A New Dredge for the Sea Scallop Fishery

Final Report Prepared for the
Sea Scallop Research TAC Set Aside
NOAA Grant # NA06NMF4540258

Start Date: July 1, 2006

April, 2008

By

Ronald Smolowitz, Mathew Weeks
Coonamessett Farm

In Collaboration with

Bill Dupaul- Virginia Institute of Marine Science
Ronnie Enoksen- Dockside Repair, Inc – New Bedford, MA
Cliff Goudey- MIT Sea Grant
Kenneth Doherty- McLane Research Labs

277 Hatchville Road
East Falmouth, Massachusetts, USA 02536
508-564-5516 FAX 508-564-5073
cfarm@capecod.net

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Project Summary

We designed and tested a scallop dredge frame that is lighter, structurally stronger, and designed to reduce the capture and retention of sea turtles, skates and flatfish species. This project is a component of efforts started in 1994 that have successfully decreased the bycatch of the identified species. Recent efforts include the 2005 Turtle Dredge RSA (Smolowitz et al, 2007), the 2007 New Dredge Field trials RSA (Smolowitz and Weeks, 2008), and contracts with the NEFSC to test the dredge off Panama City, Florida (Milliken et al, 2007). The new dredge incorporates a number of design changes that currently are still being tested, under NMFS contracts, for efficacy in reducing sea turtle injury and mortality. We will continue to work on optimizing the design for groundfish bycatch reduction using more appropriate materials and cross-sections. This project utilized tow tank testing for cutting bar and frame hydrodynamics and computer modeling for frame component design. Besides reducing bycatch the new dredge may catch more scallops, may reduce energy consumption, and holds up to the rigors of fishing.

Project Goals and Objectives

- To design and construct a dredge frame that will reduce the bycatch of non-target species including yellowtail flounder, other flatfish species, and skates.
- To evaluate different shapes, positions, and orientation of cutting bar designs using a tow tank followed by field testing.
- To use computer assisted design programs to optimize the strength of the dredge frame components while reducing their weight.

Project Management

Ronald Smolowitz	Project coordination, administration, and final report
Bill Dupaul	Field Testing and biological analyses
Cliff Goudey	Tow Tank testing
Kenneth Doherty	Structural analysis
Ronnie Enoksen	Dredge construction

All the PI's will worked closely with each other on all aspects of the project; the purpose of the above list is to indicate the key roles of the participants.

Project Duration July 1, 2006 to February 28, 2007

Introduction

This project has been a continuation of designing and testing dredge frame modifications based on years of experience working with scallop dredges (Henriksen et al, 1997; Smolowitz et al, 2004). Frame alterations can have significant effects on catch and bycatch rates. In previous work, to reduce fish bycatch, we have altered the design of the bale so that it extends forward of the main frame eighteen inches before tapering toward the hauling point (bullring). This allowed us to test sweeps and blocking over the entire dredge width. Blocking is an approach used to prevent fish from entering the dredge from above the cutting bar and below the depressor plate. We have investigated blocking this space with rope, mesh, steel scallop rings, and 1-inch bar stock but have found these materials do not hold up to the rigors of scallop fishing.

Our basic design concept was a significant departure from existing New Bedford style dredge designs in that the cutting bar is moved forward of the depressor plate so that instead of confronting a vertical structure, a sea turtle, groundfish or skate, encounters a sloping structure. We had tested a prototype of this design, to reduce the catch of sea turtles. We had increased the width of the depressor plate and extended the struts, at twelve inch spacing, between the depressor plate and the forward positioned cutting bar. Thus a sea turtle can not get trapped in this space and is gently guided over the dredge (Milliken et al, 2007). We expected a similar behavior with most groundfish and skates.

The dredge frame modifications we are working with do not result in any major change in fabrication costs. The redesigned frame uses the same type of materials, has less weight of steel, and took about the same time to construct. We have modified the dredge frame, based on tests we conducted off Panama City Florida, by removing all of the bale stiffening bars. This change was to prevent a turtle that gets under the bale from being trapped by these bars. Removal of these bars further enhances the escape opportunity of any swimming species caught under the bale. However, these changes had significantly weakened the dredge frame. We used structural engineering to strengthen the new dredge design and at the same time decrease the weight using the conventional materials.

In early tests to reduce turtle takes in the Southeast US shrimp fishery, the forward excluder panel worked relatively well in reducing the capture of turtles (Seidel and McVea, 1995). This approach was abandoned in that fishery due to many complications with rigging and negative impacts on shrimp catch. The rigid scallop dredge frame is much more amenable to the excluder approach and that has been the direction of our design efforts. Removing the bale bars has removed an obstruction thus allowing a turtle or fish to rise up in front of the cutting bar to be “excluded” from capture in the dredge bag.

Our modifications to the dredge frame do not require any changes to the handling and operation of the dredge as there is no alteration to the overall frame length or width. However, the hydrodynamics of the dredge have changes and tow tank studies and field testing have indicated some of the impacts on catch of these changes. The change to the bale design that we discussed above was found to increase the dredge efficiency on scallops by 10-20% while reducing the weight and cost of the dredge (Smolowitz et al, 2002, 2001). We believe a lot of the hydrodynamic action that impacts catch takes place around the cutting bar. To get a better understanding of these effects we conducted limited tow tank tests of various cutting bar designs and continued field testing.

In 2006, the excluder dredge was tested aboard three different commercial scallop vessels operating under normal fishing practices. The first test trip occurred during late August in Closed Area I on George's Bank. This trip compared the excluder dredge to a standard New Bedford dredge. The second trip occurred during the beginning of November in the Elephant Trunk Closed Area of the Mid Atlantic Bight. The third trip also took place in the Elephant Trunk Closed Area, but during the end of November on a different vessel. These last two trips employed two excluder dredges, one with a test feature called "turtle guards" and one without, for the purpose of testing differences in catch. During each trip, a series of additional gear modifications underwent preliminary testing for possible application to the goal bycatch reduction. This included changes to both the excluder dredge frame and the vessel's chain bag. Trip three also applied a different bag configuration on each dredge for the purpose of testing the effect on catch and for calibrating catch data between vessels.

In total, 275 successful paired tows were conducting using the excluder dredge during the three field trail trips presented in this report. The catch of 174 tows, representing 63% of all tows, were observed and sampled by a scientist on deck. During the first test trip, the excluder dredge was found to reduce yellowtail flounder by 31% and winter flounder by 44%, while increasing scallop catch by 10%. Trip 2 showed that the two excluder dredges had similar catch levels, with the exception of the dredge with turtle guards landing 12% more skate than the dredge without turtle guards. The results from trip 3 proved that the configuration of the chain bag used on the excluder dredge affects both the catches levels and ease of use by fishers. This suggests that a standard bag configuration needs to be developed specifically for use on the excluder dredge. In addition, gear modifications to the chain bag showed promise in further reducing bycatch levels, although more extensive testing and refinements need to be completed.

A gear solution to the problem of bycatch interactions with scallop dredges has significant beneficial economic consequences to the individuals that make up the scallop industry. The only regulatory alternatives to gear modifications are seasonal area closures. A gear solution would allow optimum utilization of the scallop resource and the associated profitability. The biggest unknown was how the new frame would fish and this required field trials and design adjustments. We developed the new excluder dredge frame to be used in conjunction with turtle chain mats (Dupaul, Rudders, and Smolowitz, 2004).

Methods

The lead engineering PI on this project, Ronald Smolowitz, designed the dredge frame following the concepts identified in the introduction. In addition to redesigning the bale to accommodate moving the cutting bar forward, the dredge was designed to be as lightweight as possible. This was accomplished by eliminating many of the doublers and gusset plates. The scantlings of the various frame components were kept to a minimum but still sized for hard bottom. We had planned to construct the frame utilizing a truss type structure to provide strength and rigidity without added weight. A lighter dredge would result in significant fuel savings and be safer to handle. However, design issues developed which will be discussed in the results section.

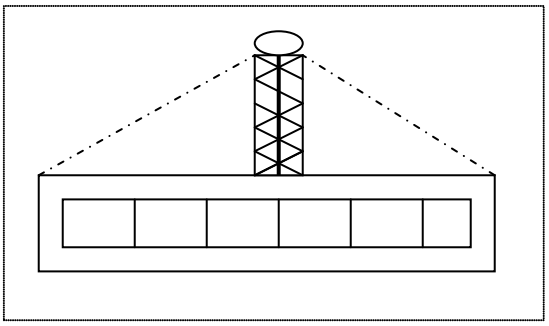
In order to better understand the hydrodynamics of the cutting bar we conducted flume tank tests at Memorial University in New Foundland. One goal was to see how we can maximize the lift created by the cutting bar. With more lift the less digging the gear will have to do to harvest scallops. Higher efficiency on scallops decreases bottom time thus reducing potential bycatch of other species. The location and functioning of the cutting bar also plays a key role in the capture of skates. We believe that any design changes that can reduce the catch of skates will also increase the efficiency of the dredge on scallops.

There have been an extensive amount of trials with the excluder dredge and many modifications were tested. In this report we have classified the changes into three general styles of excluder dredge frames; the center truss bale, the long shoe dredge, and the extended frame dredge. Each of these dredge styles were tested with various modifications. We fabricated the experimental dredges at Dockside Repair, Inc in New Bedford, MA. We worked closely with the shop personnel to address any questions that arose during construction. The completed dredges conformed to all existing regulations and were sent to sea and for the most part were compared with standard dredge frames rigged with identical bags, chains, and club sticks. During these formal tests, a scientific party onboard the vessel collected data.

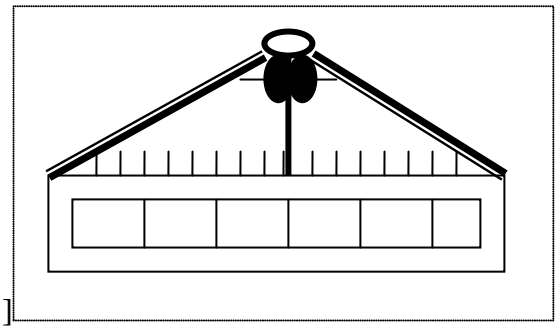
On research tows the entire scallop catch was counted, unless indicated otherwise, in bushel baskets and a one basket sub-sample measured in 5 mm increments. The fish catch was counted and measured, in one cm increments, by species. Undersized scallops and most fish were returned to the sea (except for the allowed retention of multispecies and monkfish). Data was analyzed to determine differences in catch rates between dredges of target and non-target species and any differences in size selectivity of the target and non-target catch. A paired t-test at the alpha=0.05 level was used to test for significance in catches between the standard control and experimental dredges.

Dredge Description:

Center Truss Bale or Single Bale
Chains reaching from bull ring to corners of bale.
A-Frame truss structure connecting bull ring to frame in center.
Cutting bar square to ground.
Half inch rebar added to this design to reduce space between excluder struts on face of bale. (5” spacing) 15’ wide bale



Long Shoe Dredge
Double bars replace single outer bale bar
Cutting bar rotated 45 degrees
Wheels (5”) added to cutting bar to reduce gap with sea floor
Large wheel added close to bull ring to keep neck elevated.
Half inch rebar to reduce size between excluders on face of bale. (5”)
15’ wide bale



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Model Testing

A 36-inch wide full size section of the turtle dredge was constructed for testing at the flume tank of Memorial University in Newfoundland, Canada on May 3-4, 2007. The modeled components were sandwiched between two plates to which they were mounted by bolts. One plate, away from the viewing side, was fabricated out of aluminum and the plate on the viewing side was made of Lexan. The dredge components were all of aluminum. Flow was observed by injecting a narrow stream of dye into the flume tank just ahead of the dredge components to be observed. The flume was run at speeds of 0.85 to 2.0 knots. Rubber cookies were placed on the flume tank belt ahead of the dredge model to simulate scallops. The following is a listing of actual turtle dredge components and the model versions.

Turtle Dredge Component Specifications:

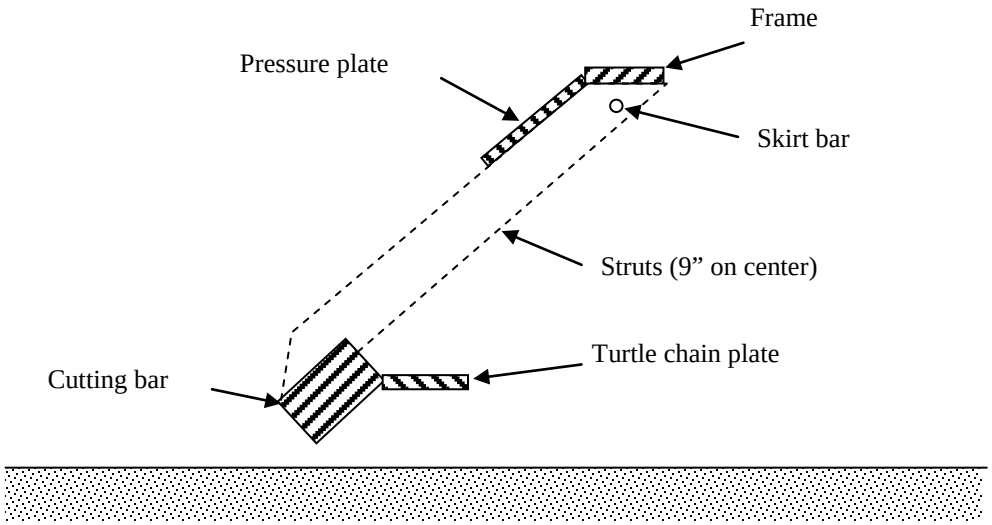
Cutting bar:	2” x 3” solid steel bar
Model:	2” x 3” rectangular aluminum tubing 36” long
Struts	5/8” x 3” steel plate cut 24” long with cut-outs at each end to fit and a tapered leading edge
Model:	5/8” x 3”aluminum flat stock (3 each) cut 24” long with cut-outs at each end to fit and a tapered leading edge
Main frame	5/8” x 3” steel plate
Model:	5/8” x 3” aluminum plate 36” long
Turtle chain plate	5/8” x 3” w/1” holes on 12” centers; plate welded to rear of cutting bar
Model:	5/8” x 3” aluminum flat stock 36” long
Pressure plate	3/8” x 8” steel plate
Model:	3/8” x 8” aluminum plate 36” long
Skirt attachment bar	3/4” round stock; passes through holes in struts
Model:	¾” x 38” aluminum round bar with threaded ends

The following dredge components were not modeled for these tests:

Shoe block:	1 1/2” x 3 1/2” x 15” long bar stock to which shoe is attached
Shoe:	1/2” x 3” spring steel cut 17 1/2” long
Main bale bar	2 1/2” round bar
Bale doubler bar:	2” round bar mounted outside of main bale bar
Bullring:	1 1/2” round bar formed to circle of 6” I.D.
Center bar:	2” x 3” steel bar
Lifting bar:	1 1/4” round bar; attached to top of center bar
Heel plate	1/2” x 3” x 11”; welded to shoe; also covers the 2 1/2 “ ears at rear of shoe

Note: The space between the struts measures 8 1/2”; the spacing between the 8-inch depressor plate and the cutting bar measures 10”. The angle of the struts is 45 degrees.

Figure 1: Typical Cross-section of dredge frame used during model tests.



At Sea Trials of the Modified Sea Scallop Dredges

Three versions of the modified dredge were tested during this set of sea trials. Version one had a central strut design for towing purposes. This included no gooseneck wheel. It did however include the previous frame modifications done to exclude sea turtles. These modifications include moving the cutting bar forward of the depressor plate to allow sea turtles to pass over the face of the dredge without being stuck and therefore dragged along inside the bale of the dredge. Another modification presented with the turtle exclusion device was removing the support bars side of the bale to allow turtles that pass under the forward edges of the bale to escape over the top of the dredge. On this design there were chains the led from the gooseneck to the corners of the bale face to help stabilize the towing point. The bull ring is connected to the dredge by a series of trusses running back to the face of the bale on the center line of the dredge.

The modified dredge was again changed before the third trip. Wheels were added to the cutting bar to extend at a 45 degree angle down from the forward face of the cutting bar. Along with this half inch rebar was added into the face of the bale, from the cutting bar to the depressor plate, to help exclude larger fish and skate. The modified dredge was changed while at sea.

The bull ring is connected to the bale face by one piece of 3-inch square steel stock running down the center line of the dredge, as well as doubled round solid bar stock extending from the gooseneck to the forward corners of the dredge frame. This modified dredge also had a gooseneck roller attached to help keep the cutting bar at the proper angle to the sea bed. The cutting bar was rotated 45 degrees so that it was at an angle to the seabed. The half inch excluder bars were replaced on the face of the bale between the cutting bar and depressor plate. The wheels were also welded back on; This time perpendicular to the forward, downward facing edge of the cutting bar, but still at a 45 degree angle to the seabed. 14 wheels were welded to the face of the cutting bar the dredge was towed along the port side of the vessel with a standard dredge towed along the starboard side. Throughout the trip the wheels that were attached to the face of the bar wore down, some eventually breaking off at the cutting bar. The modification used during this trip presented a reoccurring problem of the twine top coming over the face of the bale and becoming caught on the cutting bar wheels.

Sea Trials Results

During the winter of 2006 and spring/summer of 2007, a total of 8 commercial scallop trips were conducting utilizing 3 different experimental dredge designs. These sea trials were made aboard 5 different fishing vessels in 5 different fishing grounds, including both areas in the mid Atlantic and Georges Bank. A total of 996 successful paired tows were conduct under normal commercial conditions. An observer onboard these trips completely sampled the catches of 403 tows. A summary all trips included for this study is provided below in table # 1. A brief summary of the sea trials conducted for each version of the experimental dredges follows.

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Sea Trial 1: Single Bale Dredge Design Concept:

The F/V Resolution was used to test the Single Bale Dredge design. This vessel is considered "western rigged" with the dredges being released from the stern of the vessel rather then the sides. Both vessels tow two 15 foot scallop dredges. During each sea trial the vessel towed one standard scallop dredge (control) and one modified dredge (experimental.) The dredges were shifted between the port and starboard sides of the ships to insure randomization within the sea trials. The chain bags of both dredges were rigged the same with regards to the number of and orientation of the rock chains. The bags were 38 rings wide and 9 rings deep. The turtle chains were rigged so that there were 15 up and down's and 7 ticklers. The ring size on all the dredges was 4 inches.

The initial trip with the Single Bale Dredge was to the Nantucket Lightship Closed Area during October of 2006. This area has high concentrations of sea scallops with few to no rocks. Both the standard and the modified dredge were towed on a standard amount of wire (3:1 plus 10 fms.) There were no significant differences in how the gear was hauled or set during this sea trial. The modified dredge was towed from the starboard side of the vessel, with the standard dredge towed along the port side. This was held constant throughout this trip.

Five tows were removed from the data set (3, 5, 6, 20, and 25). Tow 3 was removed because the port dredge (control) was towed upside-down for the duration of the tow. Tows 6 and 25 were removed because the starboard twine top hung up on the wheels that are attached to the cutting bar. Tow number 5 was removed because the dredges became hung up on the seafloor. Because forward progress of the dredges was stopped, an unknown about of scallops and or by catch were lost. The data set for tow twenty was removed because the sweep chain broke during the tow and therefore the dredge did not fish properly.

During this trip the Single Bale Dredge caught approximately the same amount of scallops as the control dredge while showing potential of significantly decreasing the catch of most fish species. A statistical summary of the first trip utilizing the Single Bale Dredge is provided below in table #. The Bridge Log, Catch Log, and length frequencies collected during Resolution-2006-1 are provide in the Appendices.

Resolution 2006-1														
Descriptive Statistics and t-Test: Paired Two Sample for Means														
Single Bale Dredge														
Species	**Scallop Bushels (entire trip)**		**Scallop Bushels (obs tows)**		**Skate**		**Yellowtail Flounder**		**Monkfish**		**Fluke**		**Other Flatfish**	
Dredge	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***
Total Count	463	484	223	231	1112	1459	36	59	41	48	22	33	315	455
% Difference in Count	**-4%**		**-3%**		**-24%**		**-39%**		**-15%**		**-33%**		**-31%**	
Fish Count/Scallop Bushel Catch Ratio					2.30	6.5	0.07	0.3	0.08	0.2	0.05	0.1	0.65	2.0
% Difference in Catch Ratio					**-65%**		**-72%**		**-61%**		**-69%**		**-68%**	
Mean	18.5	19.3	15.9	16.5	79.4	104.2	2.6	4.2	2.9	3.4	1.6	2.4	22.5	32.5
Standard Error	2	2	1	1	9	11	1	1	0	1	1	0	4	6
Median	16	16	16	15	76	102	3	4	3	4	1	2	24	27
Mode	16	14	16	25	#N/A	101	3	0	2	4	1	2	29	27
Standard Deviation	11	9	5	5	35	39	2	4	2	2	2	2	15	22
Sample Variance	121	88	21	29	1198	1552	6	16	3	6	4	3	214	495
Kurtosis	6	1	0	0	0	1	1	0	-1	0	1	-1	0	-1
Skewness	2	1	0	0	1	0	1	1	0	0	2	0	0	0
Range	53	38	18	19	117	156	8	13	6	8	6	5	52	72
Minimum	4	6	7	6	39	34	0	0	0	0	0	0	0	0
Maximum	56	44	25	25	156	190	8	13	6	8	6	5	52	72
Confidence Level(95.0%)	4.54	3.88	2.65	3.13	19.98	22.74	1.37	2.32	1.05	1.37	1.13	0.92	8.44	12.84
Variance	120.88	88.35	20.99	29.48	1197.65	1551.57	5.65	16.18	3.30	5.65	3.80	2.55	213.81	494.73
Observations	25	25	14	14	14	14	14	14	14	14	14	14	14	14
Pearson Correlation	0.85		0.81		0.90		0.65		0.13		0.67		0.79	
Hypothesized Mean Difference	0		0		0		0		0		0		0	
df	24		13		13		13		13		13		13	
α	0.05		0.05		0.05		0.05		0.05		0.05		0.05	
t Stat	-0.72		-0.62		-5.29		-2.01		-0.67		-1.99		-2.69	
P(T<=t) one-tail	0.24		0.27		0.00		0.03		0.26		0.03		0.01	
t Critical one-tail	1.71		1.77		1.77		1.77		1.77		1.77		1.77	
P(T<=t) two-tail	0.48		0.54		0.00		0.07		0.51		0.07		0.02	
t Critical two-tail	2.06		2.16		2.16		2.16		2.16		2.16		2.16	

After the encouraging results found during the first trip with the Single Bale Dredge, a second on the F/V Resolution was conducted into Close Area II. This area also has a high concentration of sea scallops and flat fish, specifically yellowtail flounder. The sea bed in closed area two consists of both sand and rocky terrain. The modified dredge was again changed before the second trip. Wheels were added to the cutting bar to extend at a 45 degree angle down from the forward face of the cutting bar. Along with this half inch rebar was added into the face of the bale, from the cutting bar to the depressor plate, to help exclude larger fish and skate. The modified dredge was changed while at sea.

Because of reduced catch rates the captain moved the experimental dredge from the starboard side to the port side of the vessel after tow number 11. After tow 14 he removed the half inch rebar from between the cutting bar and the depressor plate. Then after tow 15 he removed the wheels from the face of the cutting bar. On tow number 21 the experimental dredge was towed on longer wire (more then the 3:1 plus 10) then the standard (control) dredge. From tow number 26 until the end of trip number 2 the dredge was fished on short wire (less then 3:1 plus 10.)

These changes were made with the hopes of increasing the amount of sea scallops caught to more closely mirror the standard dredge. Throughout trip number two a bend could be seen in both the face of the bale and a twist in the center towing structure that appeared to worsen as the number of tows increased. By the end of the trip the dredge was bent so the face was concaved from front to back and from right to left, as well as a significant twist in the center structure that connected the bull ring to the bale face. The results for the entire second trips are provided below in table # 3. Two data sub sets are also provided to summarize the dredge's catch before and after the damage occurred. The Bridge Log, Catch Log, and length frequencies collected during Resolution-2006-2 are provide in the Appendices.

Resolution-2006-2 All Tows														
Descriptive Statistics and t-Test: Paired Two Sample for Means														
Single Bale Dredge														
Species	**Scallop Bushels (entire trip)**		**Scallop Bushels (obs tows)**		**Skate**		**Yellowtail Flounder**		**Monkfish**		**Fluke**		**Other Flatfish**	
Dredge	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***
Total Count	1620	1657	546	571	542	622	1159	1192	541	507	7	7	137	118
% Difference in Count	**-2%**		**-4%**		**-13%**		**-3%**		**7%**		**0%**		**-23%**	
Fish Count/Scallop Bushel Catch Ratio					0.99	1.1	2.12	2.1	0.99	0.9	0.01	0.0	0.25	0.3
% Difference in Catch Ratio					**-9%**		**2%**		**12%**		**5%**		**-20%**	
Mean	17.8	18.2	18.2	19.0	18.1	20.7	38.6	39.7	18.0	16.9	0.2	0.2	4.6	5.9
Standard Error	1	1	2	2	2	2	7	7	2	2	0	0	1	1
Median	16	18	17	19	16	20	29	26	17	18	0	0	4	3
Mode	2	25	2	25	10	13	5	19	20	18	0	0	0	2
Standard Deviation	12	10	12	11	13	12	36	38	11	9	1	1	5	6
Sample Variance	137	102	141	121	168	137	1315	1447	110	85	0	0	22	41

Resolution 2006-2 Tows 1-31: Before Experimental Frame Damaged
Descriptive Statistics and t-Test: Paired Two Sample for Means
Single Bale Dredge

Species	**Scallop Bushels (entire trip)**		**Scallop Bushels (obs tows)**		**Skate**		**Yellowtail Flounder**		**Monkfish**		**Fluke**		**Other Flatfish**	
Dredge	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***
Total Count	157	244	71	81	129	108	248	143	97	63	1	2	19	15
% Difference in Count	**-36%**		**-12%**		**19%**		**73%**		**54%**		**-50%**		**27%**	
Fish Count/Scallop Bushel Catch Ratio					1.82	1.3	3.49	1.8	1.37	0.8	0.01	0.0	0.27	0.2
% Difference in Catch Ratio					**36%**		**98%**		**76%**		**-43%**		**45%**	
Mean	5.8	9.0	10.1	11.6	18.4	15.4	35.4	20.4	13.9	9.0	0.1	0.3	2.7	2.1
Standard Error	1	1	4	3	4	2	16	7	4	2	0	0	2	0
Median	3	6	7	6	13	16	9	19	16	7	0	0	1	2
Mode	2	4	2	6	#N/A	#N/A	#N/A	19	#N/A	#N/A	0	0	1	2
Standard Deviation	6	7	10	9	12	5	42	18	9	6	0	0	4	1
Sample Variance	38	52	92	76	136	25	1780	337	88	34	0	0	16	0
Kurtosis	4	0	-2	-1	-2	-2	-1	-1	-2	-1	7	-1	3	0
Skewness	2	1	1	1	0	0	1	1	0	1	3	1	2	0
Range	23	24	23	19	28	13	101	45	23	15	1	1	11	2
Minimum	1	1	1	5	6	9	2	2	1	3	0	0	0	1
Maximum	24	25	24	24	34	22	103	47	24	18	1	1	11	3
Confidence Level(95.0%)	2.44	2.86	8.86	8.08	10.77	4.59	39.02	16.99	8.67	5.39	0.35	0.45	3.73	0.64
Variance	37.93	52.42	91.81	76.29	135.62	24.62	1780.29	337.29	87.81	34.00	0.14	0.24	16.24	0.48
Observations	27	27	7	7	7	7	7	7	7	7	7	7	7	7
Pearson Correlation	0.59		0.52		0.52		0.50		0.59		-0.26		0.56	
Hypothesized Mean Difference	0		0		0		0		0		0		0	
df	26		6		6		6		6		6		6	
α	0.05		0.05		0.05		0.05		0.05		0.05		0.05	
t Stat	-2.72		-0.42		0.79		1.09		1.70		-0.55		0.41	
P(T<=t) one-tail	0.01		0.34		0.23		0.16		0.07		0.30		0.35	
t Critical one-tail	1.71		1.94		1.94		1.94		1.94		1.94		1.94	
P(T<=t) two-tail	0.01		0.69		0.46		0.32		0.14		0.60		0.70	
t Critical two-tail	2.06		2.45		2.45		2.45		2.45		2.45		2.45	

Resolution 2006-2 Tows 32-99: After Experimental Frame Damaged
Descriptive Statistics and t-Test: Paired Two Sample for Means
Single Bale Dredge

Species	**Scallop Bushels (entire trip)**		**Scallop Bushels (obs tows)**		**Skate**		**Yellowtail Flounder**		**Monkfish**		**Fluke**		**Other Flatfish**	
Dredge	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***
Total Count	1463	1413	475	490	413	514	911	1049	444	444	6	5	118	163
% Difference in Count	**4%**		**-3%**		**-20%**		**-13%**		**0%**		**20%**		**-28%**	
Fish Count/Scallop Bushel Catch Ratio					0.87	1.0	1.92	2.1	0.93	0.9	0.01	0.0	0.25	0.3
% Difference in Catch Ratio					**-17%**		**-10%**		**3%**		**24%**		**-25%**	
Mean	22.9	22.1	20.7	21.3	18.0	22.3	39.6	45.6	19.3	19.3	0.3	0.2	5.1	7.1
Standard Error	1	1	2	2	3	3	7	8	2	2	0	0	1	1
Median	24	22	19	20	18	22	36	30	17	19	0	0	4	4
Mode	25	25	11	25	7	26	5	88	14	19	0	0	7	1
Standard Deviation	10	9	12	11	14	13	35	41	11	9	1	1	5	7
Sample Variance	92	72	133	116	184	163	1244	1661	114	77	0	0	23	49
Kurtosis	2	0	5	0	-1	0	-1	0	2	2	4	6	4	1
Skewness	1	0	2	1	0	1	1	1	1	1	2	2	2	1
Range	56	43	56	45	44	47	107	148	45	38	2	2	21	26
Minimum	4	5	4	3	1	4	0	1	6	6	0	0	0	0
Maximum	60	48	60	48	45	51	107	149	51	44	2	2	21	26
Confidence Level(95.0%)	2.40	2.13	4.99	4.65	5.86	5.51	15.25	17.62	4.63	3.80	0.27	0.22	2.08	3.01
Variance	92.34	72.45	133.42	115.58	183.77	162.60	1243.89	1660.89	114.40	77.22	0.38	0.27	23.21	48.54
Observations	64	64	23	23	23	23	23	23	23	23	23	23	23	23
Pearson Correlation	0.76		0.83		0.74		0.86		0.77		-0.18		0.79	
Hypothesized Mean Difference	0		0		0		0		0		0		0	
df	63		22		22		22		22		22		22	
α	0.05		0.05		0.05		0.05		0.05		0.05		0.05	
t Stat	0.98		-0.48		-2.19		-1.37		0.00		0.24		-2.16	
P(T<=t) one-tail	0.33		0.33		0.02		0.09		0.50		0.41		0.02	
t Critical one-tail	1.67		1.72		1.72		1.72		1.72		1.72		1.72	
P(T<=t) two-tail	0.66		0.64		0.04		0.18		1.00		0.81		0.04	
t Critical two-tail	2.00		2.07		2.07		2.07		2.07		2.07		2.07	

A summary of data compiled of successful tows completed during both trips using the Single Bale Dredge is provided below in Table # 4. A total of 116 successful paired tows were completed using the Single Bale Dredge and 44 tows were sampled. Overall the Single Bale Dredge showed potential in reducing skate and flatfish catch while maintaining efficiency in catching scallops relative to a standard New Bedford dredge. However this was overshadowed by the Single Bale Dredge being unable to withstand the rigors of commercial fishing over an extended period.

Single Bale Dredge
Descriptive Statistics and t-Test: Paired Two Sample for Means
All Trips

Species	**Scallop Bushels (entire trip)**		**Scallop Bushels (obs tows)**		**Skate**		**Yellowtail Flounder**		**Monkfish**		**Fluke**		**Other Flatfish**	
Dredge	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***
Total Count	2083	2141	769	802	1654	2081	1195	1251	582	555	29	40	452	633
% Difference in Count	**-3%**		**-4%**		**-21%**		**-4%**		**5%**		**-28%**		**-29%**	
Fish Count/Scallop Bushel Catch Ratio					2.15	2.6	1.55	1.6	0.76	0.7	0.04	0.0	0.59	0.8
% Difference in Catch Ratio					**-17%**		**0%**		**9%**		**-24%**		**-26%**	
Mean	18.0	18.5	17.5	18.2	37.6	47.3	27.2	28.4	13.2	12.6	0.7	0.9	10.3	14.4
Standard Error	1	1	2	1	5	7	5	5	2	2	0	0	2	3
Median	16	17	16	17	28	25	7	14	11	10	0	0	6	5
Mode	2	25	16	25	10	13	0	1	2	4	0	0	0	2
Standard Deviation	12	10	10	10	36	46	34	36	11	10	1	1	12	18

Sea Trial 2: Long Shoe Dredge Design Concept

Three commercial trips (Resolution-2006-3, Nordic Pride-2007-1, and Nordic Pride-2007-2) were conducted using the Long Shoe Dredge design between November 2006 and February 2007. The majority of tows completed during these trips occurred on the northern edge of George's Bank. This sea bed has a high concentration of discarded clam shells and rocks. The rocks range in size from pea gravel to large boulders. Throughout these sea trials the dredges were fished in a manner considered standard practice for sea scallops. The tow speeds ranged between 4 and 5 knots. The sea conditions ranged greatly from clam seas and winds to 40 knot winds with 15-20 foot waves. The tows consisted of both straight line tows and turn around tows across all trips.

The first trip with the Long Shoe Dredge occurred on the F/V Resolution. The Bridge Log, the Catch Log, and all length frequency data collected from this trip can be found in the Appendices. A total of 185 paired tows were successful during this trip and the catches of 74 tows were quantified by an observer. During this trip, the experimental dredge caught approximately the same number of all species relative to the paired tows with the standard New Bedford dredge. A statistical summary of the catch from successful tows completed during this trip is given below in Table # 5.

Resolution 2006-3												
Descriptive Statistics and t-Test: Paired Two Sample for Means												
Long Shoe Dredge												
Species	**Scallop Bushels (entire trip)**		**Scallop Bushels (obs tows)**		**Skate**		**Yellowtail Flounder**		**Monkfish**		**Other Flatfish**	
Dredge	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***
Total Count	2394	2399	505	495	3623	4060	55	56	95	99	533	538
% Difference in Count	**0%**		**2%**		**-11%**		**-2%**		**-4%**		**-1%**	
Fish Count/Scallop Bushel Catch Ratio					7.17	8.2	0.11	0.1	0.19	0.2	1.06	1.1
% Difference in Catch Ratio					**-13%**		**-4%**		**-6%**		**-3%**	
Mean	12.9	12.9	6.8	6.7	49.0	54.9	0.7	0.8	1.3	1.3	7.2	7.3
Standard Error	6	6	0	0	3	4	0	0	0	0	1	1
Median	6	6	6	7	47	48	0	0	1	1	5	5
Mode	6	6	6	7	53	48	0	0	0	0	1	2
Standard Deviation	87	88	3	2	22	35	1	1	1	2	7	6
Sample Variance	7626	7658	7	5	465	1216	2	1	2	3	51	41
Kurtosis	186	186	0	0	0	2	2	1	4	7	1	0
Skewness	14	14	1	0	1	2	2	1	2	2	1	1
Range	1196	1199	12	11	95	164	5	4	7	8	29	23

The second trip during this set of sea trials took place on the F/V Nordic Pride. This vessel places and hauls the gear in a similar manner to the F/V Resolution. This trip began at the cultivator section of western Georges Bank. This area is a softer bottom, with few rocks. There is a higher concentration of buttons (sand dollars) and sea stars in this area. Tows 1-14 were made in this area. The experimental dredge was deployed on the starboard side of the vessel with a standard dredge towed along the port side as a control. Throughout the trip the wheels that were attached to the face of the bar wore down, some eventually breaking off at the cutting bar. The modification used during this trip presented a reoccurring problem of the twine top coming over the face of the bale and becoming caught on the cutting bar wheels. No modifications were made to the dredge while at sea during this trial.

This trip's data set consists of 252 tows after unusable data is removed. A total of 98 tows were observed. Tows lasted an average of 53.4 minutes fishing. A statistical summary of the trip is provided below in Table # 6. The experimental dredge caught relatively the same number of scallop bushels while catching a significantly higher number of monkfish and skate.

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The final trip with the Long Shoe Dredge also took place on the F/V Nordic Pride. A total of 254 successful paired tows were conducted and the catch of 75 were sampled by observers. During this trip the experimental dredge caught a statistically significant larger number of scallop bushels, at 8% more relative to the standard dredge. However, the experimental dredge also caught more yellowtail flounder when compared to the control dredge. Catch statistics from this trip are provided in Table # 7. All data logs are found in the Appendix.

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A total of 692 paired tows were conducted with the Long Shoe Dredge. Observers counted and sampled the catch of 248 tows. The complied results of these sea trials are summarized below in Table # 8. No significant statistical difference was found in the scallop catches between the two dredges. Overall, the experimental dredge appears to have caught more skate and yellowtail flounder than the standard New Bedford dredges.

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Sea Trial 3: Extended Bale Dredge

During this project, the Extended Bail Dredge was fished on three different fishing vessels over the course of three trips (Westport-2007-1, Celtic-2007-1, and Diligence-2007-1) during the spring and summer of 2007. Two trips occurred in the Elephant Trunk Closed Area of the mid Atlantic and one occurred on Georges Bank in Closed Area I.

The first trip took place on the F/V Westport in the Elephant Trunk Closed Area during March of 2007. A total of 68 tows were conducted, of which 45 were sample by observers onboard. During this trip the Extended Bail Dredge did not catch fish or scallop at statistically significant difference levels when compared to the standard New Bedford dredge. A catch summary is provided below in Table # 9. All Bridge Logs, Catch Logs, and length frequencies collected during the trip are provided in the Appendices.

Westport 2007-1
Descriptive Statistics and t-Test: Paired Two Sample for Means
Extended Bale Dredge

Species	**Scallop Bushels (entire trip)**		**Scallop Bushels (obs tows)**		**Skate**		**Monk**		**Summer Fd.**		**Grey Sole**		**Yellowtail Fld.**		**Four Spot Fld.**		**Sand Dab**	
Dredge	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***
Total Count	1279	1210	675	637	4840	4637	63	50	343	377	50	45	17	22	14	18	68	92
% Difference in Count	**6%**		**6%**		**4%**		**26%**		**-9%**		**11%**		**-23%**		**-22%**		**-26%**	
Fish Count/Scallop Bushel Catch Ratio					7.17	7.3	0.09	0.1	0.51	0.6	0.07	0.1	0.03	0.0	0.02	0.0	0.10	0.1
% Difference in Catch Ratio					**-2%**		**19%**		**-14%**		**5%**		**-27%**		**-27%**		**-30%**	
Mean	18.8	17.8	15.0	14.1	107.6	103.0	1.4	1.1	7.6	8.4	1.1	1.0	0.4	0.5	0.3	0.4	1.5	2.0
Standard Error	2	2	1	1	10	10	0	0	1	1	0	0	0	0	0	0	0	0
Median	16	15	14	13	80	89	1	1	7	7	0	0	0	0	0	0	1	1
Mode	14	13	18	13	78	67	0	1	4	7	0	0	0	0	0	0	0	0
Standard Deviation	14	13	5	5	66	65	2	1	5	6	2	1	1	1	1	1	2	2
Sample Variance	191	160	29	27	4326	4286	2	1	27	38	3	2	1	1	1	1	3	6
Kurtosis	19	18	16	9	3	4	3	2	0	2	2	1	5	6	12	7	3	0
Skewness	4	4	3	2	2	2	2	1	1	1	2	1	2	2	3	3	2	1
Range	82	76	35	30	293	323	7	4	20	28	7	5	3	4	4	4	8	8
Minimum	8	8	8	8	24	17	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	90	84	43	38	317	340	7	4	20	28	7	5	3	4	4	4	8	8
Confidence Level(95.0%)	3.34	3.06	1.62	1.56	19.76	19.67	0.47	0.30	1.57	1.86	0.54	0.43	0.23	0.26	0.23	0.27	0.53	0.72
Variance	190.79	159.67	29.23	26.87	4326.16	4285.91	2.47	0.96	27.47	38.15	3.24	2.09	0.60	0.76	0.58	0.79	3.16	5.82
Observations	68	68	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Pearson Correlation	0.95		0.80		0.85		0.32		0.68		0.20		0.29		0.05		0.64	
Hypothesized Mean Difference	0		0		0		0		0		0		0		0		0	
df	67		44		44		44		44		44		44		44		44	
α	0.05		0.05		0.05		0.05		0.05		0.05		0.05		0.05		0.05	
t Stat	1.93		1.70		0.85		1.24		-1.08		0.36		-0.76		-0.52		-1.90	
P(T<=t) one-tail	0.03		0.05		0.20		0.11		0.14		0.36		0.23		0.30		0.03	
t Critical one-tail	1.67		1.68		1.68		1.68		1.68		1.68		1.68		1.68		1.68	
P(T<=t) two-tail	0.06		0.10		0.40		0.22		0.28		0.72		0.45		0.61		0.06	
t Critical two-tail	2.00		2.02		2.02		2.02		2.02		2.02		2.02		2.02		2.02	

The second trip was on the F/V Celtic during April of 2007 in the Elephant Trunk Closed Area. During this trip the scallop catch of 32 tows were quantified and 16 tows were observed. A summary of this trip is provided below in Table # 10.

Celtic-2007-1
Descriptive Statistics and t-Test: Paired Two Sample for Means
Extended Bale Dredge

Species	**Scallop Bushels (entire trip)**		**Scallop Bushels (obs tows)**		**Skate**		**Monkfish**		**Fluke**		**Four Spot Flounder**		**Sand Dab**		**Sea Robin**	
Dredge	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***
Total Count	632	571	308	279	684	617	36	39	78	90	16	17	6	7	7	8
% Difference in Count	**11%**		**10%**		**11%**		**-8%**		**-13%**		**-6%**		**-14%**		**-13%**	
Fish Count/Scallop Bushel Catch Ratio					2.22	2.2	0.12	0.1	0.25	0.3	0.05	0.1	0.02	0.0	0.02	0.0
% Difference in Catch Ratio					**0%**		**-16%**		**-22%**		**-15%**		**-22%**		**-21%**	
Mean	19.8	17.8	19.2	17.4	42.8	38.6	2.3	2.4	4.9	5.6	1.0	1.1	0.4	0.4	0.4	0.5
Standard Error	1	1	1	1	7	6	0	1	1	1	0	0	0	0	0	0
Median	20	18	19	18	39	43	3	2	4	6	0	1	0	0	0	0
Mode	25	22	18	22	#N/A	#N/A	1	1	3	6	0	0	0	0	0	0
Standard Deviation	5	5	4	5	30	22	2	2	4	3	1	1	1	1	1	1
Sample Variance	27	29	20	26	893	488	2	5	13	9	2	1	0	1	1	1
Kurtosis	0	0	-1	-1	4	2	-1	1	3	1	0	1	2	1	1	0
Skewness	0	0	0	0	2	1	0	1	2	0	1	1	2	1	1	1
Range	23	24	16	18	121	88	5	8	15	12	4	4	2	2	2	2
Minimum	6	6	12	8	8	7	0	0	0	0	0	0	0	0	0	0
Maximum	29	29	27	26	129	95	5	8	15	12	4	4	2	2	2	2
Confidence Level(95.0%)	1.88	1.96	2.39	2.72	15.92	11.77	0.84	1.17	1.95	1.61	0.73	0.63	0.33	0.39	0.39	0.39
Variance	27.24	29.48	20.17	25.97	892.73	487.86	2.47	4.80	13.45	9.18	1.87	1.40	0.38	0.53	0.53	0.53
Observations	32	32	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Pearson Correlation	0.90		0.95		0.90		-0.01		0.24		0.12		0.20		-0.06	
Hypothesized Mean Difference	0		0		0		0		0		0		0		0	
df	31		15		15		15		15		15		15		15	
α	0.05		0.05		0.05		0.05		0.05		0.05		0.05		0.05	
t Stat	4.55		4.62		1.21		-0.28		-0.72		-0.15		-0.29		1.00	
P(T<=t) one-tail	0.00		0.00		0.12		0.39		0.24		0.44		0.39		0.41	
t Critical one-tail	1.70		1.75		1.75		1.75		1.75		1.75		1.75		1.75	
P(T<=t) two-tail	0.00		0.00		0.24		0.79		0.48		0.88		0.77		0.82	
t Critical two-tail	2.04		2.13		2.13		2.13		2.13		2.13		2.13		2.13	

The final trip during these sea trials was onboard the F/V Diligence in Closed Area I of George's Bank. A total of 88 tows successful tows were conducted, 50 of which were sampled by an observer. In total the experimental dredge landed a significantly larger amount of scallops compared to the standard New Bedford dredge. However the experimental dredge also caught more of the bycatch species as well. A summary of the catch during this trip is listed in Table # 11 below. All Bridge Logs, Catch Logs, and length frequencies are provided in the Appendices.

Diligence-2007-1														
Descriptive Statistics and t-Test: Paired Two Sample for Means														
Extended Bale Dredge														
Species	**Scallop Bushels (entire trip)**		**Scallop Bushels (obs tows)**		**Skate**		**Monkfish**		**Fluke**		**Grey Sole**		**Four Spot Flounder**	
Dredge	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***
Total Count	1259	1021	678	555	2669	2110	99	62	146	106	79	21	107	69
% Difference in Count	**23%**		**22%**		**26%**		**60%**		**38%**		**276%**		**55%**	
Fish Count/Scallop Bushel Catch Ratio					3.94	3.8	0.15	0.1	0.22	0.2	0.12	0.0	0.16	0.1
% Difference in Catch Ratio					**3%**		**31%**		**13%**		**208%**		**27%**	
Mean	14.3	11.6	13.6	11.1	53.4	42.2	2.0	1.2	2.9	2.1	1.6	0.4	2.1	1.4
Standard Error	0	0	1	0	5	4	0	0	0	0	0	0	0	0
Median	14	11	14	11	42	40	2	1	2	2	1	0	2	1
Mode	16	14	16	14	37	24	1	1	2	1	0	0	2	1
Standard Deviation	4	4	4	3	37	28	1	1	2	2	2	1	2	2
Sample Variance	17	14	14	11	1344	775	2	1	4	2	3	1	4	2
Kurtosis	5	9	2	1	2	3	-1	0	2	0	0	2	3	2
Skewness	1	2	-1	0	1	2	0	1	1	1	1	2	2	1
Range	32	31	23	18	153	132	4	4	10	6	6	3	9	6
Minimum	1	2	1	2	9	3	0	0	0	0	0	0	0	0
Maximum	33	32	25	19	162	135	4	4	10	6	6	3	9	6
Confidence Level(95.0%)	0.88	0.80	1.08	0.93	10.42	7.91	0.38	0.31	0.59	0.44	0.47	0.22	0.56	0.43
Variance	17.33	14.32	14.41	10.78	1344.44	775.47	1.82	1.17	4.36	2.39	2.78	0.58	3.88	2.28
Observations	88	88	50	50	50	50	50	50	50	50	50	50	50	50
Pearson Correlation	0.83		0.85		0.94		0.26		0.46		0.14		0.50	
Hypothesized Mean Difference	0		0		0		0		0		0		0	
df	87		49		49		49		49		49		49	
α	0.05		0.05		0.05		0.05		0.05		0.05			
t Stat	10.84		8.78		5.50		3.50		2.90		4.74		3.02	
P(T<=t) one-tail	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
t Critical one-tail	1.66		1.68		1.68		1.68		1.68		1.68		1.68	
P(T<=t) two-tail	0.00		0.00		0.00		0.00		0.01		0.00		0.00	
t Critical two-tail	1.99		2.01		2.01		2.01		2.01		2.01		2.01	

A total of 188 tows were completed using the Extended Bale Dredge. Observers sampled the catch of 111 tows. Data complied from these three trips show that the Extended Bale Dredge out fished the standard New Bedford dredges for scallops by a statistically significant margin. The experimental dredge maintained a similar catch ratio for skates: scallops bushels compared to the New Bedford design. The Extended Bale Dredge captured significantly more monkfish and grey sole relative to the control dredge. A listing of the compiled data for the Extended Bale Dredge is below in Table # 12.

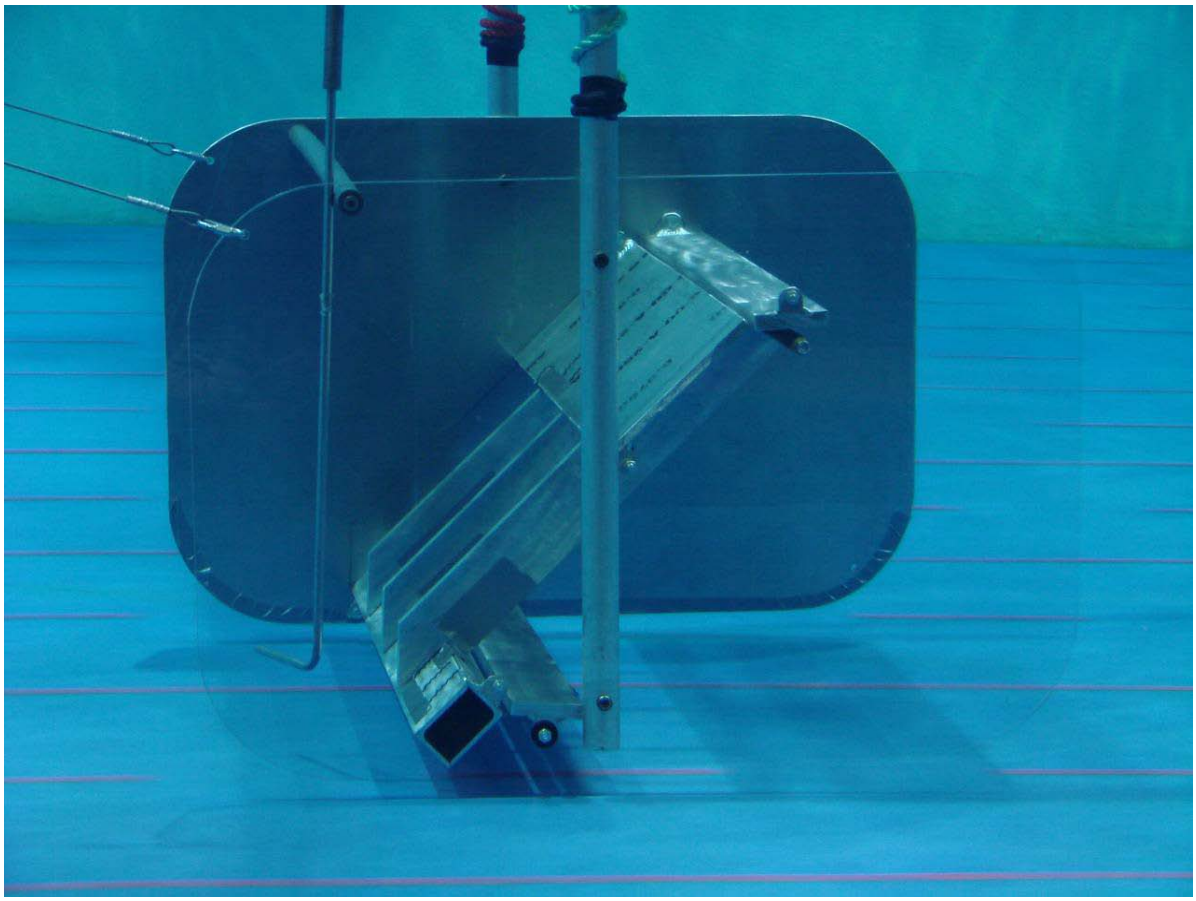
Extened Bale Dredge																				
Descriptive Statistics and t-Test: Paired Two Sample for Means																				
All Trips																				
Species	**Scallop Bushels (entire trip)**		**Scallop Bushels (obs tows)**		**Skate**		**Yellowtail Flounder**		**Monkfish**		**Fluke**		**Grey Sole**		**Four Spot Flounder**		**Sand Dab**		**Sea Robin**	
Dredge	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***	***Experimental***	***Control***
Total Count	3170	2802	1660	1470	8193	7364	23	22	198	151	567	573	129	76	137	104	74	99	7	8
% Difference in Count	**13%**		**13%**		**11%**		**5%**		**31%**		**-1%**		**70%**		**32%**		**-25%**		**-13%**	
Fish Count/Scallop Bushel Catch Ratio					4.93	5.01	0.01	0.01	0.12	0.10	0.34	0.39	0.08	0.05	0.08	0.07	0.04	0.07	0.00	0.01
% Difference in Catch Ratio					**-2%**		**-7%**		**16%**		**-12%**		**50%**		**17%**		**-34%**		**-23%**	
Mean	16.9	14.9	15.0	13.2	73.8	66.3	0.2	0.2	1.8	1.4	5.1	5.2	1.2	0.7	1.2	0.9	0.7	0.9	0.1	0.1
Standard Error	1	1	0	0	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Median	15	13	15	13	56	50	0	0	1	1	4	4	1	0	1	0	0	0	0	0
Mode	14	14	16	14	53	25	0	0	1	1	2	3	0	0	0	0	0	0	0	0
Standard Deviation	9	9	5	5	57	55	1	1	1	1	4	5	2	1	2	1	1	2	0	0
Sample Variance	87	78	24	24	3247	3055	0	0	2	2	20	26	3	1	3	2	2	3	0	0
Kurtosis	38	33	9	5	5	7	12	19	0	5	1	5	1	3	5	3	10	4	29	24
Skewness	5	5	2	1	2	2	3	4	1	2	1	2	1	2	2	2	3	2	5	5
Range	89	83	42	37	309	337	3	4	7	8	20	28	7	5	9	6	8	8	2	2
Minimum	1	2	1	2	8	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	90	84	43	38	317	340	3	4	7	8	20	28	7	5	9	6	8	8	2	2
Confidence Level(95.0%)	1.34	1.27	0.93	0.92	10.72	10.40	0.10	0.11	0.28	0.25	0.83	0.96	0.31	0.21	0.32	0.25	0.25	0.34	0.06	0.06
Variance	86.80	78.38	24.39	24.05	3246.99	3054.57	0.31	0.36	2.24	1.76	19.53	26.05	2.73	1.22	2.94	1.73	1.82	3.33	0.10	0.10
Observations	188	188	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Pearson Correlation	0.94		0.85		0.90		0.34		0.23		0.71		0.14		0.48		0.73		0.23	
Hypothesized Mean Difference	0		0		0		0		0		0		0		0		0		0	
df	187		110		110		110		110		110		110		110		110		110	
α	0.05		0.05		0.05		0.05		0.05		0.05		0.05		0.05		0.05		0.05	
t Stat	8.19		6.73		3.13		0.14		2.54		-0.16		3.02		1.98		-1.89		-0.24	
P(T<=t) one-tail	0.00		0.00		0.00		0.44		0.01		0.44		0.00		0.03		0.03		0.40	
t Critical one-tail	1.65		1.66		1.66		1.66		1.66		1.66		1.66		1.66		1.66		1.66	
P(T<=t) two-tail	0.00		0.00		0.00		0.89		0.01		0.88		0.00		0.05		0.06		0.81	
t Critical two-tail	1.97		1.98		1.98		1.98		1.98		1.98		1.98		1.98		1.98		1.98	

The dredge design continued to evolve during the five field trials described in this report. We started the field trials by testing a single strut design which did not maintain its structural integrity over the fishing period. We are not sure at this time what forces caused the dredge to gradually deform and lose efficiency. We then went back to testing a reinforced bale frame with all but the center bale bars removed. The design currently at sea being tested has a shortened shoe, increased frame struts, and an angled cutting bar.

Model Testing Results

Test 1: The cutting bar was placed at a 45 degree angle to the horizontal with the bottom 1.5 inches off the flume floor (a moving belt). The turtle chain plate was located as shown in Figure 1 and had tell-tales rigged underneath. The pressure plate was 8” wide. The space between the bottom of the pressure plate and the top of the cutting bar was 10”. The test speed was 0.85 knots. Dye injection clearly showed the flow was separated by the pressure plate and that flow stalled behind the pressure plate. The cutting bar and turtle chain plate formed a crude wing and flow was observed to accelerate over the top of the cutting bar. The tell-tales under the chain plate pointed forward.

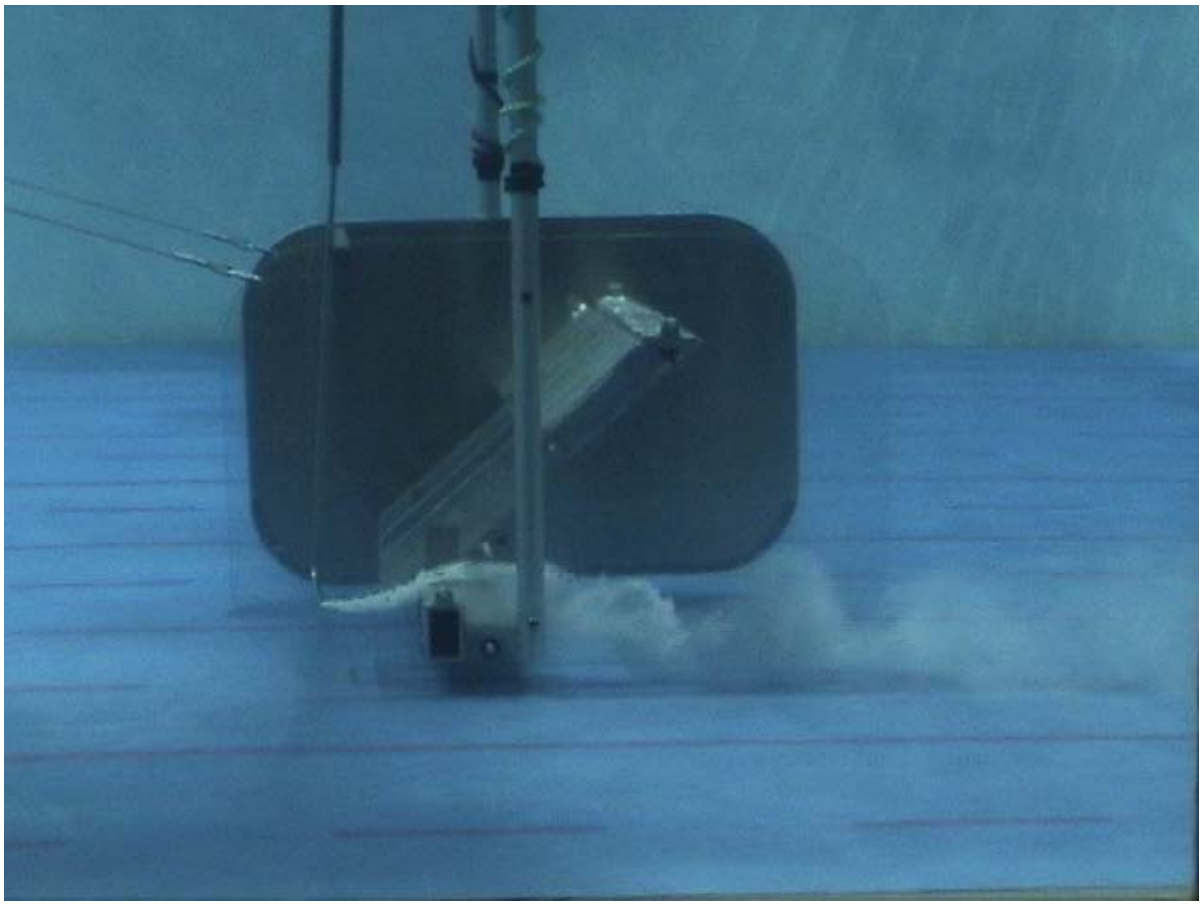
Figure 2: Model test 1 rigging



Test 2: The cutting bar was rotated so that the 3” face was perpendicular to the tow direction as found on standard dredges. The turtle chain plate was located horizontally half way up the rear side of the cutting bar. The test started at a speed of 0.85 knots. The horizontal turtle chain plate is located in a position that reduces drag created by the cutting bar. No vortex shedding was observed. The turtle chain plate in effect acts as a splitter plate reducing the drag coefficient of the vortex-stress producing shape of the blunt cutting bar. The stagnant water behind the cutting bar travels along with the cutting bar so the slip stream does not go up. When the die injector is located close to the tank floor the dye stream shows some turbulence several diameters beyond the cutting bar.

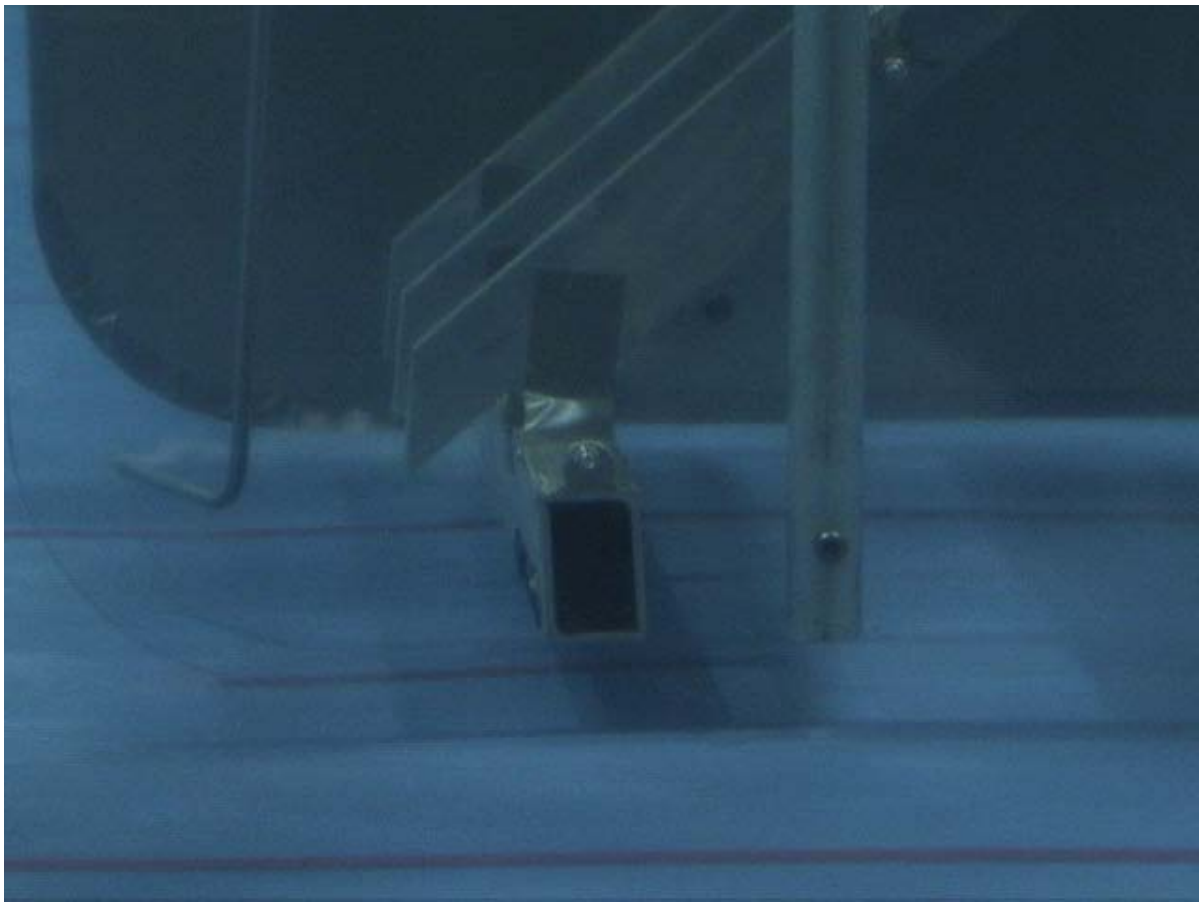
When speed was increased to 2.0 knots no clear change in flow pattern was observed. We attempted to introduce the rubber disks to simulate scallops on the bottom but they were caught up on the cutting bar and did not go under.

Figure 3: Model test 2 rig with dye flowing over the cutting bar.



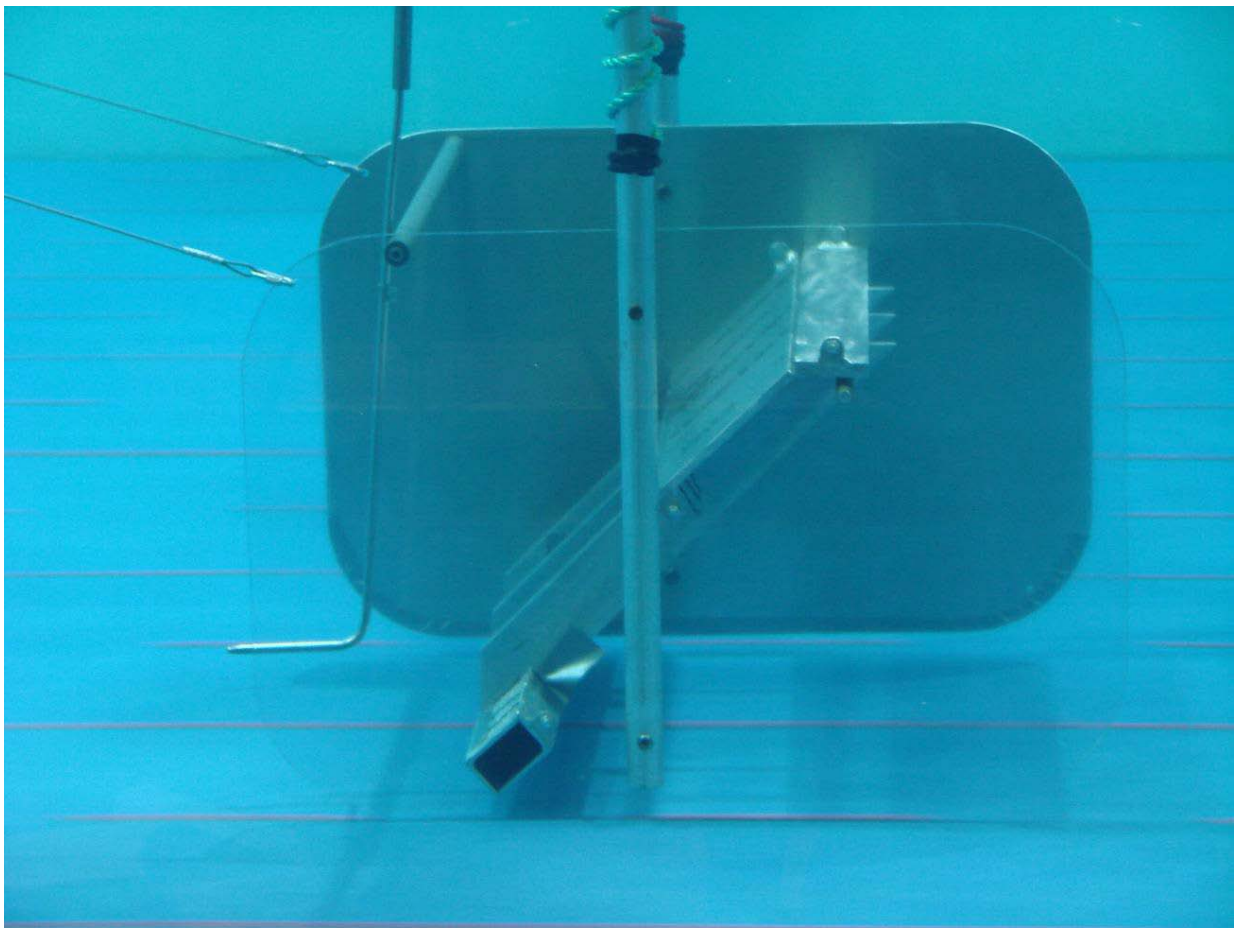
Test 3: The turtle chain plate was removed and the cutting bar remained rigged as in the previous test. The test was conducted at 2.0 knots. Without the chain plate there was pulsating vortex shedding. Over the top the spinning was clockwise; underneath the cutting bar the spinning was counter-clockwise.

Figure 4: The test #3 rig without the turtle chain plate.



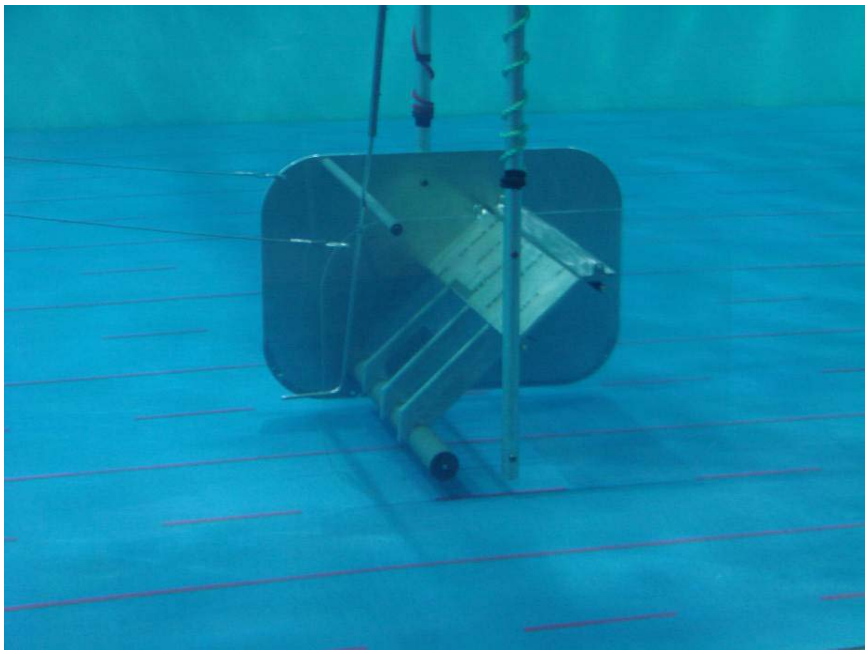
Test 4: The cutting bar was rotated to the 45 degree position as used in the rig 1 test but with the turtle chain plate removed.. The test started at 0.85 knots. In this test the vortex shedding as seen in the previous test was not very pronounced over the top of the cutting bar and was not seen below the cutting bar.

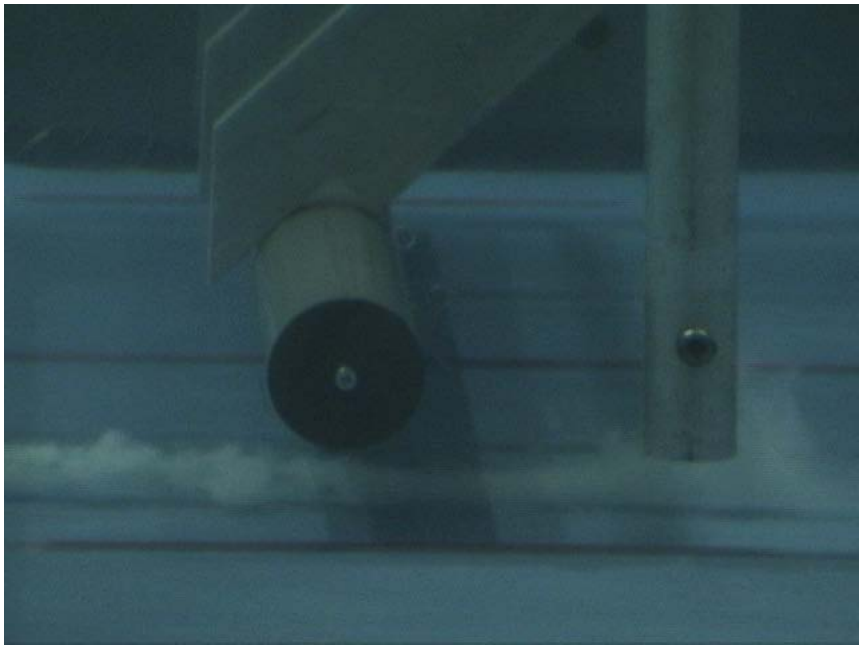
Figure 5: Test #4 rigged without turtle chain plate.



Test 5: A 2 5/8” diameter piece of solid PVC round stock was used as the cutting bar without a turtle chain plate attached. Speed was 0.85 knots. Periodic vortex shedding took place several diameters behind the round cutting bar creating a lifting situation. The speed was increased to 2.0 knots and a similar pattern was observed.

Figure 6 : Test #5 demonstrating a round cutting bar with flow passing underneath.



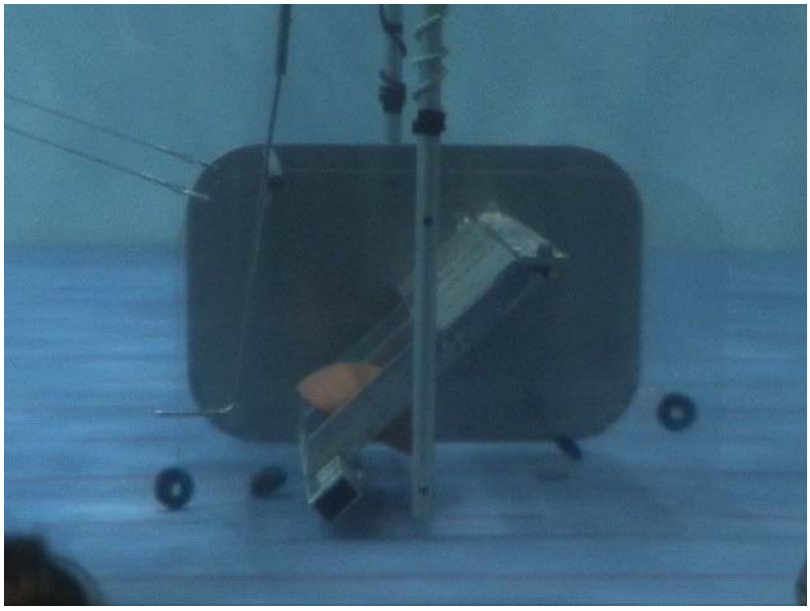


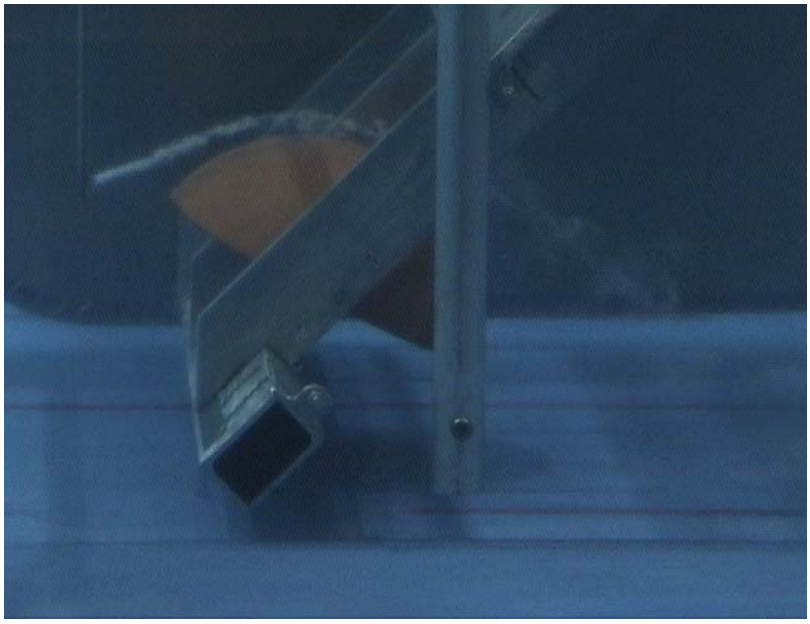
Test 6: The test was conducted with the same rig as in Test 1; cutting bar at a 45 degree angle with the turtle chain plate attached as in Figure 1. Speed was increased to 2.0 knots and the rubber cookies were released. The cookies showed a little lift after the cutting bar and one remained stalled behind the cutting bar.

Figure 7: Test #6 showing lift behind the cutting bar using rubber cookies to simulate scallops.

Test 7: An 11” diameter “hat” was mounted between two struts at a 30 degree angle to the tank floor above the cutting bar. Speed was kept at 1.0 knots. The hat directed water flow down behind the cutting bar creating turbulence. Water flow going over the top of the hat was also directed down. Speed was increased to 2.0 knots and cookies released. The cookies demonstrated significant lift behind the unit.

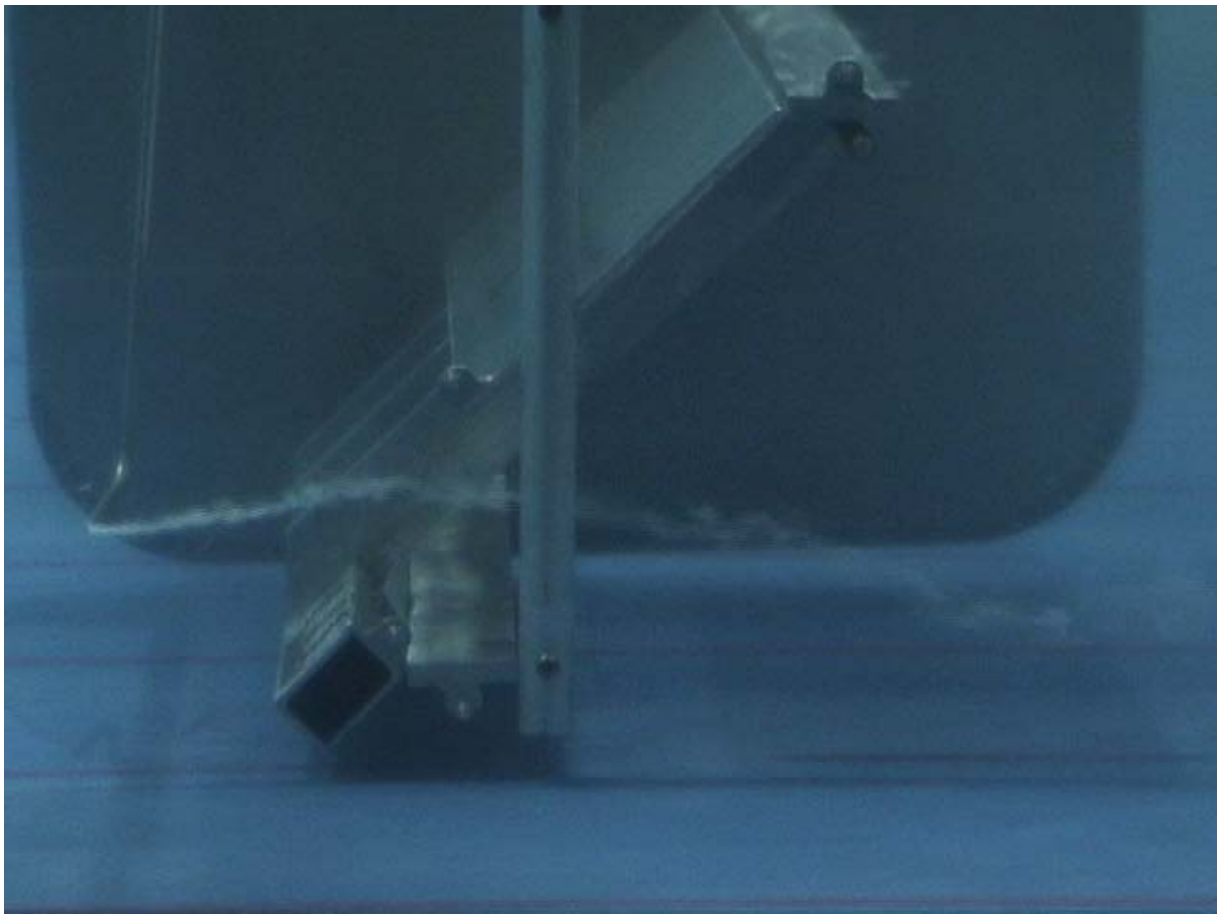
Figure 8: Flow around the “hat”





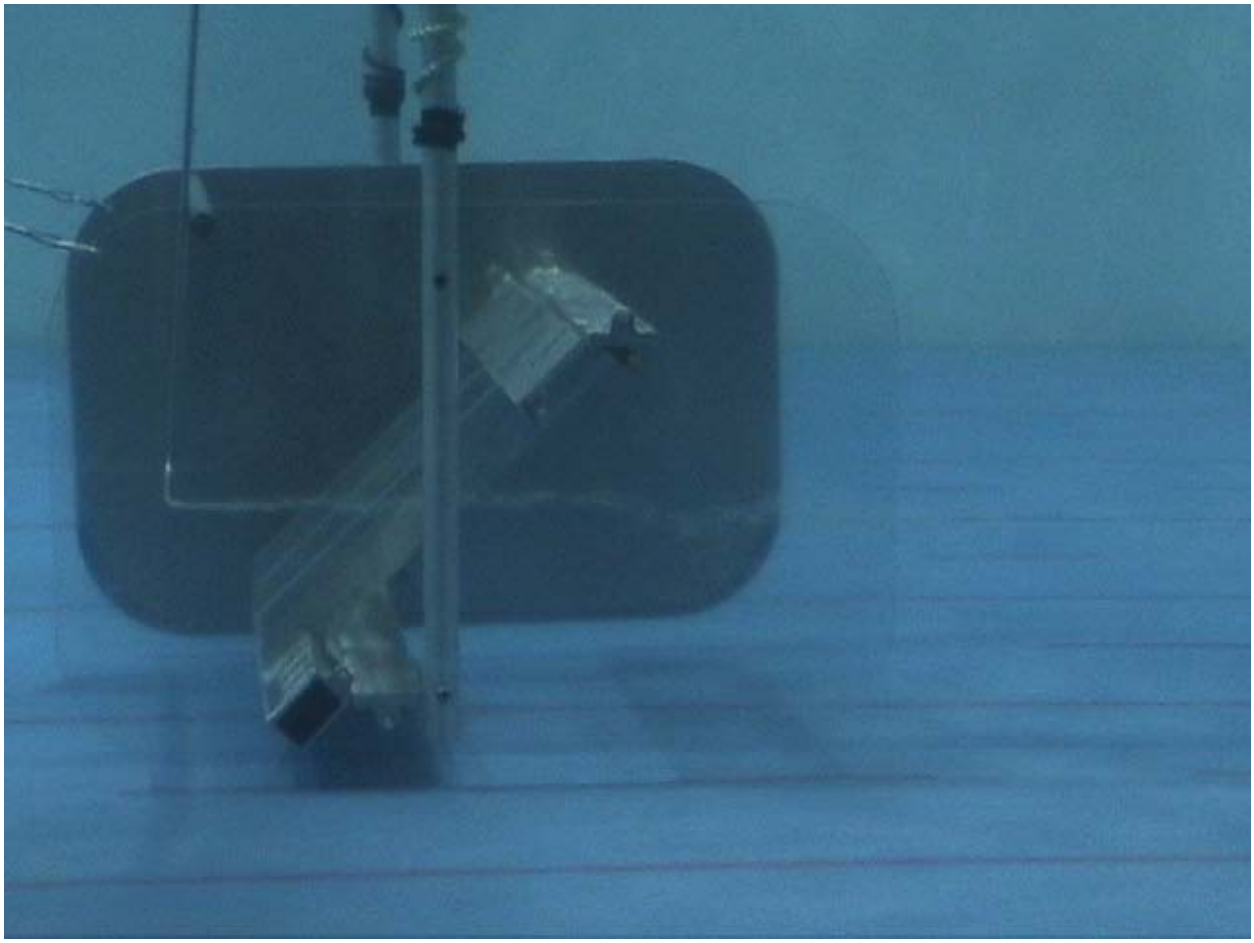
Test 8: The pressure plate width was increased to 12”. The space between the bottom of the pressure plate and the top of the cutting bar was thus decreased to 6.5”. Flow was observed to be directed downward after passing between the pressure plate and the cutting bar. This occurs to the flow stream encountering the cutting bar directly; it flows over then is directed downward. The combined flow creates increased turbulence. Rubber cookies, inserted at 2.0 knots, were lifted by the turbulence behind the cutting bar.

Figure 9: The wide pressure plate deflects flow downward.



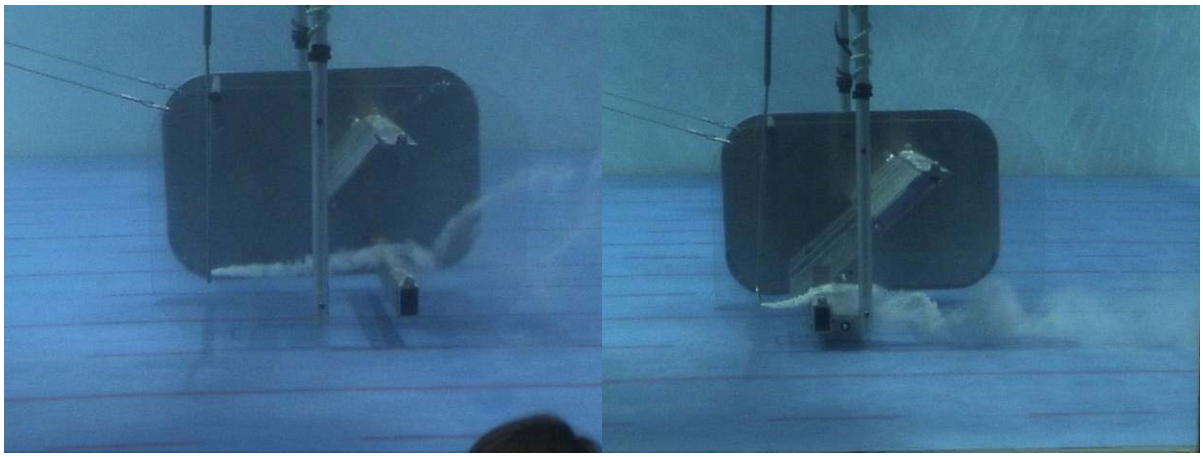
Test 9: The pressure plate width was decreased to 4”. The space between the cutting bar and bottom of the pressure plate was thus increased to 14”. The flow over the cutting bar was directed downward but at a point further aft than in the previous test. There were also smooth undisturbed flow streams in the space between the cutting bar and pressure plate. The pressure plate was not observed to disturb flow to any great extent when compared to the wider plates.

Figure 10: The narrow pressure plate barely disturbed flow passing just below.



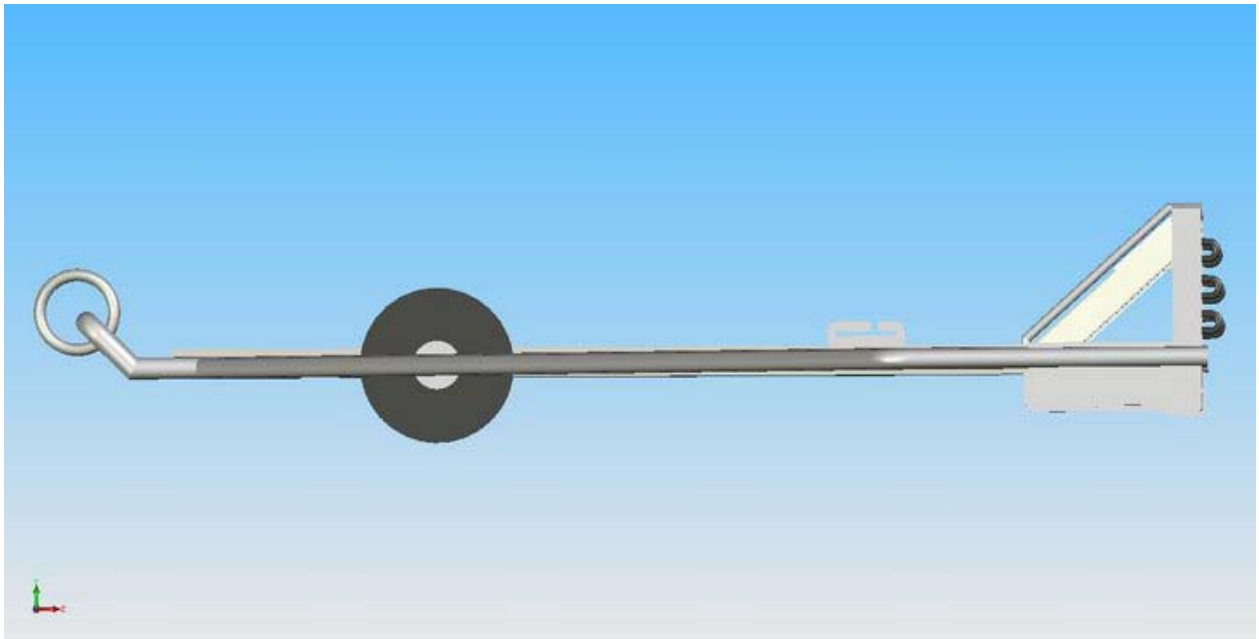
Test 10: The cutting bar was placed under the frame as in a standard dredge; the 3” face perpendicular to the flow. The 8” pressure plate was mounted in the standard dredge position. No struts were used. The flow behind the cutting bar was very turbulent. Vortexes were being shed off the top of the cutting bar and flowing upward. The flow around the pressure plate indicated the same stall area behind the plate as in the previous test. It was difficult to discern if the flow streams from the pressure plate influenced the flow from the cutting bar.

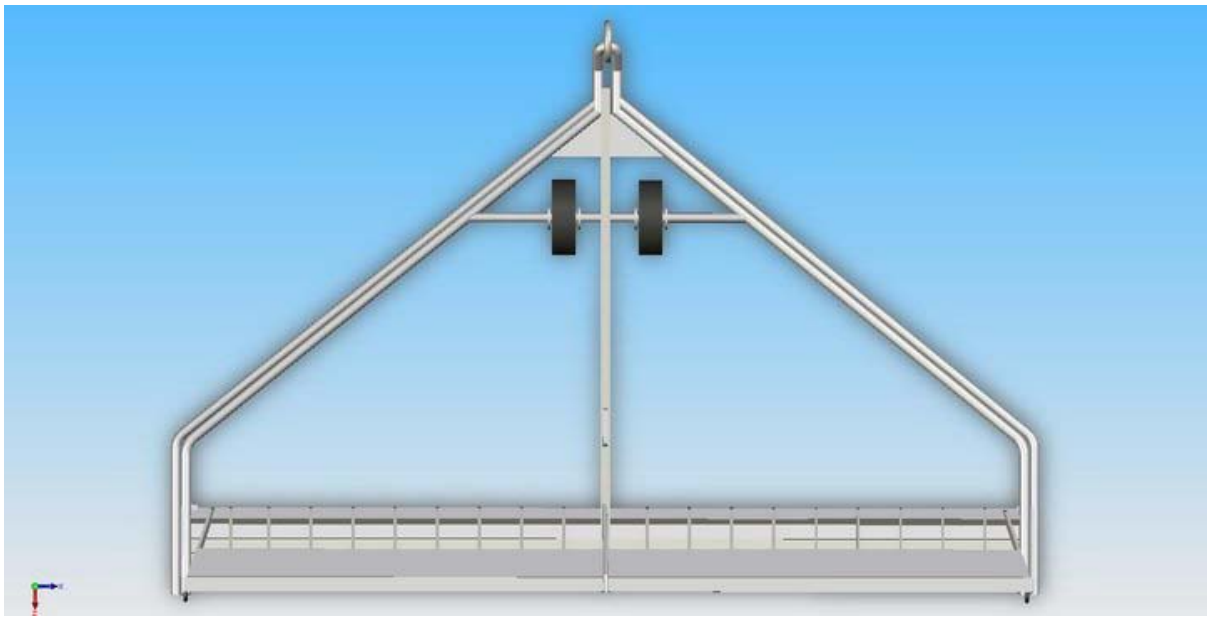
Figure11: Flow comparison between standard dredge and turtle dredge cutting bar placement.



Dredge Design Software

As part of this project we procured a computer aided design (CAD) program called Solid Works to assist in the development of the new dredge. Each individual component of the dredge was specified and entered into the software. Once this was completed, various designs could be fabricated on the computer using those components. Some illustrations from this software are provided below.





Discussion

Evolution of the Dredge Design

The New Bedford style scallop dredge has evolved over a long period of time (Smolowitz and Serchuk, 1988). The dredge evolved to fish multiple types of bottom including flat sand and gravel, substrates contoured by sand waves, and substrates with occasional cobbles and boulders. The dredge is highly ineffective on soft or mud bottom as it clogs up with substrate before obtaining any significant catch. However, harvestable scallops are seldom abundant in these low energy environments. The dredge is also ineffective on bottom with large amounts of boulders due to getting hung-up and/or substantially damaged. The dredge can be outfitted with rock chains but there is a tradeoff in efficiency that makes it extremely costly to fish on bottom with even a relatively small amount of cobble/boulder present. Given these conditions, dredge design was driven by the need for strength and bottom tending.

In the 1990's fish bycatch became an issue; primarily flatfish and specifically yellowtail flounder. We found that increasing the mesh size of the twine top greatly reduced the flatfish bycatch and helped release some of the smaller skates (Henriksen et al, 1997; Smolowitz et al, 2001, 2002). We decided to examine options to reduce the capture of larger skates by deterring them in front of the dredge. However, the dredge needs to move fast to be efficient in catching scallops and at these speeds fish and skates don't have much time to avoid the gear. Attempts to lead them to either side of the oncoming gear were not successful. We opted to lead them over the gear by placing a sweep far enough forward of the cutting bar so they would be directed upward and over the oncoming frame and bag. On the standard dredge the bale tapers inwards starting at the frame thus a sweep placed 15 inches ahead of the cutting bar would only cover 10 feet of the 15 foot dredge width. These lead us to our first structural design change; having the bale extend straight out 15 inches before tapering towards the tow point. A sweep placed at this location covered the entire mouth of the dredge.

At about this time loggerhead sea turtle takes started to occur in the fishery and our dredge design work shifted focus to address this situation. We had no idea how or where the encounters were taking place. After some discussion we decided a chain mat, similar to rock chains, could keep turtles out of the dredge bag. We tested the turtle chains and they were 100% effective in that regard (Dupaul et al, 2004). We still had turtles being caught on top of the dredge frame and there still was concern that the turtles might be getting "run-over" by the dredge. This lead us back to the general concept for large skates; moving the cutting bar forward to provide a cow catcher style to the dredge frame so a turtle would go up and over without snagging on the frame.

We conducted tests using turtle carcasses off Panama City, Florida. Results of the Florida tests demonstrated turtles potentially can be trapped by the bale bars and possibly injured underneath the standard New Bedford dredge bale or caught in the frame mouth between the cutting bar and depressor plate (Milliken et al, 2007). To reduce this problem the frame and bale were redesigned and tested again in Florida and at sea during this project. While design changes were to minimize turtle mortality, consideration was also given to reduce the trapping of other unwanted species, to reduce the dredge's hydrodynamic drag, to improve fishing efficiency and to improve the dredge's overall strength.

In our prototype of the forward cutting bar design we maintained the overall dredge length by shortening the bale. We kept the distance from the bull ring (tow point) to the heel of the shoe the same which resulted in a longer show; 30 inches versus the standard 15 inches. Field testing suggested that the longer shoe was not serving any purpose so the dredge design was modified again. The shoe was now designed to end at the dredge box frame; this placed the heel of the shoe in the same position relative to the cutting bar as in the standard dredge. Cutting the shoe short allowed the bale to be extended and that was accomplished by first coming out straight 15 inches and then bending towards the tow point. This widened the opening between bale and cutting bar considerably for potential turtle escapement. Strut spacing was reduced to nine inches. Hardened steel round bar stock was used to face the lower portion of the strut, overlapping the cutting bar, to allow for a smoother transition.

As discussed previously, the dredge frame was changed from a vertical frame to one that is sloped back at 45 degrees to act like a “cattle guard” and direct turtles up and over the top. This sloped frame efficiently guided large animals up over it but the large strut spacing between the depressor plate and cutting bar allows smaller turtles and other animals to enter. This area was reduced by decreasing the strut spacing from 12 to 9 inches. Since the depressor plate is supported by these struts, a reduction in spacing reduces the unsupported beam length which increased the depression plate bending strength by 78% for a uniform load or 33% for a point load. This eliminated the need for the reinforcing bar across the to of the depressor plate.

The cutting bar located at the bottom of the frame was rotated 45 degrees to increase fishing efficiency. The tow tank tests we conducted under this project would suggest this increase in efficiency is probably due to slightly higher flow disturbances beneath the bar. This orientation results in slightly higher drag which was moderated by welding the turtle chain attachment plate at the center line of the cutting bar. In this configuration the plate acts as a splitter plate to interfere with the motions of the vortex street to decrease the overall drag coefficient.

Two redesigns of the existing bale were constructed and then tested at sea. Each of these designs minimized the bale’s trapping potential by reducing the bale’s potential turtle trapping areas (foot print). In the first new design the "V" shape bale frame was discarded and a single tow bar was constructed that attached to the centerline of the dredge. This single point bar design reduced the number of bale bars, potential trapping surfaces, from 9 to 1 and reduced both weight and hydrodynamic drag. This simpler design however required heavy construction to resist large bending moments when the dredge came in contact with large boulders. The design can resist a bending moment of 200,000 NM. Which is equal to a force of 133,333 N at 2/3 the distance (5 feet) out from the center line. The load was chosen to equal the potential maximum operating load of the typical scallop vessel winch

Although simple in concept, test results were poor. The single tow bar showed no sign of bending but the dredge itself showed a small amount of twisting, probably due to the loss of torsional stiffness supplied by the V-shaped bale. This mechanical problem coupled with poor fishing performance resulted in this design being discarded.

The second design kept the existing V-shape bale and the center support rod. The other six horizontal rods, three on each side of the center support, were removed to reduce potential turtle trapping areas. Removing the six support rods greatly weakens the bale and could result in severe bending on contact with large boulders. To strengthen the bale bar, a second bar of equal diameter was attached along side it by a continuous weld in the horizontal axis. Adding a bar was more weight efficient than just increasing the diameter of the tow bar. The resulting strength was increased by a factor of ~5 in the x (towed direction) and by a factor of 2 in the y (vertical direction) as compared to a single rod. Not only is this geometry efficient in strength, it decreases hydrodynamic drag. The drag coefficients (at Reynolds number~ 10^5) for the single bar is 1.17 and for the two welded bars 0.7 (Hoerner 1965, pg. 8-1) .

In both of the preceding designs the potential of turtle trapping was reduced by decreasing the number of places where they could get caught. Also, the hydrodynamic drag was lowered which leads to a decrease in diesel fuel consumption. This in turn, reduces pollutants NOx compounds and particulates and the global warming gas, CO2. Also the fuel savings should reduce consumer price and the excuse of going to war with oil producing countries and the prevalence of asthma in young children. It's a win win.

Future Design Considerations

There is great room for improvement in the hydrodynamic characteristics of the dredge frame. The depressor plate is of poor hydrodynamic design with lift to drag ratio of ~1. This ratio can easily be increased by changing the angle of attack to a ratio of greater than 3. Drag on this plate as now implemented at 4.5 knots is 2900 N. At a tow sped of 4.5 knots this is equal to 6.35 Kw. At propulsion efficiency of 50% equals 12.7 Kw. The uprights thickness can be reduced from 1.6 to 1.27 cm. and the leading and trailing edges can be rounded to decrease weight and drag.

In this project we did not investigate different materials beyond hardened steel used for the cutting bar extensions. There are a number of dredge frame components that could be replaced with alternate materials. Initially we planned to try replacing solid steel components with steel truss shapes but found these were not readily available in standard forms that we could utilize. However by the end of this project we learned enough to revisit this idea in the future.

The other major component of the scallop dredge that needs major redesign is the chain bag. We experimented with some changes but existing regulations made for limited choices. We plan to explore bag and twine top changes in future work.

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APPENDICES

Resolution 2006-1-Bridge Log

Date	Tow #	Time Start	Tow Time Minutes	Start Position Latitude	Longitude	End Position Latitude	Longitude	Speed Knots	Depth Fathoms	Wire out Fathoms	Vessel Heading	Catch (bu) port	stbd	we
11/7/2006	**1**	2335	30	40 45.3	69 14.75	40 43.3	69 15.6	4.7	33	112	210	14	15	10
11/8/2006	**2**	0015	40	40 43.3	69 15.6	40 44.9	69 11.6	4.9	34	120	096	40	43	10
11/8/2006	**3**	0110	35	40 45.3	69 10.5	40 47.2	69 07.7	4.8	37	130	082	0	45	10
11/8/2006	**4**	0157	43	40 47.2	69 07.7	40 45.2	69 11.0	4.9	37	130	233	44	56	10
11/8/2006	**5**	0254	46	40 45.1	69 10.9	40 46.9	69 07.9	4.5	37	135	075	52	60	10
11/8/2006	**6**	0700	30	40 45.2	69 14.2	40 43.1	69 15.8	4.7	33	110/115	219	26	16	10
11/8/2006	**7**	0740	30	40 43.1	69 15.8	40 45.0	69 14.0	4.7	33	110/115	062	17	16	10
11/8/2006	**8**	0820	32	40 45.0	69 14.0	40 43.0	69 16.0	4.7	33	110/115	190	18	21	10
11/8/2006	**9**	0910	30	40 43.8	69 15.9	40 45.7	69 13.2	4.7	33	105/110	070	14.5	13	E
11/8/2006	**10**	1100	30	40 45.4	69 13.6	40 43.6	69 15.2	4.7	33	110/115	196	6	7	10
11/8/2006	**11**	1210	30	40 38.7	69 14.9	40 38.9	69 12.8	4.7	31	110	152	10	3.5	10
11/8/2006	**12**	1255	30	40 38.9	69 13.1	40 40.2	69 15.5	4.7	31	110	327	15	16	10
11/8/2006	**13**	1340	32	40 40.1	69 15.3	40 38.5	69 13.1	4.7	31	110	153	8	20	10
11/8/2006	**14**	1430	30	40 38.4	69 13.2	40 39.8	69 15.4	4.7	31	110	330	17	19	10
11/8/2006	**15**	1510	30	40 39.5	69 15.3	40 38.6	69 12.9	4.7	31	110	125	20	12	10
11/8/2006	**16**	1600	30	40 38.7	69 13.5	40 40.1	69 15.5	4.7	31	110	330	25	25	10

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11/8/2006	**17**	0210	30	40 40.5	69 13.2	40 39.7	69 15.5	4.7	31	110	285	15	14	15
														S
11/8/2006	**18**	0255	35	40 40.0	69 15.6	40 40.6	69 12.6	4.7	31	110	080	24	17	15
														S
11/8/2006	**19**	0343	48	40 40.6	69 12.6	40 38.9	69 16.3	4.7	31	110/105	250	28	30	10
														S
11/8/2006	**20**	0440	35	40 38.9	69 16.3	40 39.9	69 14.0	4.7	31	110/105	085	8	30	10
														S
11/9/2006	**21**	0625	30	40 41.1	69 13.6	40 39.3	69 12.1	4.7	31	112/107	136	13	14	10
														S
11/9/2006	**22**	0725	35	40 39.6	69 13.7	40 39.2	69 12.3	4.7	31	105/110	023	25	18	10
														S
11/9/2006	**23**	0815	30	40 39.1	69 12.3	40 41.0	69 14.1	4.7	31	110/105	351	12	10	10
														S
11/9/2006	**24**	0855	30	40 41.1	69 14.1	40 39.7	69 11.4	4.7	31	105/110	126	14	16	10
														S
11/9/2006	**25**	0935	30	40 41.2	69 13.8	40 40.7	69 13.3	4.7	31	105/110	358	24.5	1	10
														S
11/9/2006	**26**	1035	30	40 40.7	69 13.3	40 39.0	69 11.5	4.7	31	115	145	16	9	10
														S
11/9/2006	**27**	1120	30	40 39.1	69 11.7	40 40.6	69 14.3	4.7	31	105	340	25	18	10
														S
11/9/2006	**28**	1200	30	40 40.7	69 13.7	40 39.7	69 11.5	4.7	31	105	124	15	18	10
														S
11/9/2006	**29**	1250	30	40 40.0	69 11.8	40 41.3	69 13.7	4.7	31	110	330	14	12	10
														S
11/9/2006	**30**	1330	30	40 41.0	69 13.4	40 39.4	69 11.2	4.7	31	110	148	34	20	10

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SKATE LENGTHS (CM) CELTIC-2007-1 *Experimental Dredge ON POR C= Control Dredge*

TOW #	7	7	8	8	9	9	11	11	16	16	18	18	24	24	26	26	35	35	37	37	39	39	TOTAL	TOTAL
DREDGE	**P**	**S**	**P**	**S**	**P**	**S**	**P**	**S**	**P**	**S**	**P**	**S**	**P**	**S**	**P**	**S**	**P**	**S**	**P**	**S**	**P**	**S**	**P**	**S**
6-10																							0	**0**
11-15																							0	**0**
16-20	1																						1	**0**
21-25	0													2	1		2	2		2	1	7	4	**13**
26-30	0					1					1	1		1	1	1	4	2	2	2		5	8	**13**
31-35	2				1				2	2	3	2	2	1	0	1	3	3	1	4		4	14	**17**
36-40	2			2	1	2		1	1		4	2	2	2	0	1	3		4		2	3	19	**13**
41-45	12	14	19	15	14	17	13	20	18	19	16	16	16	16	16	20	9	9	15	9	7	8	155	**163**
46-50	6	8	6	2	9	5	2	5	3	4	1	4	6	4	7		1	2	3	12	3	3	47	**49**
51-55																							0	**0**
TOTAL MEASURED	23	22	25	19	25	25	15	26	24	25	25	25	26	26	25	23	22	18	25	29	13	30	248	**268**

MONK LENGTHS (CM) CELTIC-2007-1 *Experimental Dredge ON PORT SIDE*

TOW #	2	2	3	3	7	7	8	8	9	9	15	15	16	16	17	17	18	18	24	24	25	25	26	26	27	27	35	35	36	36	37	37	38	38	39	39	40	40	TOTAL	TOTAL
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
16-20									1														1																	
21-25		1					1						1		1				1														1	1					5	2
26-30			2		1														1				1		1						1				2			2	9	2
31-35								1					1						1								1	1	1							2			4	4
36-40																	1	2		1		1	1															2	2	6
41-45			1	1		1						1					1		1				1						1		1	1						1	6	5
46-50			1	1									1		1					1					1		1		1	1			1	2			1		8	5
51-55	1	2				1									1		2								1				1	1		1						1	6	6
56-60				1						1			1																					1		1			1	4
61-65			1							1	1						1	1												1									3	3
66-70														1			1										1			1	1				1				4	2
71-75						1																		1										1					0	3
76-80										1							1		1												2							1	4	2
81-85																		1		1																		1	0	3
86-90																																							0	0
91-95																																							0	0
96-100																																							0	0
101-105																																							0	0
106-110																																							0	0
TOTAL MEASURED	1	3	5	3	1	3	1	1	0	3	1	1	4	1	3	0	7	4	5	3	0	1	3	1	3	0	3	1	4	4	5	2	2	5	3	3	1	8	52	47

WITCH LENGTHS (CM) CELTIC-2007-1 *Experimental Dredge ON PORT SIDE*

TOW #	11	11	15	15	16	16	18	18	24	24	25	25	26	26	27	27	38	38	39	39	40	40	TOTAL	TOTAL
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
21-25																							0	0
26-30															1								1	0
31-35		1	1				1			1				1		1							2	4
36-40				1							1	1						1					1	3
41-45					1	1								1						1		1	1	4
TOTAL MEASURED	0	1	1	1	1	1	1	0	0	1	1	1	0	2	1	1	0	1	0	1	0	1	5	11

FLUKE LENGTHS (CM) CELTIC-2007-1 *Experimental Dredge ON PORT SIDE*

TOW #	2	2	3	3	7	7	8	8	9	9	11	11	15	15	16	16	17	17	18	18	24	24	25	25	26	26	27	27	35	35	36	36	37	37	38	38	39	39	40	40	TOTAL	TOTAL
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
21-25																						1																			1	0
26-30										1	1																1							2		2		1	1		3	6
31-35		3		1	1		1	2	1	1	2	3	2	1	1		1	1	3		4	2					2		2			4	1	1			1	2	1	1	21	20
36-40	1	4	5	7	6	2	3	6	2	4	1	3		3	1	4	2	5	2	3	1	11	2		1	4	2	3	4		3	1	1	4	4	5	1	3	4	2	56	63
41-45		2	3	3		1	1	2			1			1	1	1		2		1		1			1	1		1	1	2		2						1	3	1	12	21
46-50		1		1			1	2										1	2		1		1				1	1								2			1		6	8
51-55		1	1						1							1			1											1					1			1			4	4
56-60			1																		1				1																2	0
61-65							1		1									1																							2	1
66-70				1																																					0	1
TOTAL MEASURED	1	11	10	13	7	3	7	12	5	6	5	6	2	5	3	6	3	10	8	4	7	15	3	0	3	5	6	5	7	3	3	7	2	7	5	9	2	8	10	4	107	124

4 spot LENGTHS (CM) CELTIC-2007-1 *Experimental Dredge ON PORT SIDE C= Control Dredge*

TOW #	2	2	7	7	8	8	11	11	15	15	24	24	25	25	26	26	27	27	36	36	37	37	39	39	TOTAL	TOTAL
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
11-15																									0	0
16-20													**1**						1					1	2	1
21-25	1										1														2	0
26-30																		1							0	1
31-35			1						2	1	1				1	2					1				6	3
36-40		1	2			1		2	2		1		**1**	1	1	2	1			2		1			8	10
41-45													**1**				1								2	0
TOTAL MEASURED	1	1	3	0	0	1	0	2	4	1	3	0	3	1	2	4									20	15

SEA ROBIN LENGTHS (CM) CELTI *Experimental Dredge ON PORT C= Control Dredge*

TOW #	2	2	3	3	7	7	9	9	11	11	15	15	16	16	18	18	25	25	26	26	36	36	38	38	TOTAL	TOTAL
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
16-20																									0	0
21-25																									0	0
26-30	1								1									1				1			2	2
31-35			1								1			**1**	1							1	1		4	2
36-40					1						1		**2**							2					4	2
41-45								1																	0	1
46-50																									0	0
51-55																									0	0
TOTAL MEASURED	1	0	1	0	1	0	0	1	1	0	2	0	2	1	1	0	0	1	0	2	0	2	1	0	10	7

SCALLOP SHELL HEIGHTS (mm) DILIGENCE-2007-1 (Experimental Dredge was switched to starboard side starting on tow #59)

Experimental Dredge was on port side (P) from tows 1 to 58 *Control Dredge was on starboard side from tows 1 to 58*

TOW #	8	8	9	9	10	10	11	11	12	12	13	13	19	19	20	20	21	21	22	22	23	23	24	24
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
40-45																								
45-50	1						1							1										
50-55	1																1	1						
55-60		3							2	2		1					1	5						
60-65																				2				
65-70									1											1				
70-75							1													1				
75-80																								1
80-85	1							1						2		2							1	0
85-90		2					1		1	4	1	1	2	2	1	0	2						1	1
90-95							4	1	7	3			3	4	3	2	5	3	1	3		1	2	6
95-100								2	2	2	1		1	2	1	4	2	1		1			2	
100-105	2			1	2		4	3	2	1	2		5	2	6	6	3	3		2			3	
105-110		1			6	6	0	3	10	5	5	4	7	10	8	4	6	7	6	3	1	3	6	8
110-115	6	0	6	3	12	10	9	3	19	14	8	11	9	13	8	5	12	18	11	14	1	5	6	9
115-120	8	9	10	11	17	26	10	8	8	9	3	3	9	12	8	11	12	9	10	5	5	4	7	12
120-125	21	10	16	17	22	23	11	8	3	6	8	5	7	11	5	9	8	4	10	5	9	11	10	4
125-130	23	19	15	19	25	24	21	26	16	17	14	24	9	20	26	28	17	13	12	11	17	17	15	15
130-135	20	25	20	18	7	12	27	22	20	22	22	15	13	11	22	26	11	14	12	13	9	20	17	15
135-140	8	15	18	11	8	3	7	15	16	16	12	15	16	12	14	10	17	13	14	14	25	13	12	13
140-145	3	3	3	4	3	8	9	4	5	5	6	11	10	7	9	4	8	9	8	10	14	10	9	7
145-150		1	2	1		1	0		1	1	2	3	3			1	2	6	4	6	4	4	0	1
150-155				2			2				1	1	1				1	1	2	1			1	1
155-160											1								1					
160-165																								
165-170																								
TOTAL PER TOW	94	88	90	87	102	113	107	96	113	107	86	94	95	109	111	112	108	107	91	92	85	88	92	93
BUSHELS MEASURED	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

TOW #	25	25	26	26	27	27	28	28	31	31	32	32	33	33	34	34	35	35	36	36
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
40-45																				
45-50						1	1													
50-55											1									
55-60	1	1		1						1			1							
60-65	2	3																	1	
65-70	1	1																1		
70-75	0																			
75-80	0																		1	
80-85	1	1			1		1	2	1	1		1	1				2			
85-90	4	2		3	0	1	1	1	8	3		2		1		1	1		1	4
90-95	2	2	4	2	3	0	0	1	2	3	2	2			1	1				0
95-100	2	2	1		1	1	3	2	2	2		2			2	1	2	2		2
100-105	1	1		2	2	1		3	6	2	1	3	6	4	6	4	7	2	6	9
105-110	5	5	4	5	6	5	5	12	7	10	9	13	13	4	5	9	15	17	8	9
110-115	10	1	9	5	11	16	9	18	14	8	17	26	8	12	9	8	8	21	8	9
115-120	11	8	10	8	10	18	11	13	7	8	10	18	8	9	4	4	18	8	10	14
120-125	9	8	7	12	6	1	10	5	7	8	5	1	8	8	13	10	17	7	17	14
125-130	16	16	7	17	10	9	9	8	24	14	12	17	14	19	21	28	17	32	18	27
130-135	16	18	16	15	18	15	11	12	15	14	16	14	19	17	22	14	16	15	14	14
135-140	10	16	15	18	12	14	9	14	9	14	9	11	15	15	12	13	6	8	13	12
140-145	9	3	8	6	11	11	11	9	5	6	7	9	5	4	2	6	2	4	5	3
145-150	3	2	5	3	1	3	4	2	3	1	8	4	3	1	3	1	1		1	1
150-155	1	1			2	2	3	0					0	1		2				
155-160							1	0					1							
160-165								1												
165-170																				
TOTAL PER TOW	104	91	86	97	94	98	89	103	110	95	97	123	102	95	100	102	112	117	103	118
BUSHELS MEASURED	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

TOW #	37	37	38	38	39	39	40	40	44	44	45	45	46	46	47	47	48	48	49	49
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
40-45																				
45-50									1											
50-55																				
55-60																				
60-65																				
65-70																				
70-75				1		1														
75-80								1		2	1			2						
80-85			1				1	0						0		2				
85-90				1				1					3	1		0	1	1	2	2
90-95	1	1							1				1	2		1		2		
95-100		2				2	1	2	1	1	1		1			2	1	1		1
100-105	1	1		1	4	5	2	2	3	4	3	3	1	3	2	1	1	1	3	4
105-110	3	3	1	3	9	4	5	6	8	4	5	7	3	7	6	7	5	2	4	10
110-115	1	5	6	3	6	2	4	1	4	1	4	3	4	6	4	5	1	7	4	4
115-120	4	4	5	1	5	7	6	1	0	5	4	3	1	2	1	5	1	3	2	4
120-125	12	3	10	7	9	5	11	7	9	11	3	6	11	7	12	10	6	13	5	11
125-130	27	18	18	13	19	20	18	18	28	19	26	17	17	18	22	18	16	14	19	17
130-135	19	13	19	24	17	20	21	25	26	26	21	27	25	24	13	24	21	22	23	20
135-140	11	13	12	17	14	15	14	13	11	10	15	8	9	13	18	12	10	14	15	14
140-145	7	9	5	4	7	4	5	4	7	4	6	7	8	7	9	6	13	6	8	5
145-150	3	7	4	2	1	2	0	3	4	2	2	3	0	0	0	0	3	2	1	1
150-155	1		1	1	1	1	2	1		0	1		1	2	2	1			1	
155-160										1				1		1				
160-165																				
165-170																				
TOTAL PER TOW	90	79	82	78	92	88	90	85	103	90	92	84	85	95	89	95	79	88	87	93
BUSHELS MEASURED	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

TOW #	50	50	51	51	58	58	TOTAL	TOTAL		59	59	60	60	61	61	62	62	63
DREDGE	P	S	P	S	P	S	P	S		P	S	P	S	P	S	P	S	P
40-45							0	0										
45-50							4	2										
50-55							3	1									1	
55-60							5	14										
60-65							3	5					1			1		
65-70							2	3										
70-75							1	3										
75-80		1					2	7				1				1		
80-85							11	12			2		1					
85-90		1				1	30	36			1		1			1	1	1
90-95	1	1	1				44	41				2	1	1				
95-100	2		1	1	1	1	31	39				1				3	2	2
100-105	2	2	6	0	3	1	95	77		2	4	2	3	4	3	3	3	3
105-110	6	1	6	5	9	2	202	204		6	4	3	4	4	2	3	4	7
110-115	4	4	4	7	7	1	263	278		3	11	3	4	1	4	5	5	4
115-120	3	3	4	5	3	4	245	274		3	2	6	0	3	3	4	3	8
120-125	3	8	5	11	5	12	330	298		9	8	8	6	6	4	5	6	8
125-130	16	21	14	17	15	21	613	651		29	26	24	24	21	18	13	23	31
130-135	21	18	21	20	22	25	632	649		16	18	21	20	22	28	23	23	18
135-140	13	17	11	12	19	12	449	455		11	9	16	13	12	16	10	16	11
140-145	7	7	9	5	3	2	246	213		7	2	5	9	6	5	12	3	10
145-150	2	1	7	2	4	0	81	68		2	5	2	2	1	1	2	4	1
150-155	2	3			1	1	27	22			1				2		1	
155-160							4	3										
160-165							0	1										
165-170							0	0										
TOTAL PER TOW	82	88	89	85	92	83	3323	3356	0	88	93	94	89	86	86	86	95	104
BUSHELS MEASURED	1	1	1	1	1	1	35	35		1	1	1	1	1	1	1	1	1

SKATE LENGTHS (CM) DILIGENCE-20N *Experimental Dredge ON POH C= Control Dredge*

TOW #	8	8	9	9	11	11	12	12	13	13	19	19	20	20	21	21	23	23	25	25	27	27	31	31	33	33	35	35	37	37	41	41	44	44	46	46	48	48	50	50	TOTAL	TOTAL
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
6-10																																									0	0
11-15								1																																	0	1
16-20																																									0	0
21-25												1		1								4				1				1	1			1		1	1	1			2	11
26-30						1				1		1	1			2			1					1			1	1	2	1		1			1		2		1	1	10	9
31-35								4	1			1			2	2	1		2	1	1				1	1		2	3			1	1	2	1	1		1	1	1	2	16	17
36-40	1	2				2	2		1	1		1		2	4		1					4	2	3				3	2		1	1	1			1	2		1	1		22	17
41-45	16	14	15	19	18	15	18	18	19	15	12	15	18	19	12	16	13	12	14	15	11	8	15	15	13	11	9	9	14	15	13	13	14	7	11	6	5	11	10	10	270	263
46-50	2	3	10	6	7	6	5	2	4	8	12	6	6	5	5	5	6	8	3	4	4	6	6	4	6	7	5	4	5	3	4	5	4	11	6	5	6	2	2	3	108	103
51-55																																									0	0
TOTAL MEASURED	19	19	25	25	25	24	25	24	25	25	24	25	25	27	23	25	21	20	20	20	20	20	25	20	20	20	20	20	20	20	21	20	20	20	20	14	15	16	15	16	428	420

TOW #	59	59	61	61	62	62	63	63	64	64	71	71	72	72	73	73	74	74	76	76	84	84	85	85	86	86	TOTAL	TOTAL
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
6-10																											0	0
11-15																											0	0
16-20															1												1	0
21-25	2	1					3	1			2	2			2	1			1	1		2					10	8
26-30	1		1								1	1			1	3				2		1					4	7
31-35	2	2									1	2				1			1		1	1			1	1	6	7
36-40	1														2	2			2		1						6	2
41-45	11	13	3	6			10	12			5	4			13	5			8	9	7	4			5	8	62	61
46-50	3	4	6	4			2	2			1	1			1	8			3	3	1	2			4	1	21	25
51-55																												
TOTAL MEASURED	20	20	10	10	0	0	15	15	0	0	10	10	0	0	20	20	0	0	15	15	10	10	0	0	10	10	110	110

MONK LENGTHS (CM) DILIGENCE-200 *Experimental Dredge ON POF C= Control Dredge*

TOW #	8	8	9	9	10	10	11	11	12	12	13	13	19	19	20	20	21	21	22	22	23	23	24	24	25	25	26	26	27	27	28	28
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
21-25																	1						1					1				
26-30						1									1																	
31-35	2	1		1		2						1			1	1				1	1				1					1		
36-40																1	2														1	
41-45	2	2			2			1	1										1											1		
46-50											1				1																	
51-55																																
56-60																															1	
61-65										1																	1		1			
66-70																							1									
71-75												1	1		1	1	1															
76-80																																
81-85																																
86-90																																
91-95																																
96-100																																
101-105																																
106-110			1																													
TOTAL MEASURED	4	3	1	1	2	3	0	1	1	1	1	2	1	0	4	3	4	0	1	1	1	0	2	0	1	0	1	1	1	2	2	0

TOW #	31	31	32	32	33	33	34	34	35	35	36	36	37	37	38	38	39	39	40	40	41	41	44	44	45	45	46	46	47	47	48	48	49	49	50	50	51	51	58	58	TOTAL	TOTAL
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
21-25	1					1			1								1	1											1												6	3
26-30					2						1															1					1				1		1			1	7	3
31-35					1	1	1					1		1	1		1		1		1									1									1	1	12	13
36-40						1		1			1								1		1	1			1													2			7	6
41-45												1			1																			1				1			7	7
46-50	1																												1		1		1					1			6	1
51-55			2																				1												1						4	0
56-60																																									1	0
61-65											1								1																	1					4	2
66-70											1						1																1								4	0
71-75																									1						1		1								6	2
76-80	1									1																			1												2	1
81-85																																									0	0
86-90																																									0	0
91-95																																									0	0
96-100																																									0	0
101-105																																									0	0
106-110																																									1	0
TOTAL MEASURED	3	0	2	0	3	3	1	1	1	1	4	2	0	1	2	0	3	1	3	0	2	1	1	0	2	1	0	0	3	1	3	0	3	1	2	1	1	4	1	2	67	38

TOW #		59	59	60	60	61	61	62	62	63	63	64	64	71	71	72	72	73	73	74	74	76	76	84	84	85	85	86	86	TOTAL	TOTAL
DREDGE		P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
21-25					2									1			1													1	3
26-30			1		1	1			3			1			1	1	3								1				1	3	11
31-35										1								1			1		1					1		3	2
36-40				2	1			1											1		1			1	1				1	4	5
41-45												1		1	1				1		1				1					2	4
46-50									1																				1	0	2
51-55															1					1				2	1	1				4	2
56-60																														0	0
61-65								1								1					1					1			1	3	2
66-70												1				1														2	0
71-75		1																									1			1	1
76-80																														0	0
81-85																												1		1	0
86-90																														0	0
91-95																														0	0
96-100																														0	0
101-105																														0	0
106-110																														0	0
TOTAL MEASURED	0	1	1	2	4	1	0	2	4	1	0	3	0	2	3	3	4	1	2	1	4	0	1	3	4	2	1	2	4	24	32

FLUKE LENGTHS (CM) DILIGENC *Experimental Dredge ON PORT SIDE C= Control Dredge*

TOW #	8	8	9	9	10	10	11	11	12	12	13	13	19	19	20	20	21	21	22	22	23	23	24	24	25	25	26	26	27	27	28	28
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
31-35								1	1			1		1					1	1	3						1	1	1	1	2	
36-40	1	1	1	2	1		1		1	2	3	2	3	1	1				1		3	4	1	1	1		1	1	3	3	4	1
41-45		2				1	1	1		1	1		1		1	1	2	1			2				1	1	2				1	3
46-50	1	2														1									2	1					2	
51-55											1		1																			
56-60																																
61-65			1																							1					1	
TOTAL MEASURED	2	5	2	2	1	1	2	2	2	3	5	3	5	2	2	2	2	1	2	1	8	4	1	1	4	3	4	2	4	4	10	4

TOW #	31	31	32	32	33	33	34	34	35	35	36	36	37	37	38	38	39	39	40	40	41	41	44	44	45	45	46	46	47	47	48	48	49	49	50	50	51	51	58	58	TOTAL	TOTAL
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
31-35		1							1	1											1		1									1	1		2	1	1		1		17	10
36-40	3	4		1	1		1	1	2	2	1		1		3		1	1	1		2		2	2					1	2	3	3		2	1		1		1		51	36
41-45	1		1		1	1							1	1									1							2							1		1		19	15
46-50	1	1												1			1						1				1											1			9	7
51-55																								1																	2	1
56-60	2																						1							1											3	1
61-65									2																												1				5	1
TOTAL MEASURED	7	6	1	1	2	1	1	1	5	3	1	0	2	2	3	0	2	1	1	0	3	0	6	3	0	0	1	0	1	5	3	4	1	2	3	1	4	1	3	0	106	71

TOW #		59	59	60	60	61	61	62	62	63	63	64	64	71	71	72	72	73	73	74	74	76	76	84	84	85	85	86	86	TOTAL	TOTAL
DREDGE		P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
31-35							1	3				1			2				1			1			1		2		1	5	8
36-40		1		1		2	2	1				2	1	1	2	2	1	1	1	1	2		2	1	2		4	2	1	15	18
41-45			1				1		1					2	1						1			1		1		2	2	6	7
46-50			1	1			1		1	1	1											2								4	4
51-55																					1								1	0	2
56-60																								1						1	0
61-65									1																					0	1
TOTAL MEASURED	0	1	2	2	0	2	5	4	3	1	1	3	1	3	5	2	1	1	2	1	4	3	2	3	3	1	6	4	5	31	40

4 spot LENGTHS (CM) DI *Experimental Dredge C= Control Dredge*

TOW #	8	8	9	9	10	10	11	11	12	12	13	13	19	19	20	20	21	21	24	25	25	26	26	27	27	28	28	31	31	32	32
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	S	P	S	P	S	P	S	P	S	P	S	P	S
11-15															1																
16-20																1										1					
21-25	1																														1
26-30		2			1								1		1										1						
31-35		1				1	1	2				1	1	1				1								1		1			
36-40					1				1										1	1	1			1			1	1			
TOTAL MEASURED	1	3	0	0	2	1	1	2	1	0	0	1	2	1	2	1	0	1	1	1	1	0	0	1	1	2	1	2	0	0	1

TOW #	33	33	34	34	35	35	36	36	37	37	38	38	39	39	40	40	41	41	44	44	45	45	46	46	47	47	48	48	49	49	50	50	51	51
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
11-15																																		
16-20											1								1										1					
21-25					1																										1			
26-30			1		1				1																	1	1							
31-35		1	1		3	3	4	2		1			3			1	2	1		1		1	2	2	1		1		2			2	1	1
36-40	1	1			4		1	2	1					1	1	1		1		1			4	1					1		2		3	
TOTAL MEASURED	1	2	2	0	9	3	5	4	2	1	1	0	3	1	1	2	2	2	1	2	0	1	6	3	1	1	2	0	4	0	3	2	4	1

TOW #	58	58	59	59	60	60	61	61	62	62	63	63	64	64	71	71	72	72	73	73	74	74	76	76	84	84	85	85	86	86	OTA	OTA
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
11-15																															0	0
16-20																			2					1							2	1
21-25													1	1									1								2	1
26-30	1		1	1	1		1	1				1		1						1	3	2	1	2							7	9
31-35	1	1	2		2	2			1	1	1	1				2		1	1	3	3		2	3		1				1	12	15
36-40	1			2	2			1		1		1				1		1	2	1			1	2		1		2		2	5	15
TOTAL MEASURED	3	1	3	3	5	2	1	2	1	2	1	3	1	2	0	3	0	2	5	5	6	2	5	8	0	2	0	2	0	3	28	41

SEA ROBIN LENGTHS (CM) DILIGENCE- *C= Control Dredge*

TOW #	8	8	9	9	12	12	13	13	19	19	20	20	22	22	23	23	24	24	25	25	26	26	27	27	28	28	31	31	32	32
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
16-20	1																													
21-25	2		1																											
26-30					1		1						2							1				1						
31-35			1		1		1		1				1		1		1							2		1	1	1	1	
36-40												1			1															
41-45					1																									
46-50																														
51-55																														
TOTAL MEASURED	3	0	2	0	3	0	2	0	1	0	0	1	3	0	2	0	1	0	0	1	0	0	0	3	0	1	1	1	1	0

TOW #	33	33	34	34	35	35	36	36	37	37	38	38	39	39	40	40	41	41	44	44	46	46	47	51	58	58
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
16-20																								1		
21-25																										
26-30	1																1									
31-35	1							1		1					1				1		1		1			
36-40																			1						1	
41-45																										
46-50																										
51-55																										
TOTAL MEASURED	2	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	2	0	1	0	1	1	1	0

TOW #	59	59	60	60	61	61	62	62	63	63	64	64	71	71	72	72	73	73	74	74	85	85	86	86
DREDGE	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
16-20																								
21-25															1				1					
26-30				1																	1			
31-35	1	1					1											1				1		1
36-40				1																				
41-45																								
46-50																								
51-55																								
TOTAL MEASURED	1	1	0	2	0	0	1	0	0	0	0	0	0	0	1	0	0	1	1	0	1	1	0	1