellowtail and winter flounder.

Standard					**Turtle**		
	Scallops (bu)	Yellowtail flounder	Winter flounder		Scallops (bu)	Yellowtail flounder	Winter flounder
Celtic 2010	946.55	491	106		1048	577	118
Arcturus	1385.4	436	41		1253.9	229	11
Celtic 2011	1191.05	307	35		1112.55	225	17
Westport	1344.5	294	80		1502.75	218	41
Combined	4867.5	1528	262		4917.2	1249	187
% diff	**101.0%**	**81.7%**	**71.4%**				

	Turtle		**Standard**	
	Number	**Weight**	**Number**	**Weight**
Celtic 2010	577	619.35	491	537.95
Arcturus	229	248.6	436	477.35
Celtic 2011	225	224.25	292	282.2
Westport	194	181.9	276	260.4



Conclusion: The CFTTD fishes about the same as the standard New Bedford dredge design. There is a lot of variability in scallop fishing that impacts scallop catch bycatch that we don’t understand.

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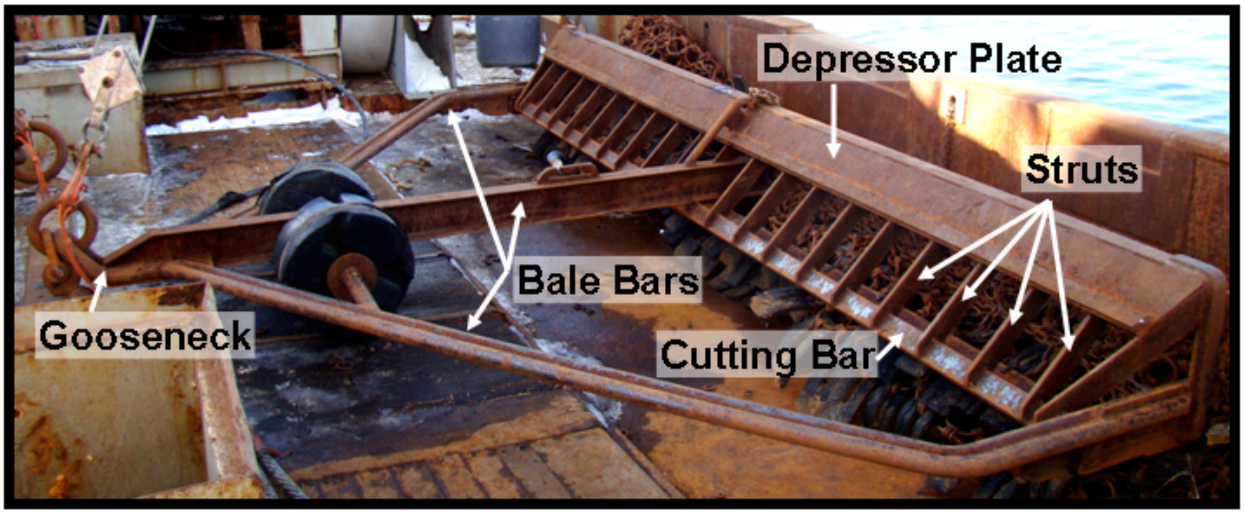
Figure 1. Photo of CFarm turtle deflector dredge frame (top) and illustration of completely rigged standard scallop dredge (bottom).



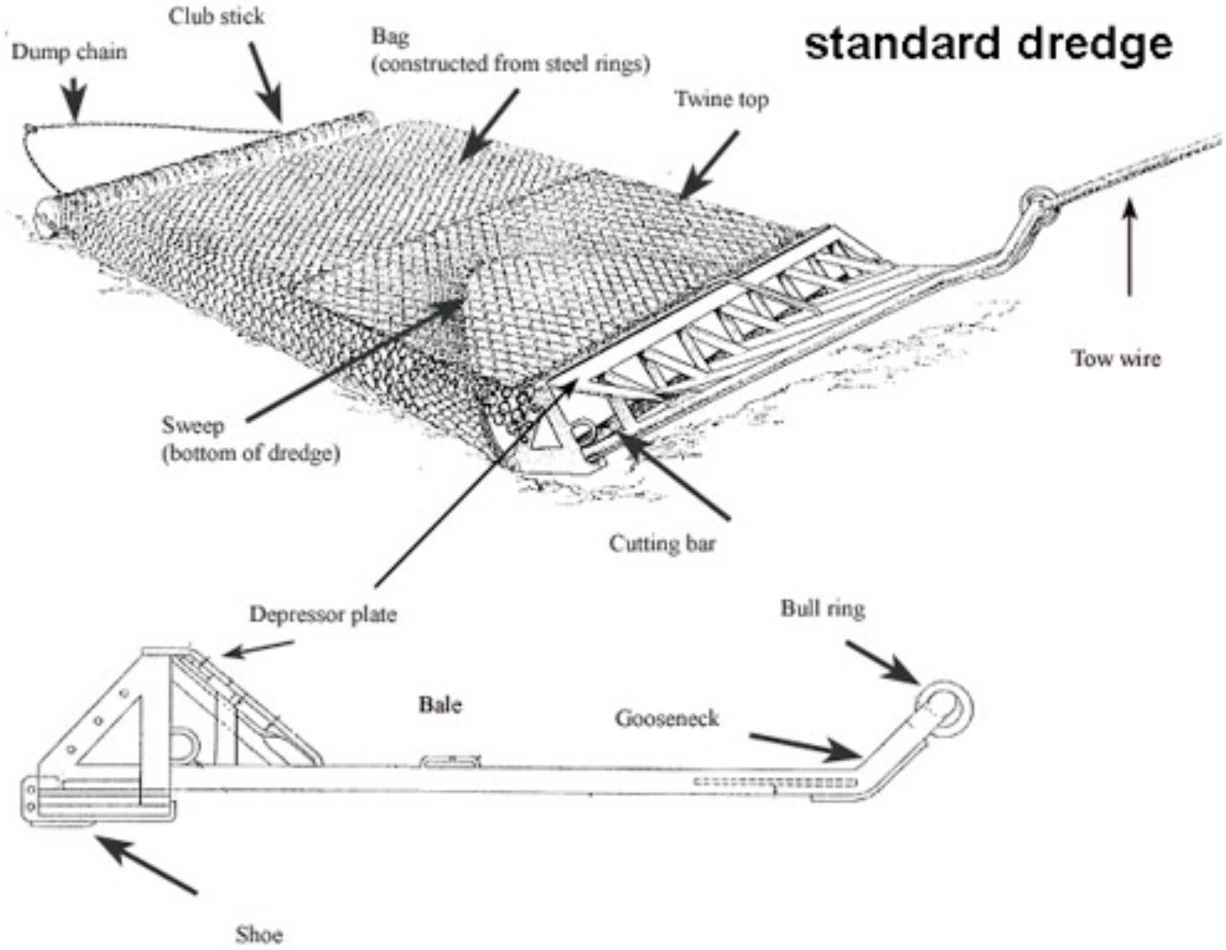
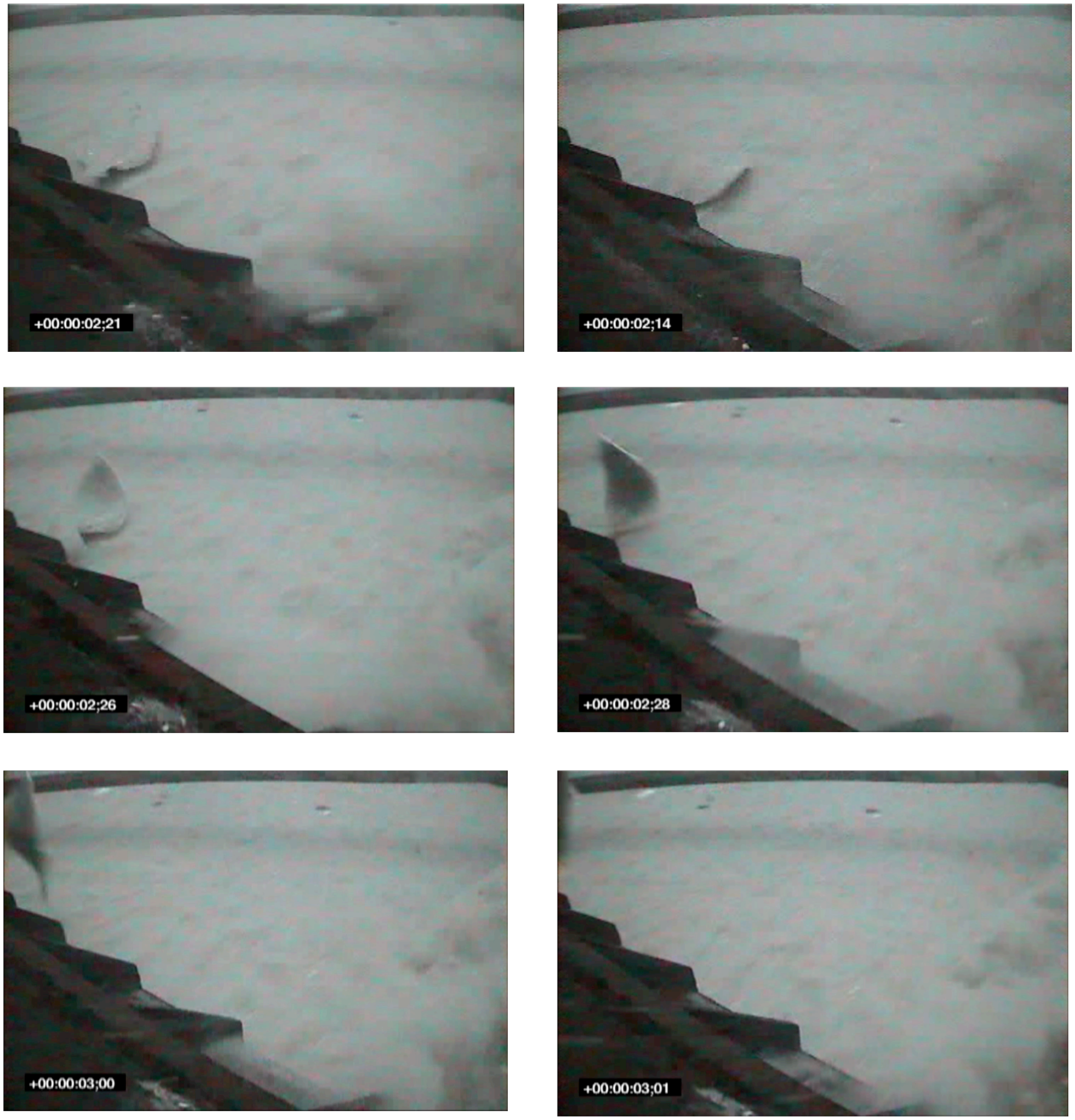


Figure 2: A yellow tail flounder show escaping the turtle excluder dredge.



Appendix A:

Figure1 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).

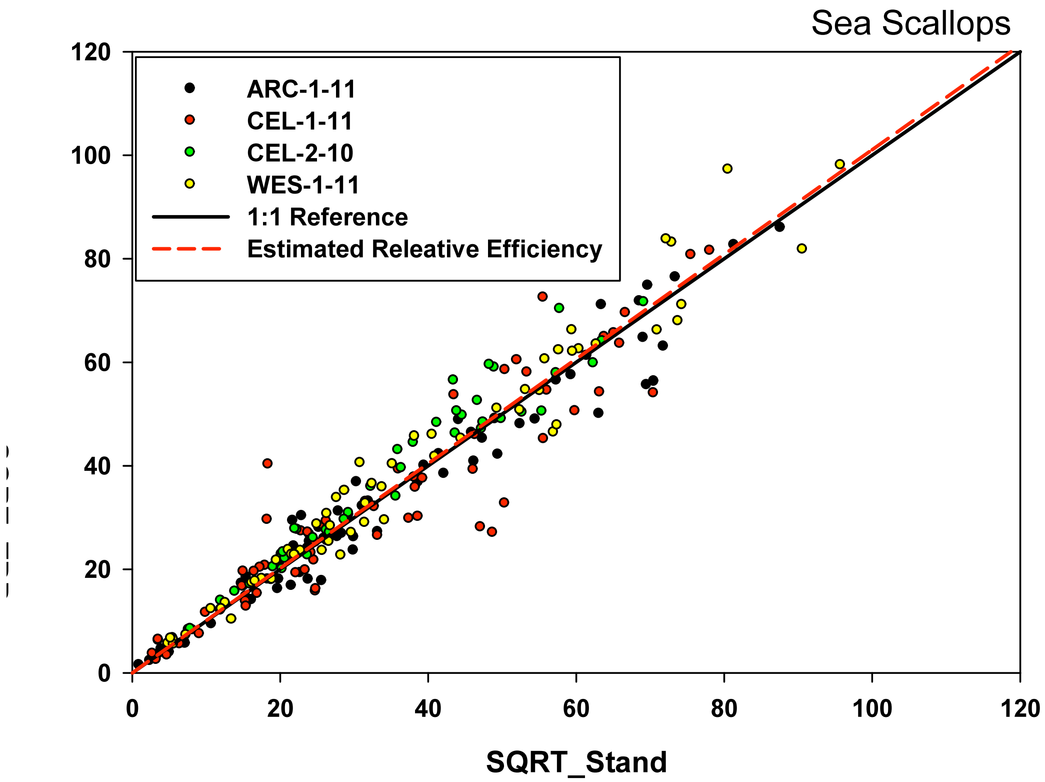
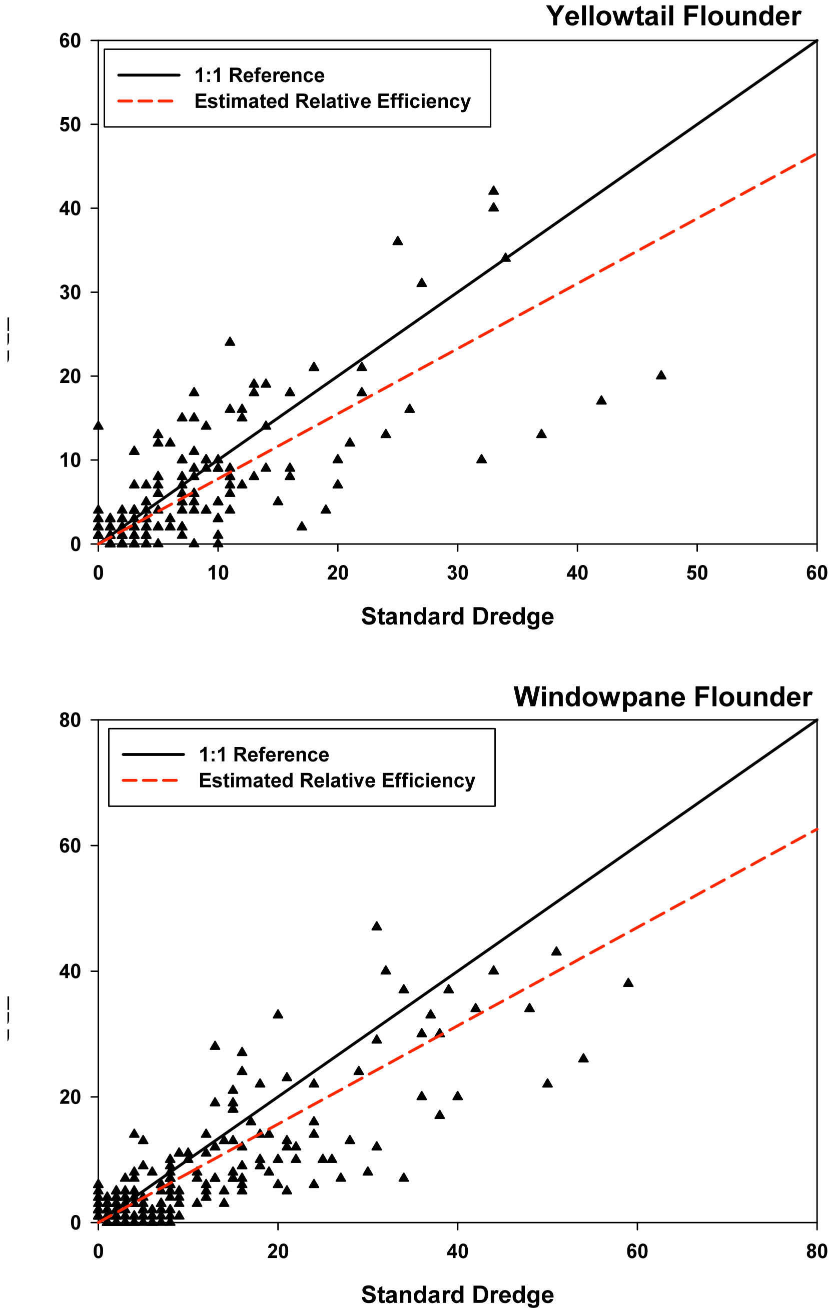
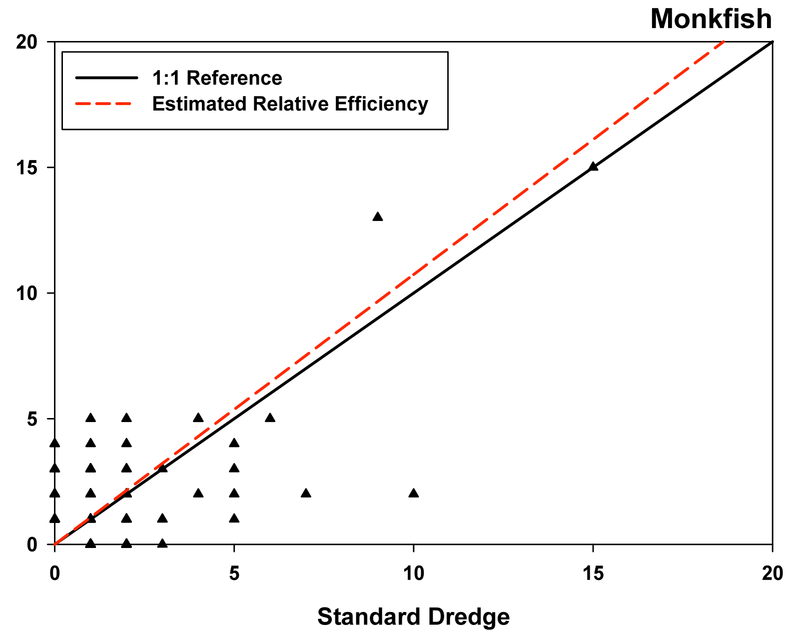
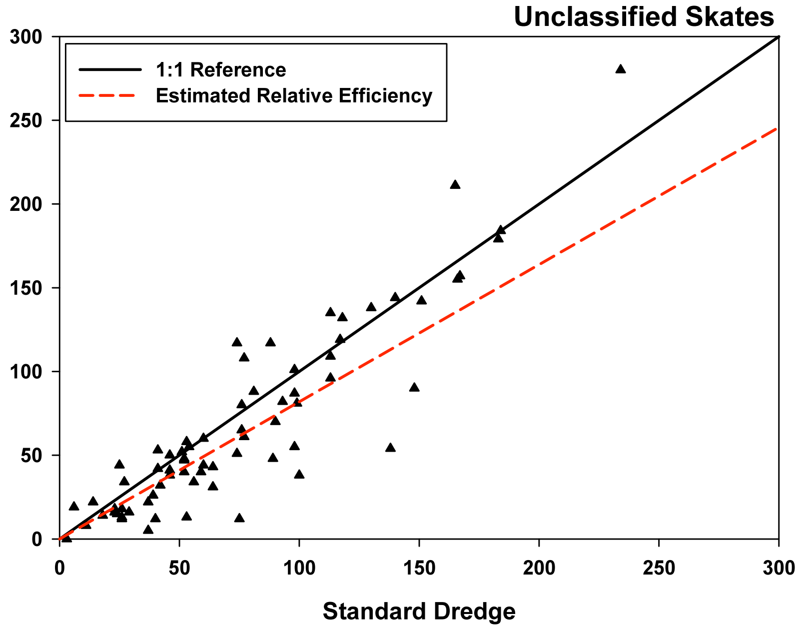


Figure 2 Total scaled pooled finfish catches for CFTDD vs. the standard New Bedford style scallop dredge (top panel) The black line has a slope of one. The dashed line has a slope equal to the estimated relative efficiency (from the one parameter gear effect only model).




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


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

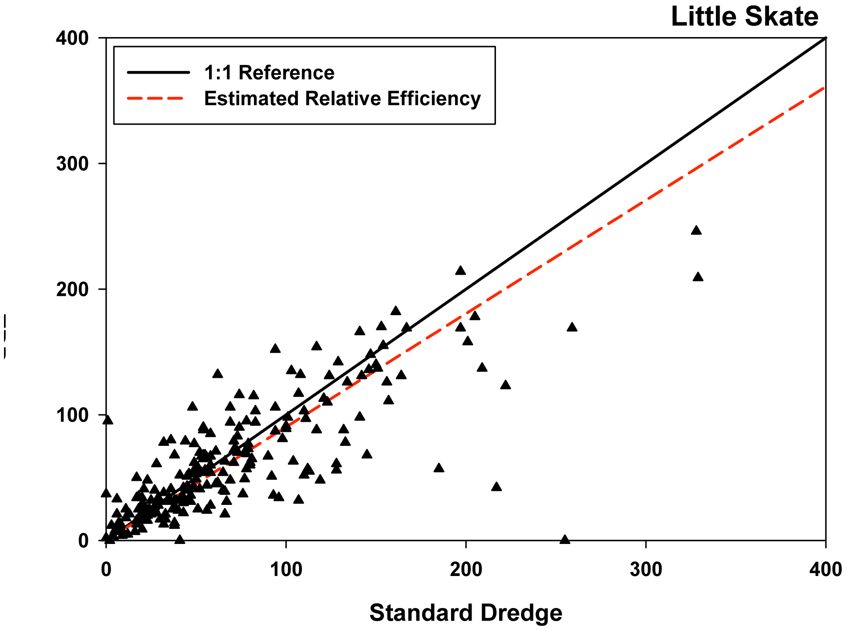
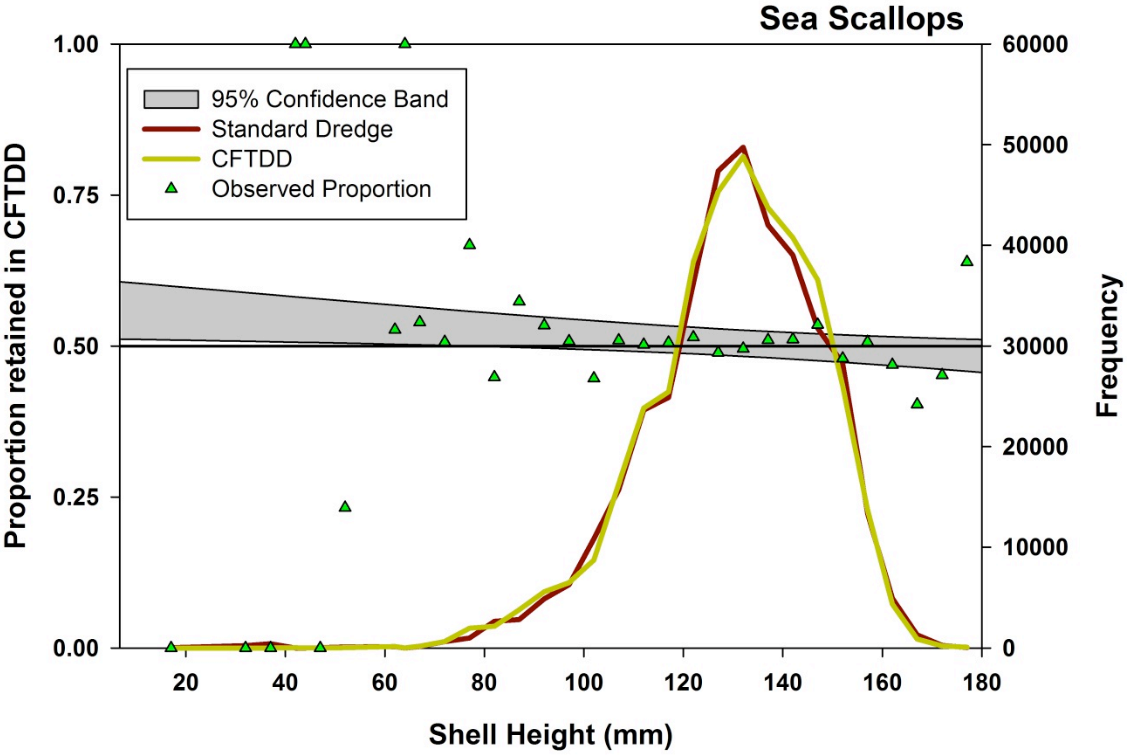
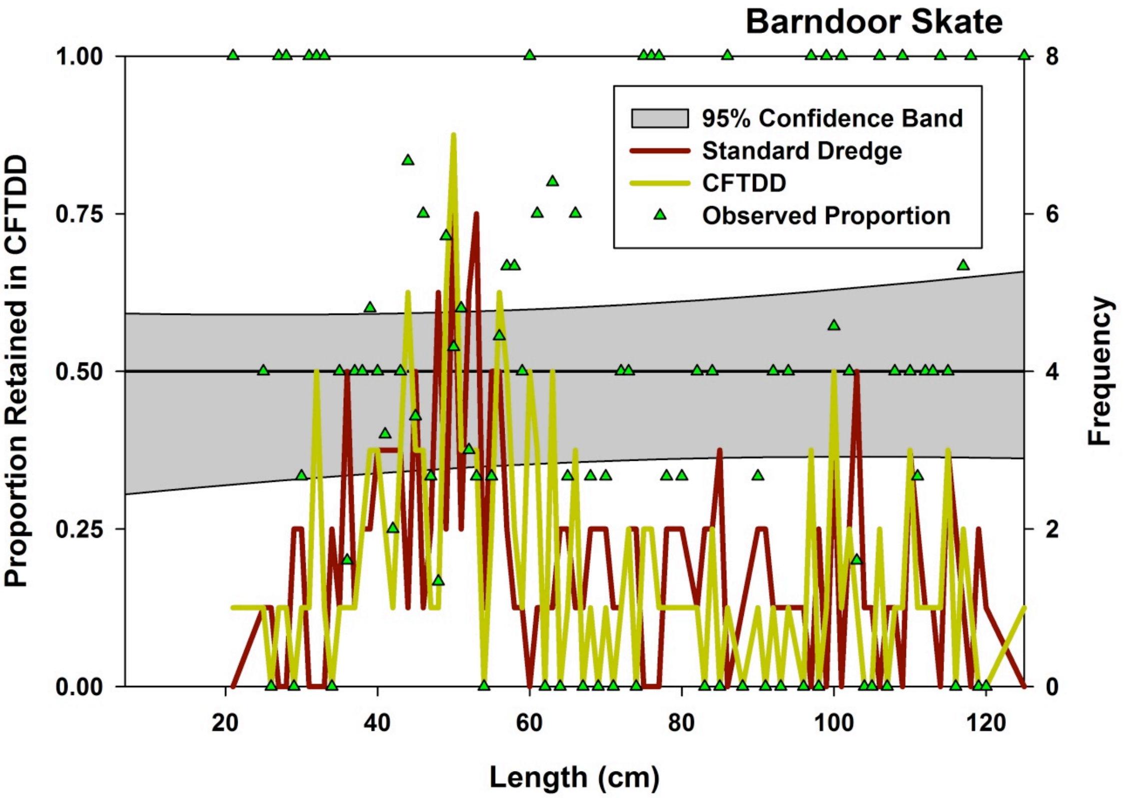
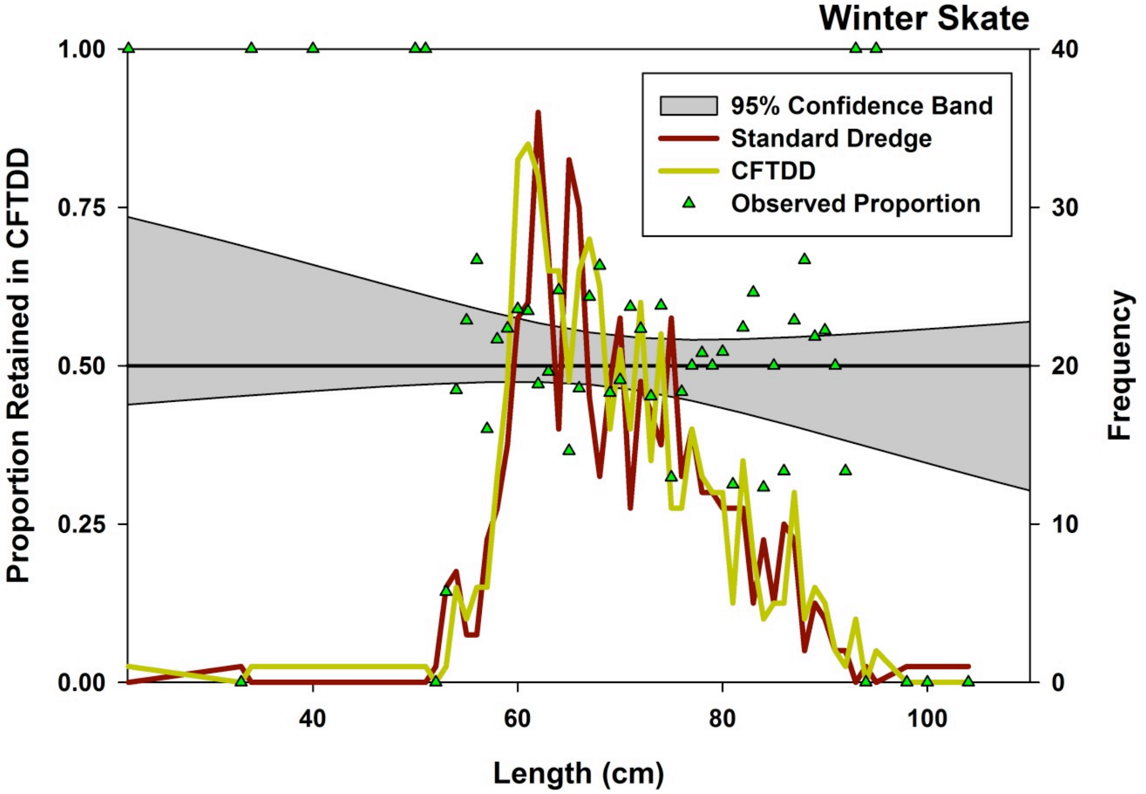
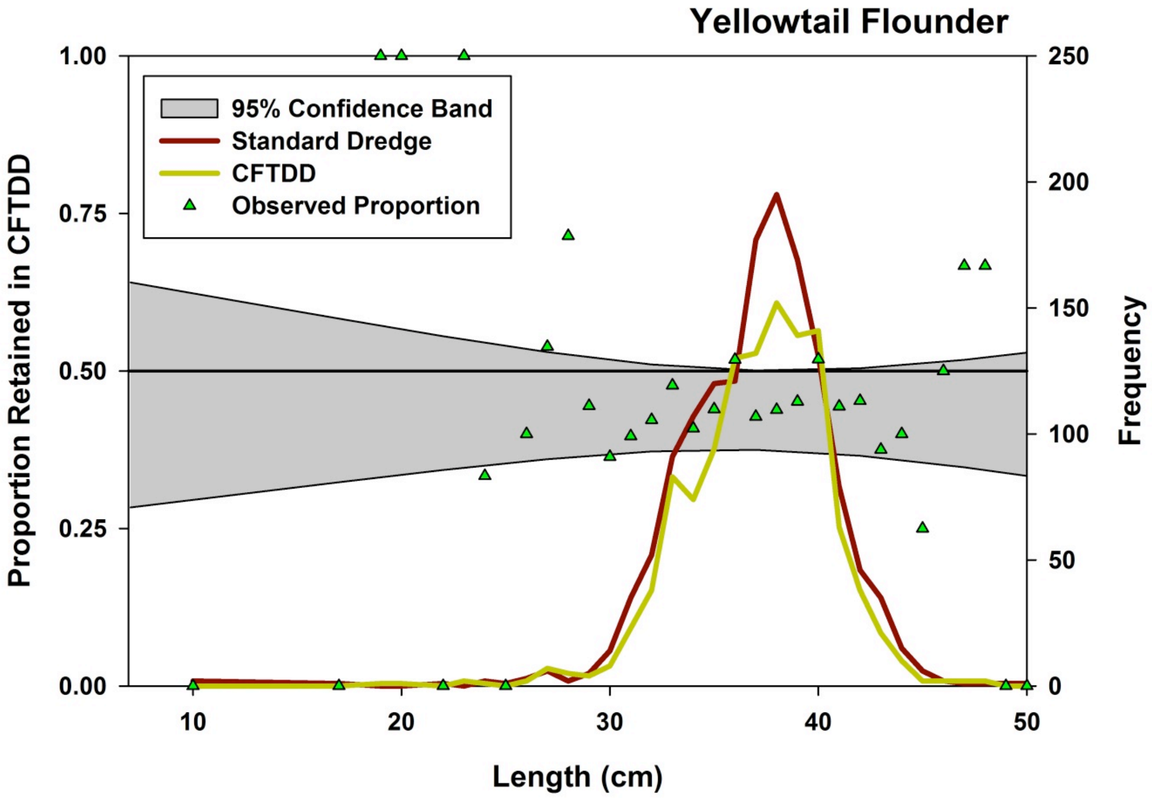

Little Skate
1:1 Reference
Estimated Relative Efficiency
400
300
200
100
0
0
100
200
300
400
Standard Dredge

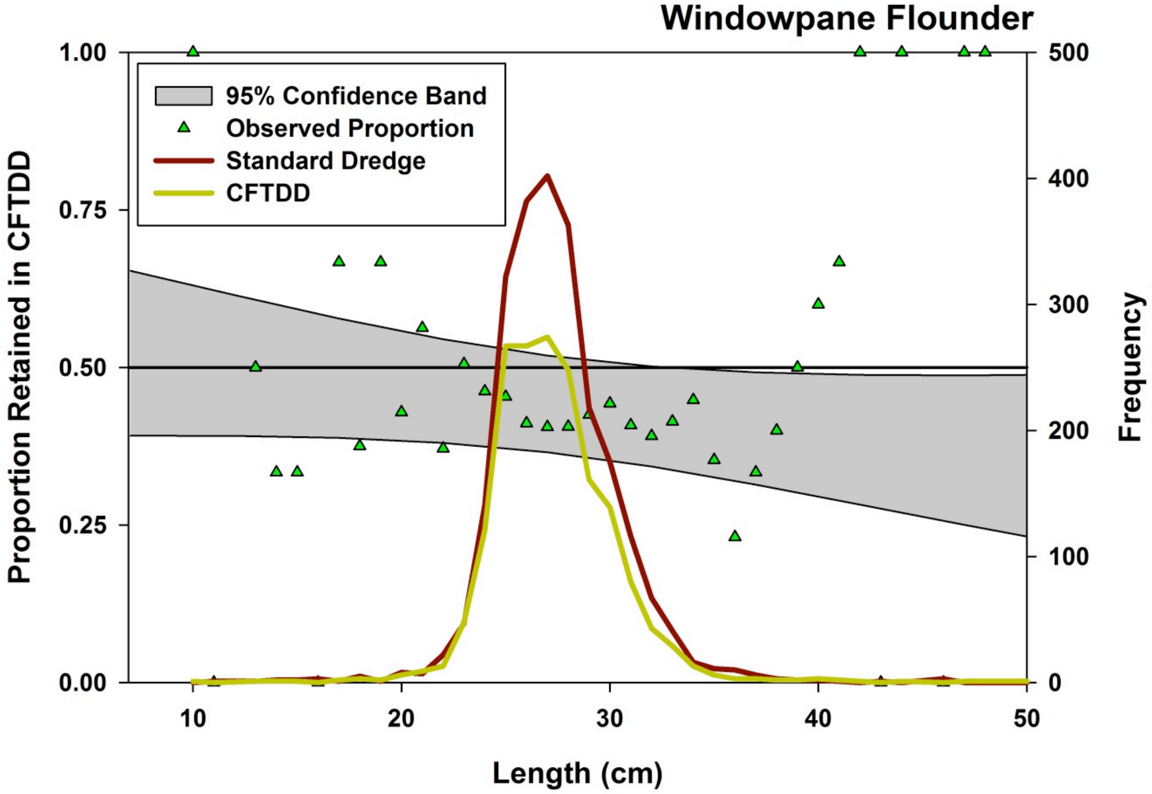
Figure 3 Observed scaled length frequency distributions for the CFTDD and the New Bedford style scallop dredge. The green triangles represent the observed proportions ($\text{Catch}_{\text{CFTDD}}/(\text{Catch}_{\text{STAND}} + \text{Catch}_{\text{CFTDD}})$. The grey shaded area represents the 95% confidence band around the estimated relative efficiency values as estimated by the two parameter (gear and length effect model.

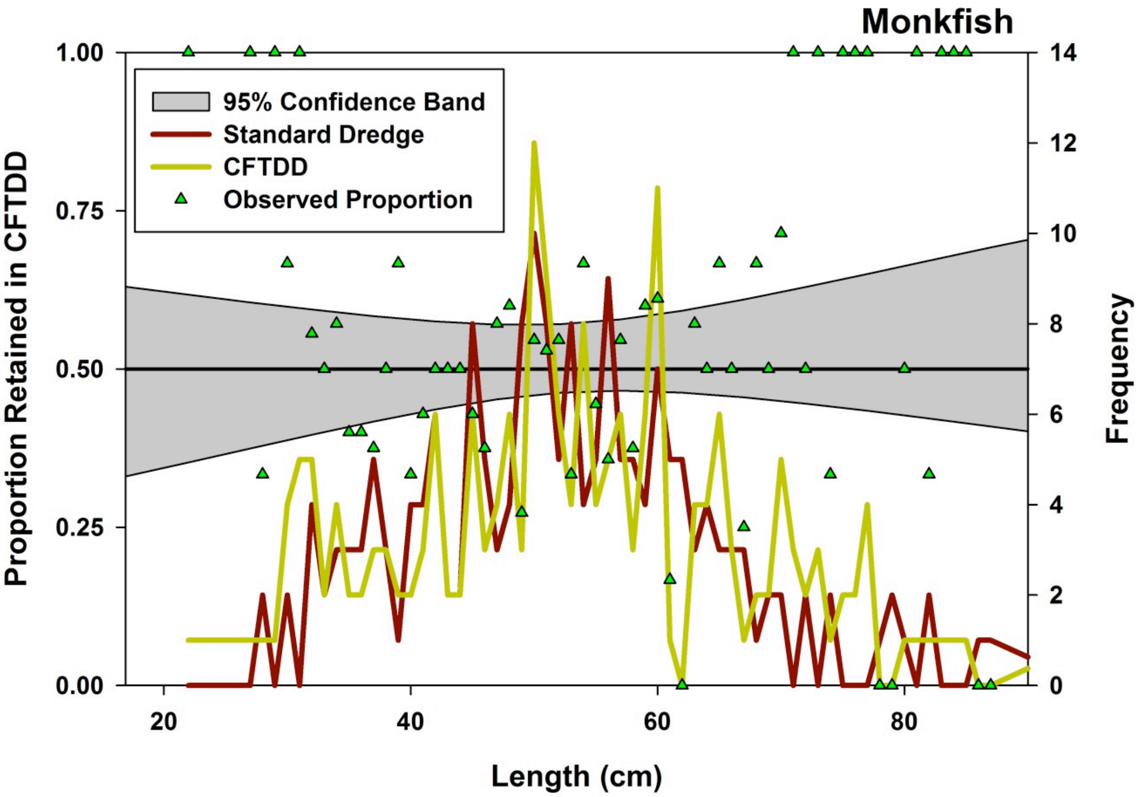



Barndoor Skate
95% Confidence Band
Standard Dredge
CFTDD
Observed Proportion
Proportion Retained in CFTDD
0.00
0.25
0.50
0.75
1.00
Frequency
0
2
4
6
8
20
40
60
80
100
120
Length (cm)


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


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


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


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