Final Report on a Project Designed to Reduce Damage to Sinking Groundlines by Adjusting Lobster Gear Hauling Equipment

Submitted to NOAA Fisheries
by

Richard Allen
R. B. Allen Associates
145 High St. # A
Westerly, RI 02891

Erin Burke, Protected Species Specialist

Daniel McKiernan, Deputy Director
Division of Marine Fisheries
251 Causeway St., Suite 400
Boston, MA 02114

Bonnie Spinazzola, Executive Director
Atlantic Offshore Lobstermen's Association
114 Adams Rd., Candia, NH 03034


Deval Patrick, Governor, Commonwealth of Massachusetts
Ian A. Bowles, Secretary of Energy and Environmental Affairs
Mary B. Griffin, Commissioner, Department of Fish and Game
Paul Diodati, Director, Division of Marine Fisheries

Table of Contents

List of Figures

List of Tables

Abstract

This project is a continuation of efforts to reduce the risk of entanglement of whales in offshore lobster lines. In particular, this project has the objective of identifying sources of rope wear that are related to trap hauler components and their adjustment. We conducted trials on 22 distinct hauler configurations. We catalogued, photographed, and shipped all of the usable rope samples to Southwest Ocean Services (SWOS) in Houston, TX for break-testing. The break-testing data has been organized and analyzed to determine the statistical significance of the observed differences in residual breaking strength from each treatment. Our total project trials produced 124 rope samples for break-testing. SWOS broke each sample twice except for the samples from the final four treatments, which were broken three times to increase our ability to determine the statistical significance of differences between the treatments.

The results of the majority of our treatments show statistically significant differences in rope deterioration depending on hauler configuration. Detailed results are presented in the body of this report in the form of t-test results with accompanying explanations.

The most noteworthy potential for a reduction in rope wear through hauler modification was demonstrated by the increase in residual breaking strength of sinking groundlines tested with 17” Hydroslave hauler sheaves compared to the 16” machined steel sheaves that we considered our standard hauler setup. **The Hydroslave stamped steel sheaves gave the best results of all of our hauler tests, producing a 30% increase in residual breaking strength of sinking rope compared to standard hauler sheaves.** Additional details on the differences between our hauler configurations are provided in the body of the report. **Our research leads us to believe that the surface smoothness of hauler sheaves (related to the machining process) is a critical factor in determining rope wear.** Our observations also indicate that the angle between hauler sheaves and the depth at which the rope rides in the sheaves, determined by sheave spacing, is an important factor in rope wear for variable angle sheaves like the Hydroslave stamped steel sheaves. To our knowledge, the relationship between machining ridges on hauler sheaves and rope wear has not received any previous attention. The same holds true concerning the importance of sheave angles and spacing.

Another key finding of our research is that sinking groundlines constructed from blended polyester and Polysteel © show greater loss of breaking strength compared to floating rope constructed of straight Polysteel © when used in machined steel trap haulers, regardless of the presence or absence of sediment. Some characteristic of the construction of blended fiber ropes apparently leads to a loss of strength that is attributable to the hauling process alone. Whereas the physical attributes of polyester and Polysteel © fibers are quite different in size, elasticity, and other factors, we assume that these factors affect the durability of the different ropes.

The prevailing wisdom has been that the shorter service life of sinking ropes is solely the result of sediment abrasion. That belief has guided efforts to improve the durability of sinking groundlines. Our discovery that sinking groundlines deteriorate faster than sinking ropes when hauled by standard, machined-steel hauler sheaves in the absence of sediment points to other approaches that might improve the service life of sinking groundlines. We consider this information to be important to rope manufacturers as they

continue to improve the durability of sinking groundlines. This series of tests established the relative importance of sediment in causing damage to groundlines[1] and also demonstrated the potential to improve rope longevity through hauler modifications.

This project represents the first time that load cell readings have been recorded to measure the force with which the rope pushes against the rope extractor, or splitter. We observed that the hauler configurations with the least rope damage also had the lowest splitter load cell readings. This finding is likely to be even more important in the field than it was in the lab because the force with which the rope pushes against worn splitters is likely to be a significant factor in rope damage caused by the splitters.

In summary, the results of this project provide information that fishermen can use to improve the performance of their trap haulers and information that rope manufacturers can use to improve the durability of sinking groundlines. These results are detailed in the body of this report. Notable results include the following:

1. Ropes show less rope wear from hauling when the surface angle of the sheaves is larger than the standard 4 degrees (8 degrees between the two sheaves). We have not determined the practical limit to this angle, which will require field-testing to determine the balance between reduced rope wear and adequate grip on the rope.

2. Ropes show less rope wear when variable angle sheaves are spaced closely together, thus keeping the rope closer to the rim of the sheaves where the angle is wider. Closer spacing of standard sheaves showed improved wear for floating rope but not for sinking rope. Wider spacing causes the rope to scuff across a wider surface of the sheaves as it is first squeezed into the hauler and then forced out by the splitter. The force with which the rope impinges on the splitter increases as the spacing between the sheaves and the depth of the rope in the V between the sheaves increases. When rope pushes harder against the splitter, strands are more likely to wedge between the splitter and the sheaves and to be cut by the sharp edges that are created as the rope wears a groove in the splitter.

3. Wear on sinking rope can be improved through the use of a splitter with a reverse curve on the edge that meets the rope. The reverse curve reduces the angle at which the rope impinges on the splitter, thus lifting the rope out of the V more easily.

4. Some characteristic of blended polyester/Polysteel © sinking groundlines makes them more susceptible to internal deterioration caused by trap hauling with standard, machined-steel sheaves, compared to groundlines made of straight Polysteel ©. Further research is warranted to determine the mechanism through which this deterioration occurs. No research has been done on straight polyester ropes to determine whether the problem is related to the durability of polyester or whether it is related to the blending of fibers. Possible factors include differential elasticity and fiber-against-fiber abrasion.

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[1] Tension Technology International (2007) concluded that surface abrasion, both external and internal, was the dominant cause of rope damage for a selection of used and tested groundlines examined visually and with scanning electron microscopy. TTI also concluded that damage to the internal structure of rope strands due to the abrasive effect of sediment was not a major contributor to damage, although it was seen.

Background

The Massachusetts Division of Marine Fisheries and the Atlantic Offshore Lobstermen's Association have worked since 2003 to identify durable sinking groundlines and understand the causes of groundline degradation and failure. We use a rope-wear simulator equipped with an offshore lobster trap hauler to reproduce and accelerate the wear that groundlines experience in the field. Prior to the initiation of this project, our research has focused on the rope itself as the main determinant of durability. This project responds to insights gained from our earlier testing of sinking groundlines that suggested that small changes to the hauling system may make substantial differences in rope longevity.

Figure 1. Trap hauler on offshore lobster boat showing rope leading into hauler through fairlead block. Disc at the bottom right of hauler exerts pressure on rope to prevent it from jumping out of hauler and is called a "pizza cutter."

This project will facilitate the transition to sinking groundlines by providing information to fishermen that will allow them to improve the serviceability of sinking groundlines through modifications and adjustments to lobster gear hauling equipment. The goal of this project is to evaluate how minor changes to lobster gear hauling equipment will affect the service life of non-buoyant (sinking) groundline.

We conducted trials to determine the affect of the following hauler configurations and adjustments on rope wear:

1. The angle between the hauler sheaves
2. The depth at which the rope rides in the hauler
3. The shape of the knife or splitter
4. The profile of the working surface of the hauler sheaves
5. The material from which the sheaves and knife are made

The following tasks were completed in carrying out this project:

1. Acquired two types of rope with which to conduct the testing: 1) Polysteel Atlantic Polysteel © floating rope that has been the prevailing standard for groundlines for the offshore lobster fleet; and 2) Everson three-strand blended polyester and Polysteel © sinking rope that has shown good durability in previous tests.
2. Acquired six styles of hauler sheaves: 1) standard 16" offshore machined steel sheaves with a constant 4-degree angle across the working surface; 2) machined steel sheaves with a moderately increasing angle across the working surface; 3) 17" stamped steel sheaves with a rapidly increasing angle across the working surface (Hydroslave sheaves); 4) machined steel sheaves with a variable angle surface profile identical in profile to the Hydroslave sheaves; 5) stamped steel galvanized sheave liners sold by Hydroslave for use with their 17" sheaves; 6) polyurethane sheaves in a variety of durometers.
3. Prepared two styles of steel line extractors (knives or splitters): 1) an off-the-shelf splitter that presents a straight, flat surface to the rope, and 2) a modified knife that reduces the angle at which the rope impinges on the knife.
4. Acquired a load cell and associated hardware to enable continuous recording of the force exerted on the knife by the rope.
5. Designed and fabricated a mounting system that allows the knife to pivot against the load cell.
6. Rebuilt the braking mechanism on the rope hauling simulator using ultra high molecular weight polyethylene to reduce rope wear caused by the braking mechanism.
7. Conducted 124 useable rope runs using a variety of sheave styles and spacer thickness for a total of 22 individual treatments. The first 18 treatments were conducted with no sediment in the simulator tank so that all of the observed rope wear could be attributed to hauler damage rather than sediment damage. The four final treatments were conducted with sediment in the simulator tank to more closely simulate actual hauling conditions in the field. Two of the final four treatments were intended to compare a modified configuration that is expected to reduce rope wear to the standard offshore hauler configuration. Another final treatment compared newly machined sheaves to sheaves that had been worn smooth through use. The final runs also included a trial of polyurethane sheaves that had been improved based on our experience in the earlier trials. These polyurethane sheaves still showed excessive wear under simulated offshore hauling conditions.
8. Photographed 124 rope samples for visual comparisons between ropes and to calibrate visual appearance with break-testing results.
9. Sent 124 rope samples to Southwest Ocean Services for break-testing to determine residual strength.
10. Analyzed relative loss of strength for each treatment.

11. Distributed preliminary results to the offshore lobster industry through the Atlantic Offshore Lobstermen's Association and through contacts with individual lobster boat owners and operators.

12. Partnered with the International Fund for Animal Welfare to acquire and distribute polyurethane hauler sheaves to inshore lobstermen for field-testing.

Methods

Line Testing Machine:

This project utilized a line-testing machine that simulates and accelerates some of the long-term wear and tear that is experienced by lobster trap groundlines under field conditions. The simulator has been in service since it was completed in January of 2004, having been designed and constructed for an earlier rope-testing project. The machine was designed by Richard Allen and fabricated by Rhode Island Engine Company of Narragansett, RI. The testing machine incorporates a tank that can be filled either with water or with sediment covered by water.

The testing machine simulates trap hauling by pulling a continuous loop of line through a trap hauler while a capstan maintains an opposite pull on the rope at the other end of the simulator. The simulator achieves its constant but adjustable tensioning of the sample through the use of a "bootstrap" hydraulic system. A bootstrap hydraulic system is the hydraulic equivalent of a balanced counterweight system such as an elevator. The counterweight helps the machinery to lift the elevator without the force that would be required to lift the elevator in the absence of the counterweight. In the same way, if two identical hydraulic motors receive equal hydraulic volumes and pressures, and are pulling against each other, neither will move unless one motor or the other gets a small assist. In the case of a bootstrap system, one of the motor shafts extends through the back of the motor and can be driven by a small auxiliary motor, which overcomes the otherwise equal pull and causes the entire system to move in one direction while maintaining the strain between the two larger motors. Whereas different hauler configurations create different torque arms on the hauler side of the simulator, adjustments to each of the hydraulic components is necessary to obtain the desired tension while keeping the rope moving in the desired direction.

In tests involving sediment, the simulator subjects non-buoyant test lines to a sand substrate representing a generalized offshore environment by allowing the line to lay in a relaxed (no load) state for a period of time within a 12-foot long basin of sand and water. The test line is then subject to a load typical of hauling offshore lobster gear from great depths by running the line between a 16" trap hauler and an 11" diameter drum working against each other. The cycle of simulated set and haul is repeated for a predetermined number of times and the line is then break-tested to provide a quantifiable comparison. The simulator/ tester is housed at a *Marine Fisheries'* facility in New Bedford, Massachusetts.

Figure 2. Trap hauling simulator.

Splitter Load Cell Measurements

For this project we fitted the simulator with a load cell that measured the force with which the rope pushed against the splitter. We assume that there is a higher likelihood of rope damage if the rope is pushing against the splitter with more force, which indicates that the rope is being forced out of the sheaves with more difficulty. The load cell was mounted in a bracket that was attached to the hauler frame. The splitter was mounted with one bolt, which allowed it to pivot against the load cell. The actual pivoting movement of the splitter was imperceptible. The load cell readings are intended to serve as an index that allows comparison between different hauler configurations, not necessarily to indicate the actual force exerted by the rope on the splitter. The fact that the load cell is directly opposite the point of contact of the rope, creating approximately equal torque arms for the load cell and the rope, should mean that the load cell reading approximates the actual force of the rope. The splitter was mounted in a close fitting bracket that allowed the pivoting movement but prevented sideways movement. We used an Omega Engineering, Inc. LC302-500 submini stainless steel load cell with a 500 pound capacity. This load cell had an accuracy of +/- 0.5%, or +/- 2.5 pounds. We experienced numerous failures of the load cell. We observed that the load cell experienced noticeable drift over time. We obtained useful information from the splitter load cell, but it was not consistent throughout our trials.

Figure 3 The force of the rope against the splitter was measured with a load cell mounted against the back of the splitter. The splitter was mounted with one bolt, which allowed it to pivot imperceptibly against the load cell. Any sideways movement of the splitter was constrained by the close-fitting bracket. The load cell was connected to a computer which recorded the splitter force at one second intervals.

<u>Testing Protocols:</u>

This project utilized a testing protocol that consisted of 125 test cycles or simulated hauls for all of the treatments except the final four, which subjected the rope to 250 simulated hauls. The initial treatments were shortened for the purpose of gathering more data on potential improvements that were later subjected to more intensive testing based on the preliminary results. All tests were conducted with a target line-load of approximately 1252 pounds. This line-load represents the average hauling load of a 40-trap offshore trawl from approximately 190 fathoms depth, as determined by field measurements obtained by the NOAA Fisheries Gear Research Team by attaching archiving load cells to the gear during operational hauls (Salvador and Kenney, 2002). The choice of 250 simulated hauls was based on the average number of hauls of offshore lobster gear was derived from survey results that indicated that offshore lobstermen haul their gear as many as 50 times per year, and that trawls configured with floating groundlines have an average lifespan of approximately 5 years. This load does not represent the maximum load to which groundlines might be subjected, but approximates the high end of the expected average load range.

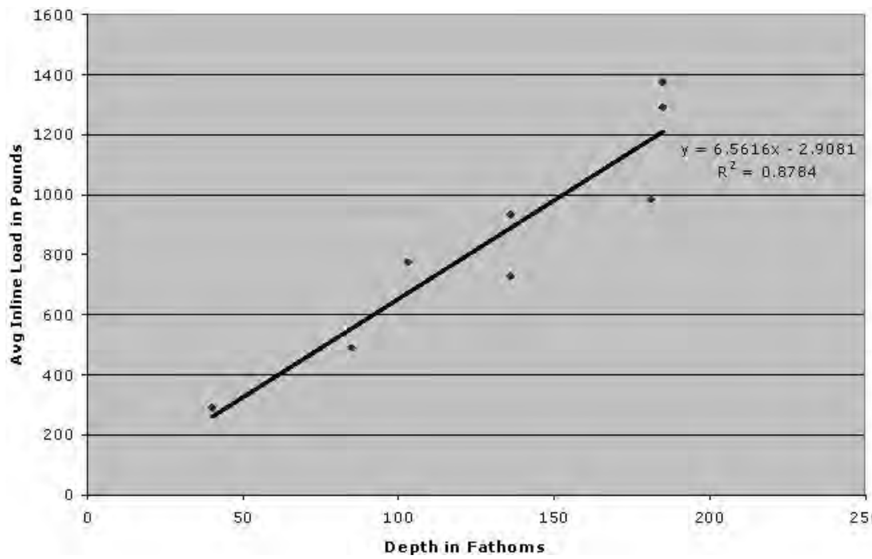

Figure 4. NOAA Fisheries Gear Technology Team data showing relationship between average hauling load and depth of set for offshore lobster gear.

Figure 5. Computer connected electronic load cell attached to groundline on simulator to measure in-line tension in rope running on the simulator.

For this project, line-load was monitored during the test run by running the line over a levered fairlead roller that was attached to a load cell. Load values were recorded to a computer. The load readings from the levered fairlead were calibrated by comparisons between the levered load reading and in-line loads measured directly by using line clamps to secure an electronic load cell in-line and running it between the brake drum and pot hauler. The in-line load was determined by taking the average of 3 consecutive load values obtained under the same simulator settings.

For this project we performed additional calibration between the in-line load and the levered fairlead load by utilizing a second load cell and taking measurements simultaneously. This calibration confirmed a levered fairlead reading of 280 to achieve our target line tension of 1252 pounds.

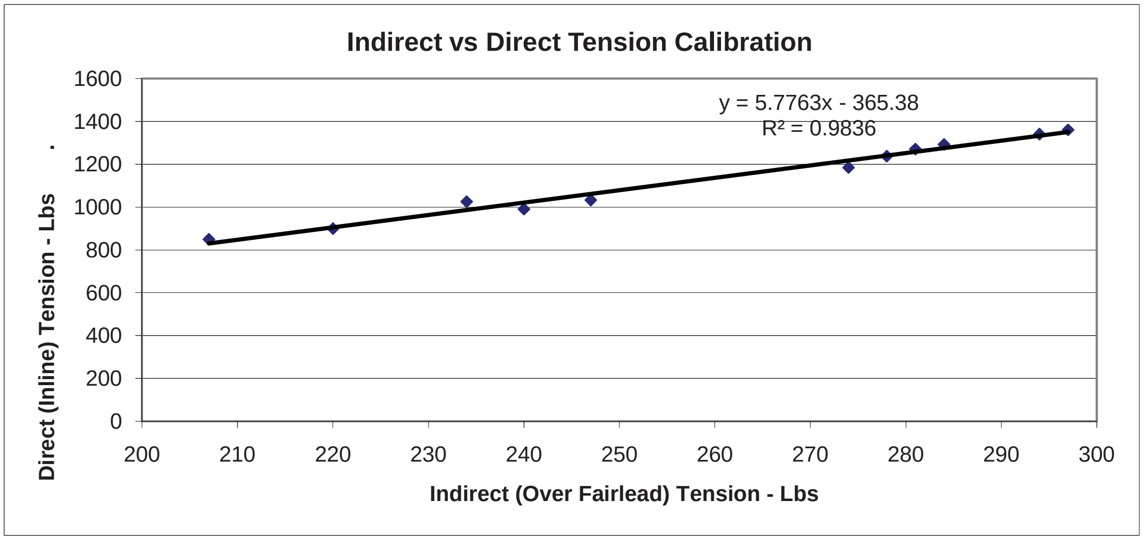

Figure 6. Regression showing indirect tension measurement using levered fairlead compared to direct measurement of in-line tension.

Table 1. Tension readings on fairlead load cell compared to in-line rope tension.

Fairlead	Inline
275	1223
276	1229
277	1235
278	1240
279	1246
280	1252
281	1258
282	1264
283	1269
284	1275
285	1281
286	1287
287	1292
288	1298
289	1304

290	1310

<u>Substrate Composition:</u>

The hauling simulator includes a stainless steel tank into which the rope falls after going through the hauler. Slack in the loop allows the rope to relax before being dragged across the tank and back into the hauling mechanism, where it is put under tension again. The tank is filled to a depth of 12”-14” with water. The tank is also filled with 6-8” of sediment for trials in which the effect of sediment is part of the treatment. In this project all of the trials except the final 16 (four treatments) were conducted with no sediment in the tank. The purpose of these trials was to focus on the impact of hauler configuration on rope wear, without the additional variable created by sediment. The final four treatments were conducted with sediment in the tank to determine the overall effect of the treatments on rope wear under simulated commercial conditions.

The range of grain sizes for bottom sediments on typical offshore lobster fishing grounds on the Atlantic coast of the U.S. was obtained from United States Geological Survey data. A mix of sand particles made up of masonry sand and silt was used to approximate the average bottom-type of the offshore environment for the treatments that included the effect of sediment. Particle size was quantified by running a sample of the substrate through a set of sieves, drying the separated sub samples, and weighing them for comparison. For the most part (>95% by weight) sand particles ranged in size between .0049” and .0787” in size (see Figure 5). A cell of water between 4 – 8 inches deep was maintained over the sediment.

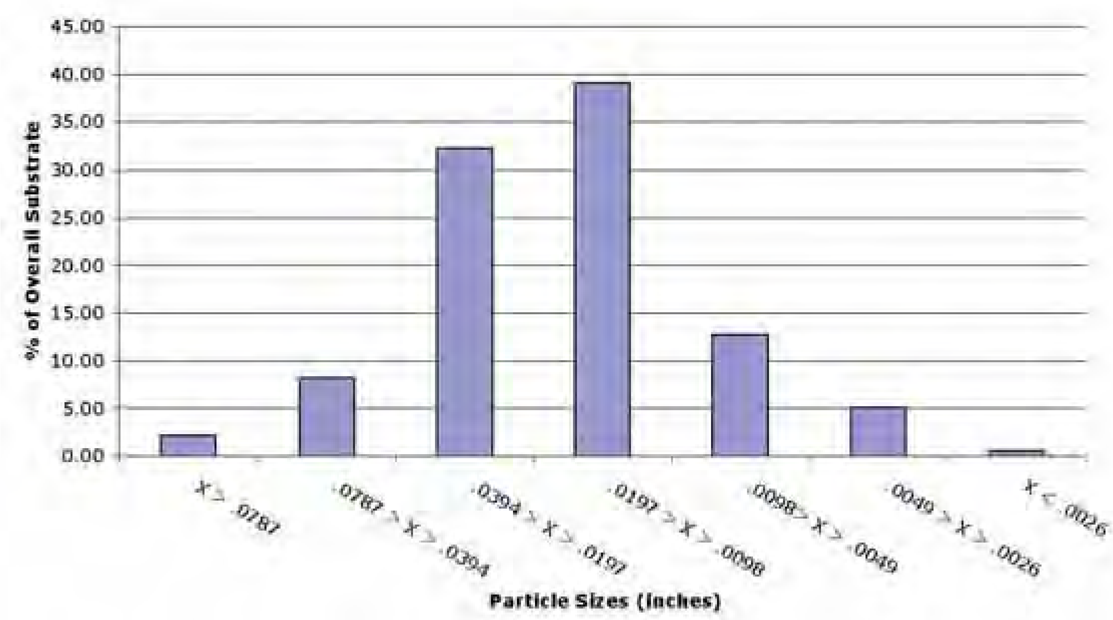

Figure 7. Substrate particle size distribution in the simulator tank.

<u>Testing:</u>

This project utilized samples of groundline ropes obtained through normal commercial channels. All treatments used two samples of floating rope (5/8" Polysteel Atlantic Polysteel ©) (denoted a) and two samples of sinking rope (5/8" Everson combination polyester/Polysteel) (denoted b). Samples were run in the order a,b,b,a or b,a,a,b for the purpose of equalizing any effect from the wear on the equipment during a treatment.

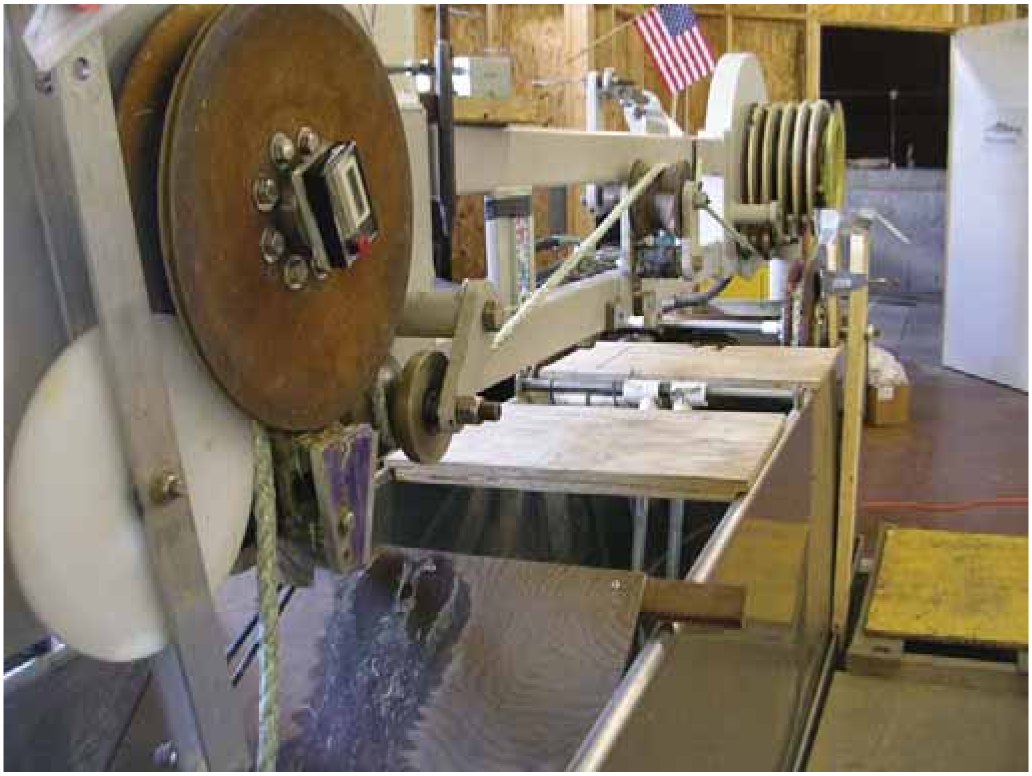

Figure 8. A test loop of groundline in the simulator.

Lines were mounted on the machine and spliced into a 47-foot loop using an elongated, tapered short splice. Three or four tucks with each whole strand were followed by two tucks in which one-third of each strand was cut away, creating a tapered splice. Previous experience demonstrated that normal short splices would fail prematurely when subjected to the short-term cycling under heavy tension that occurs on the simulator. Whereas our objective was to test the residual strength of rope samples that had undergone identical, prolonged simulated hauling cycles, we focused on making splices that would hold up through the entire run, rather than making splices typical of offshore lobster gear.[2] Our objective was to provide a consistent test for the groundline, not to test splices. If a splice did part prematurely, we re-spliced the rope and continued the treatment to the target

[2] It is important to note that our focus on consistent rope testing rather than typical gear construction leads to the possibility that field experience with comparable equipment may differ from the laboratory experience. For example, our hauler configurations may have maintained a better grip on our tapered short splices than would be the case with a more typical, un-tapered splice. Our test loops did not incorporate gangions, which create another potential cause for rope slippage or jumping that would not be evident in our tests. These considerations emphasize the need for field-testing to confirm the practicality of our results, particularly for the sheaves with variable surface angle, which are likely to require a balance between reduced rope wear and adequate grip on the groundline.

number of cycles. If the test loop was shortened due to re-splicing, the number of hauler revolutions per rope revolution was counted again and the target hauler count was adjusted to maintain the desired number of hauls.

At the beginning of each run, hydraulic pressure at the hauler, drum, and drive systems were adjusted to provide the correct load on the line as measured by the load cell at the levered center fairlead roller. Load cell readings and hydraulic pressures were monitored throughout each run to insure consistency.

Each test run took approximately 105 minutes to complete 125 hauls, depending on the effect of the configuration on the speed at which the rope moved through the simulator. The running time required for 250 cycles (simulating approximately five years of use), was approximately 3 hours and 25 minutes. The time to unload and load the simulator generally totaled about one hour, with additional time required when the hauler configuration was changed for a new treatment, requiring adjustment of the hauler components. Lines were spliced and the machine operated by either the staff of the *Marine Fisheries*' Gear Technology Group or by the Principal Investigator.   All operators maintained strict operating protocols and logged all pertinent settings and observations for each test run.

Test lines were photographed after each test run, prior to shipment to the tension-testing facility. Samples of the lines were kept at DMF and sent to Southwest Ocean Services in Houston, TX for tension testing.

<u>Tension Testing:</u>

Southwest Ocean Services of Houston, TX performed all of the tension tests on the rope samples from this project. Preliminary tension testing indicated that the breaking strengths of the samples were relatively consistent. Two breaks were performed on each sample from all of the treatments except the last four, which were subjected to three breaks each in the interest of improving our ability to detect statistically significant differences in residual breaking strengths.

<u>**Hauler Configuration Treatments**</u>

Table 4 lists the characteristics of the hauler components that were used in each of the treatments. Treatment 1 was intended to represent our version of the standard offshore trap hauler. Treatment 1 used 16" machined steel hauler sheaves with a constant 4-degree angle across the working surface and a standard Hydroslave splitter. The spacer between the sheaves measured 0.1", or slightly less than an eighth of an inch. Treatment 1 provided a baseline performance level against which we compared the other treatments in our first evaluation of the potential for improvements in rope wear through hauler configuration and adjustment. We then used the results of those initial comparisons to develop our final hauler configurations.

Readers should recognize that there is no true "standard offshore hauler" in the sense that all of the components of the haulers are identical. Offshore haulers differ primarily in the way the hub attaches to the motor shaft and the sheaves attach to the hub. Those differences should not affect rope wear. The majority of true offshore haulers use 18" machined steel sheaves, compared to 16" sheaves on the simulator. That difference should not affect comparisons between treatments run on the simulator. The differences in sheave diameters between the simulator and the fleet may affect the magnitude of any improvement in rope wear brought about by changes in hauler configuration, to the extent that diameter alone may have an effect. Offshore haulers also vary in the design and attachment of the rope extractor, or splitter. We used a splitter manufactured by the Hydroslave hauler company. The Hydroslave splitter is slightly wider at the tips than most offshore splitters, which we would expect to produce slightly better performance because of the slight reduction in the angle at which the rope impinges on the splitter. Splitters suffer from a high degree of wear in actual use and are the component of the hauling system that is most likely to cause acute damage, compared to the chronic damage that is inflicted by other components of the hauling system.

Our final hauler treatments had multiple purposes. First, we wanted to compare the performance of the configuration that appeared to provide the greatest improvement relative to the standard hauler configuration. We did not use the absolute best performing hauler configuration in our final treatments because we do not believe that offshore lobstermen would consider the standard Hydroslave sheaves that produced the least rope wear to be strong enough for sustained offshore use. For that reason, Treatment 19, which represents our best commercially practical hauler configuration, utilized standard thickness sheaves that were machined to match the surface profile of the Hydroslave sheaves. We recommend further research to determine the acceptability of Hydroslave stamped steel sheaves for the offshore lobster fleet.

It should also be noted that at the time we chose our best practical configuration we did not have quantitative break-testing results from the treatments that compared the standard steel splitter to the low angle of incidence splitter. Visual examination of the samples from those trials did not indicate any obvious improvement in rope wear with the low angle of incidence splitter. The quantitative results from break-testing have subsequently demonstrated that the low angle of incidence splitter does produce a statistically significant improvement in rope wear for sinking rope. That tells us that Treatment 19 might have shown even better results compared to Treatment 20 (the standard hauler and splitter configuration) if we had used the low angle of incidence splitter in Treatment 19.

Some treatments were abandoned before completion because it became evident that they would not produce usable results, either because the hauler configuration was eating up the rope or because the hauler components were showing excessive wear that would not be tolerable in commercial use. That was the case with our early trials of polyurethane sheaves. Our final trial of polyurethane sheaves used the hardest durometer material that we had available and showed some potential. We expect that further research with polyurethane formulations that will increase the service life of the polyurethane sheaves.

Results

New Rope Breaking Strength

Samples of new test ropes were sent to Southwest Ocean Services for break-testing to provide a baseline for measuring the loss of strength under the different treatments. The new rope breaking strength for our sinking rope was 8857 (SD 162, CI 401, N=3). The new rope strength of our floating rope was 8725 (SD 152, CI 377, N=3). Although the mean breaking strength of the new sinking rope was 132 pounds more than the mean breaking strength of the new floating rope, the difference is not statistically significant at the 95% confidence level – meaning that the variability in the observed break tests does not allow us to say with certainty that there is a real difference in the breaking strengths of the two ropes when new. The actual mean breaking strength of either rope type might have differed from our results if more samples of new rope had been broken. The overlapping confidence intervals tell us that there is some probability that the breaking strengths of the two ropes may be equal.

Visual observations make it clear that all of the characteristics of the sheaves and rope extractors (knives or splitters) work together to determine how much damage will be done to the rope by the hauling equipment. The statistical analysis of break-testing results make it equally clear that visual observations of rope deterioration do not tell the whole story, and can be misleading. Most noticeably, the break-testing results demonstrated that the residual breaking strength of sinking rope after testing is consistently lower than that of floating rope, even when the sinking rope appears to be in much better condition. The quantitative results also showed that some hauler configurations had a statistically significant effect on sinking rope when they did not have a statistically significant effect on floating rope.

T-tests that determine the statistical significance of calculated differences in residual breaking strength after running multiple samples of rope through two different hauler configurations are presented in Appendix I. The quantitative results are summarized in Table 2 and Table 3. Plain language summaries of our results are presented below.

Summary of Results

Table 2. Summary Results Table for Floating Rope Treatments.

Treatment	Mean Residual Breaking Strength	Compared to Treatment	Mean Residual Breaking Strength	Statistically Significant or Not	Abbreviated Description
1	7142	2	7324	No	Std Sheaves & Splitter cf Modif Splitter
1	7142	3	6606	Yes	Std Sheaves with 0.1" cf Same with 0.3"
1	7142	4	7855	Yes	Std Sheaves with 0.1" Spacer cf HS 0.1"
1	7142	5	8103	Yes	Std Steel cf to HS with 0.3" Spacer
8	8417	5	8103	Yes	HS No Spacer cf HS with 0.3" Spacer
1	7142	6	5761	Yes	Std Steel cf Var Angle Mach 0.2" Space
1	7142	7	7544	Yes	Std Steel cf Var Angle Mach No Spacer
1	7142	8	8417	Yes	Std Steel cf Hydroslave No Spacer
1	7142	9	7944	Yes	Std Steel cf Var Angle Mach No Spacer
7	7544	9	7944	Yes	Var Angle Machined No Space cf 0.1"
8	8417	9	7944	Yes	HS No Space cf Var Angle No Space
1	7142	10	7954	Yes	Std Steel cf HS with Galv Liners
1	7142	11	6823	No	Std Steel cf Std Steel with UHMWPE
1	7142	12	7438	No	Std Steel cf 47 Shore D Polyurethane
1	7142	13 & 14	7991	Yes	Std Steel cf 52 Shore D Polyurethane
1	7142	17	8000	Yes	Std Steel cf Var Angle Machined
1	7142	18	7394	No	Std Steel cf Var Angle Machined
8	8417	17	8000	Yes	HS cf Var Angle Machined
10	7954	8	8417	Yes	HS no liners cf HS with Galv Liners
10	7954	17	8000	No	HS liners cf Var Angle Steel
19	6342	20	5692	Yes	Var Angle cf Std Steel
20	5692	21	5445	No	Std Steel cf to Newly Machined
19	6342	22	6626	No	Var Angle Steel cf 65 Shore D PU

Table 3. Summary results table for sinking rope treatments.

Treatment	Mean Residual Breaking Strength	Compared to Treatment	Mean Residual Breaking Strength	Statistically Significant or Not	Abbreviated Description
1	6589	2	7124	Yes	Std Sheaves & Splitter cf Modif Splitter
1	6589	3	6406	No	Std Sheaves with 0.1" cf Same with 0.3"
1	6589	4	7862	Yes	Std Sheaves with 0.1" Spacer cf HS 0.1"
1	6589	5	7912	Yes	Std Steel cf to HS with 0.3" Spacer
8	8552	5	7912	Yes	HS No Spacer cf HS with 0.3" Spacer
1	6589	6	5381	Yes	Std Steel cf Var Angle Mach 0.2" Space
1	6589	7	7556	Yes	Std Steel cf Var Angle Mach No Spacer
1	6589	8	8552	Yes	Std Steel cf Hydroslave No Spacer
1	6589	9	7689	Yes	Std Steel cf Var Angle Mach No Spacer
7	7556	9	7689	Yes	Var Angle Machined No Space cf 0.1"
8	8552	9	7689	Yes	HS No Space cf Var Angle No Space
1	6589	10	8074	Yes	Std Steel cf HS with Galv Liners
1	6866	11	6824	No	Std Steel cf Std Steel with UHMWPE
1	6589	12	7158	Yes	Std Steel cf 47 Shore D Polyurethane
1	6589	13 & 14	7300	Yes	Std Steel cf 52 Shore D Polyurethane
1	6589	17	8137	Yes	Std Steel cf Var Angle Machined
1	6589	18	7774	Yes	Std Steel cf Var Angle Machined
8	8552	17	8136	Yes	HS cf Var Angle Machined
10	8074	8	8552	Yes	HS no liners cf HS with Galv Liners
10	8074	17	8137	No	HS liners cf Var Angle Steel
19	5609	20	4383	Yes	Var Angle cf Std Steel
20	4383	21	4405	No	Std Steel cf to Newly Machined
19	5609	22	5297	No	Var Angle Steel cf 65 Shore D PU

Table 4. List of hauler configuration treatments.

Treatment #	Sheaves	Angle	Spacer	Knife	Comments	Hauls
1	Std Stl**	4	0.1	Std Stl HS***	Use for standard steel sheave and std stl knife treatment	125
2	Std Stl	4	0.1	Modified-2****	Steel knife with reverse curve - low angle of incidence	125
3	Std Stl	4	0.3	Std Stl HS	Maximum sheave spacing trial	125
4	HS 17	Var	0.1	Std Stl HS	Hydroslave stamped steel 17" sheaves	125
5	HS 17	Var	0.3	Std Stl HS	Hydroslave stamped steel 17" sheaves	125
6	Mod Steel 1	Var	0.2	Std Stl HS	Modified machined steel sheaves with variable surface angle	125
7	Mod Steel 1	Var	0.1	Std Stl HS	Modified machined steel sheaves with variable surface angle	125
8	HS 17	Var	0	Std Stl HS	Hydroslave stamped steel 17" sheaves	125
9	Mod Steel 1	Var	0	Std Stl HS	Modified machined steel sheaves with variable surface angle	125
10	HS Liners	Var	0.11	Modified 1*****	Hydroslave stamped steel 17" liners, modif HS knife	125
11	Std Stl	4	0.125	UHMWPE	Std steel sheaves with ultra-high molecular weight polyethylene knife	125
12	47 Shore D	Var	0	Std Stl HS	Medium durometer polyurethane sheaves with standard steel knife	125
13	52 Shore D	Var	0	Std Stl HS	Harder durometer polyurethane sheaves with standard steel knife	125
14	52 Shore D	Var	0.165	Modified 1	Harder durometer polyurethane sheaves with modified steel knife	125
15	76 Shore A	Var	0.16	Std Stl HS	Soft green polyurethane sheaves showed excessive wear at 520 clicks	21
16	82 Shore A	Var	0	Std Stl HS	Soft polyurethane showed excessive wear, same rope as 15	148
17	Mod Steel 2	Var	0	Std Stl HS	Sheaves machined to match Hydroslave profile and smoothed	125
18	Mod Steel 2	Var	0.25	Modified 2	Sheaves machined to match Hydroslave profile and smoothed	125
19*	Mod Steel 2	Var	0.125	Std Stl HS	Sediment - sheaves modif to match Hydroslave, std HS knife	250
20*	Std Stl	4	0.03	Std Stl HS	Sediment - standard 4-degree sheaves, standard HS knife	250
21*	New Mach	4	0.03	Std Stl HS	Sediment - newly machined standard steel sheaves, standard HS knife	250
22*	65 Shore D	Var	0	65 Shore D PU	Sediment - polyurethane sheaves and reverse curve polyurethane knife	250

* Sediment in simulator tank.

** Standard Steel

*** Standard Steel Hydroslave Splitter

**** Hydroslave splitter modified to incorporate reverse curve on working surface.

***** Hydroslave splitter modified to incorporate reverse curve on working surface - thicker section.

Residual Breaking Strength Results

Twenty-two distinct hauler configurations were tested on the simulator. Some of the configurations provided data for multiple comparisons (e.g., the standard steel sheave with standard steel knife runs provided data that could be compared to other runs that used non-standard sheaves as well as runs that used non-standard splitters (knives)). A total of 124 rope samples were break-tested for residual strength following the hauling simulations. A total of 254 break-tests were done on the samples. 126 breaks were done on samples of floating rope (Polysteel Atlantic Polysteel ©), and 128 breaks were done on sinking rope samples (Everson 3-strand polyester/Polysteel combination).

Figure 9. Our observations indicated that the standard splitter can cause rope "bunching" similar to that seen in this picture under certain conditions. Bunching of the rope makes it more likely that a strand of rope will jam between the splitter and the sheaves.

Figure 10. Comparison of standard cast steel Hydroslave rope splitter (top) with modified splitter that incorporates a reverse curve for the purpose of reducing the angle at which the rope impinges on the splitter.

Treatment 1 used a hauler configuration comparable to the standard steel offshore hauler sheaves with a 4-degree surface angle and with a standard steel splitter or knife sold by the Hydroslave trap hauler company. Treatment 2 used the same sheaves with a steel splitter that had been modified to reduce the angle at which the rope impinges on the splitter (Figure 10). The modified splitter did not appreciably increase the residual breaking strength of floating rope, but the increase in breaking strength for sinking rope with the modified splitter was statistically significant.

Treatment 3 used a configuration similar to Treatment 1 except that the standard machined-steel hauler sheaves were separated by a spacer measuring 0.3 inches in thickness, the maximum practical spacer thickness that would allow the rope to sink deeply into the sheaves without bottoming out in the V between the sheaves or catching on the tip of the splitter. The wider spacing reduced the residual breaking strength of floating rope but did not have a statistically significant effect on sinking rope.

Treatment 4 utilized 17-inch steel Hydroslave hauler sheaves with a variable surface angle from the center to the rim (Figure 12). The Hydroslave sheaves have a curved profile when looked at from the side. Treatment 4 utilized a 0.1” spacer between the sheaves. It should be noted that the grip of the sheaves on the groundline is likely to vary with the angle between the sheaves. With variable angle sheaves, the angle at the point where the rope rides is determined by the spacer between the sheaves, which determines how deep in the sheaves the rope will ride. When compared to Treatment 1, our version of the standard steel offshore hauler, the Hydroslave sheaves produced a dramatic improvement in the residual breaking strength of both floating rope and sinking rope. The improvement for sinking rope was especially noteworthy, increasing from 6589 pounds after 125 hauler cycles with the standard sheaves to 7862 pounds with the Hydroslave sheaves. This is an improvement of approximately 20%. Note that the new rope breaking strength for our sinking rope was 8857 pounds.

The improvement in breaking strength for the Hydroslave sheaves held when the spacing between the sheaves was increased to 0.3”. The improvement was even more pronounced when the sheaves were mated with no spacer, forcing the rope to ride at the maximum distance from the center. The residual breaking strength for sinking rope tested with the Hydroslave sheaves with no spacer was 8552, a 30% improvement over the results with standard four-degree machined-steel sheaves.

Hydroslave sheaves have two characteristics that set them apart from standard machined offshore sheaves. First, the Hydroslave sheaves are stamped from sheet steel, which means that they do not have any ridges left from being turned on a lathe (Figure 13-15).

The second distinctive feature of Hydroslave sheaves compared to standard, machined steel sheaves is that the angle of the sheave surface increases from the center to the outer rim, meaning that the rope can be positioned to ride in a V with an angle between the sheaves that ranges from 10 degrees to approximately 16 degrees. This contrasts with standard offshore machined sheaves, which have a constant 4 degree surface angle.

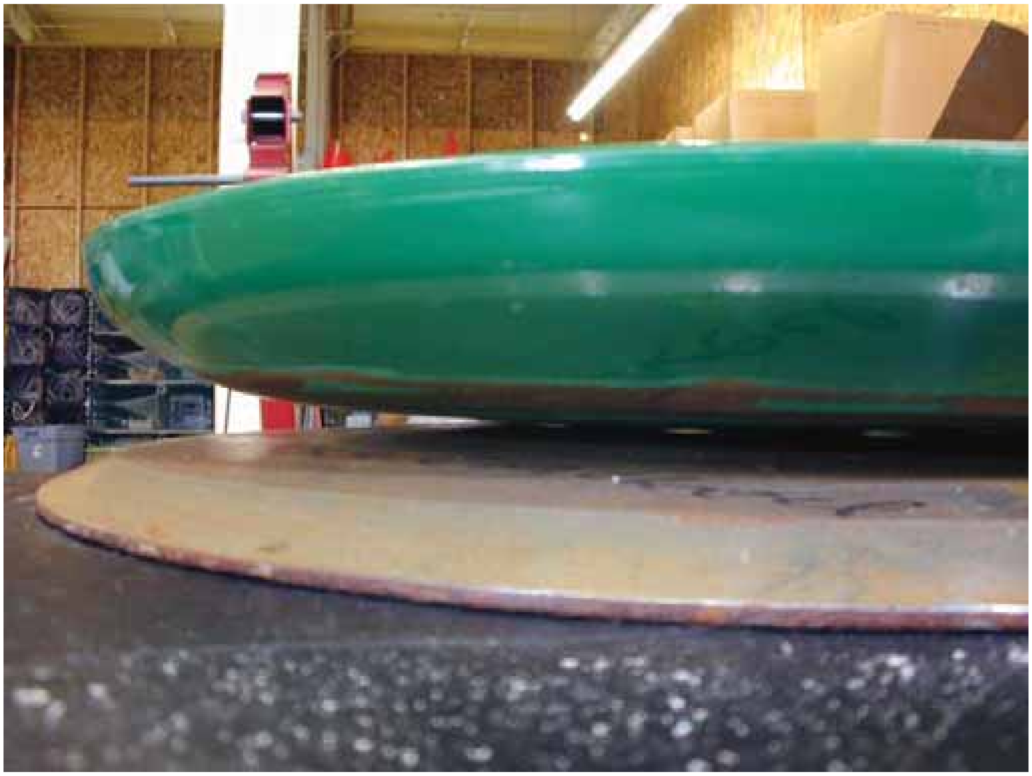

Figure 11. Hydroslave 17" sheaves (top) have a surface angle that is constantly increasing from the center of the sheave toward the rim, in contrast to the standard, machined offshore hauler sheaves (bottom). The standard sheave has a bevel at the outer rim, but the working surface is a constant 4-degree angle. When the Hydroslave sheaves are closely spaced, keeping the rope toward the rim, the surface angle where the rope rides is larger than the angle on the standard sheaves and can approach 8-10 degrees.

Figure 12. Slightly used Hydroslave 17" stamped steel sheaves next to machined steel sheaves. Hydroslave sheaves begin life with a smooth painted finish, which has been scuffed up in the picture above. Machined steel sheaves begin life with circumferential ridges left by the tooling. The depth and spacing of the machining ridges varies from machine shop to machine shop, and can be specified by the customer.

Figure 13. Two sets of machined steel sheaves showing differences in the circumferential ridges left by the lathe.

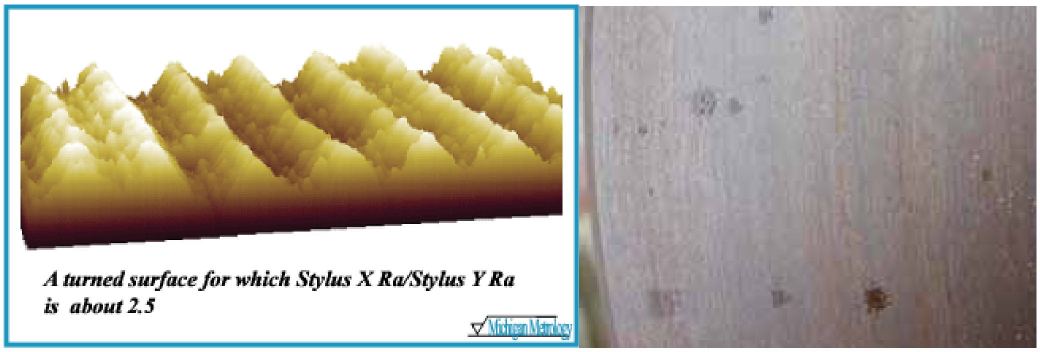

Figure 14. A computer generated blown-up image of a machined steel surface showing the rough surface left by the lathe (left). The hauler sheave on the right shows the distinct circular ridges left by the cutting tool on the lathe.

Based on the fact that standard offshore sheaves are 1 ¼" thick when new and are often retired with stress cracks when re-surfacing reduces their thickness to less than one inch, we assume that Hydroslave stamped steel sheaves that measure three-eighths inch in thickness when new would not be strong enough for sustained hauling in deep water on the offshore lobster grounds. Representatives of the Hydroslave Hauler Company tell us that fishermen are using their 17" stamped steel sheaves in water deeper than that in which lobsters are caught, with no strength problems. We are not aware of any large offshore lobsterboats that use Hydroslave hauler sheaves. We are aware of lobsterboats up to 50-feet in length that use Hydroslave haulers out to depths of 50 fathoms. Further research is necessary to determine the acceptability of the Hydroslave stamped-steel sheaves for larger boats fishing in the range of depths common for the offshore lobster fleet.

We note that three of the eight half-inch hauler bolt heads snapped off after approximately 14 hours of hauling with the Hydroslave stamped steel sheaves. Whereas we never snapped the head off a bolt when using the machined steel sheaves, we are led to wonder whether the relatively thin section of the stamped-steel sheaves did not distribute the load on the bolts as evenly as the thicker machined-steel sheaves, eventually causing the bolts to snap off.

Treatment 8 utilized the Hydroslave 17" variable surface angle sheaves with no space between the sheaves, keeping the rope riding as close to the rim as possible, given the 5/8" diameter of the rope and the angle between the sheaves.

It should be noted that Treatment 8 produced the highest residual breaking strengths of any of our hauler configurations. These impressive results must be tempered with the knowledge that the splice tended to pop out of the sheaves at times during this trial. The "pizza cutter" device kept the rope in the hauler, but it is quite likely that knots and splices would jump out of these sheaves with this close spacing under commercial use. The likelihood of slippage or popping out can be reduced by inserting spacers that widen the space between the sheaves, but trials with wider spacing showed greater rope wear (treatments 4 and 5). We believe that the grip of the sheaves on knots and splices toward the outer rim can be improved through further experimentation with the surface angle near the outer rim. The Hydroslave sheaves exhibit a radius at the outer rim that opens the angle rapidly, causing a loss of grip. A machined bevel with a shallower angle may maintain a better grip on knots and splices.

Figure 15. Front and side views of 17-inch Hydroslave stamped steel hauler sheaves that showed the least rope wear of any of our hauler treatments.

Treatment 6 utilized machined offshore sheaves that were machined with a variable surface angle, similar but not identical to the profile of the Hydroslave sheaves. No special effort was made to smooth the surface of these sheaves. The sheave spacing for Treatment 6 was 0.2”. The purpose of this trial was to duplicate the profile of the Hydroslave stamped steel sheaves on a set of machined steel sheaves, expecting the rope wear to improve relative to the standard profile offshore sheave and to be comparable to the improved rope wear seen in the trials that used the Hydroslave sheaves. Contrary to our expectations, the variable angle newly-machined sheaves produced more rope wear than the either the Hydroslave sheaves or the standard sheaves. These tests reinforced our conclusion that the roughness associated with the machining process is a significant factor in rope wear.[3] Although our standard offshore sheaves were machined, they had

[3] We learned during this project that the surface roughness that is created in the process of machining sheaves is important to rope wear. We did not have equipment to measure surface roughness so we were unable to quantify differences in sheave surface roughness. This variable complicates comparisons that are intended to measure the difference caused by factors other than surface wear. For example, the differences in performance indicated for Treatment 6 may be caused by differences in surface roughness rather than the intended comparison between a constant surface angle and a variable surface angle. In Treatment 19 we attempted to reduce the problem associated with surface roughness by instructing the machine shop to smooth the surface of the sheaves after machining them. One machine shop indicated that their sheaves were touched up with a grinder following the machining process to “rough them up.” Our experience indicated that smooth is better than rough and we expect that the grinding actually reduced the effect of the machining ridges and changed the orientation of the surface roughness from being circumferential to radial.

been used extensively compared to the newly-machined variable angle sheaves. Machine tool marks tend to be smoothed by use, which indicates that the rope is essentially sanding the sheaves smooth as the rope is hauled. We believe that considerable rope wear occurs in this process.

Readers should also note that the results reversed (the variable angle sheaves were better than the standard sheaves) when a 0.1" spacer was used between the variable angle sheaves.

Treatment 7 utilized the same machined sheaves as in Treatment 6, with a variable surface angle and a surface profile similar to the Hydroslave sheave profile. The sheave spacing for Treatment 7 was 0.1", keeping the rope riding closer to the rim of the sheaves in Treatment 7 compared to Treatment 6. Note that the performance of the standard sheaves and the modified sheaves reversed from Treatment 6 to Treatment 7, with the only known difference being the closer sheave spacing in Treatment 7. The variable angle sheaves may also have experienced some surface smoothing through use in Treatment 6.

The performance of the variable angle sheaves relative to the standard sheaves improved further when they were run with no spacer. The absence of a spacer causes the rope to ride as far out toward the rim of the sheaves as possible, given the diameter of the rope and the angle between the sheaves. Whereas the surface angle of the variable angle sheaves increases from the center toward the rim, rope that is riding further out toward the rim is also riding where the V between the sheaves has a wider angle.

The performance of the variable angle machined-steel sheaves did not equal the performance of the Hydroslave stamped-steel sheaves. We assume that the superior performance of the Hydroslave sheaves has to do with the smooth surface of the stamped-steel sheaves compared to the machined sheaves.

Treatment 10 utilized a set of Hydroslave 17" stamped steel sheave liners. These liners are commonly used with inshore trap haulers, but are seldom used in the offshore lobster fishery. The impressive performance of the Hydroslave 17" sheaves led us to experiment with the stamped steel liners to see if the liners produced more or less rope wear than did the Hydroslave sheaves without liners. We considered that knowledge to be important in advising inshore fishermen about the likely affect of hauler liners on rope wear, and in determining the future applicability of the liner concept to the offshore lobster fishery. The spacer between the liners measured 0.11" compared to 0.10" for the standard sheave spacing.

The liners showed an improvement in rope wear compared to the standard machined-steel sheaves, but less residual breaking strength than was observed with the Hydroslave sheaves without liners

Treatment 11 utilized a splitter machined from ultra-high molecular weight polyethylene – UHMWPE, in conjunction with standard, constant angle machined sheaves with 0.125" spacing. Only two samples were run with Treatment 11 and there was no significant

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Our observations indicated that rope suffers damage when it is scuffed across circumferential machining ridges as the rope is squeezed into the V-sheaves.

difference in the residual breaking strength of the samples from Treatment 11 compared to Treatment 1, which used the standard steel splitter.

Treatment 12 utilized polyurethane sheaves with a hardness, or durometer, designated as 47 Shore D, which might be characterized as a medium hardness. The configuration included a standard steel splitter and zero spacing between the sheaves. The 47 Shore D sheaves showed a statistically significant improvement in rope wear compared to standard machined-steel sheaves, but the sheaves showed excessive wear that would not mak e them practical for commercial use.

Figure 16. Treatment 11 utilized a low angle of incidence splitter machined from ultra-high molecular weight polyethylene.

Figure 17. 47 Shore D polyurethane sheaves showed excessive wear after a short period of simulated hauling.

Treatments 13 and 14 utilize polyurethane sheaves with a durometer of 52 Shore D, somewhat harder than the sheaves used in Treatment 12. These treatments were cut short because the polyurethane sheaves showed excessive wear early in the trial in order not to waste time and rope on a treatment that does not appear to have commercial application. Treatment 14 differed from Treatment 13 in the use of a modified steel splitter with a low angle of incidence. These treatments showed a statistically significant improvement in rope wear compared to the standard machined-steel sheaves.

Treatment 17 utilized machined steel sheaves that were machined to match the profile of 17” Hydroslave sheaves and were smoothed by sanding after machining. The purpose for machining sheaves to match the Hydroslave sheaves was to increase the strength of the sheaves for offshore use. 17” Hydroslave sheaves are approximately 3/8” thick. Standard offshore sheaves start their life with a thickness of 1 ¼”. They are usually retired when re-surfacing reduces their thickness to an inch or less. By that time they typically suffer from stress cracks around the bolt holes. This experience leads us to believe that the thinner Hydroslave sheaves are not likely to be accepted by offshore lobstermen for use in deep water with large boats. We may be wrong in that assumption because representatives of the Hydroslave Hauler Company assure us that their 17” sheaves have been used successfully in deep water without any problems with stress cracks. Our assumption that the stamped steel sheaves would not be adequate for sustained use in the offshore lobster fishery led us to have a set of steel sheaves machined to match the surface profile of Hydroslave sheaves that appears to extend the service life of groundlines. Treatment 17 differed from Treatments 6, 7, and 9 in greater care taken to match the profile of the Hydroslave sheaves and in surface grinding to smooth the ridges left by the machinist’s lathe. Treatment 17 used zero spacing between the sheaves based on earlier tests that showed the best performance of Hydroslave sheaves with no spacer. Treatment 17 used a standard steel splitter.

Treatment 17 showed a statistically significant improvement in rope wear compared to Treatment 1, the standard hauler set-up. This improvement held up for sinking rope when the modified sheaves were used with a 0.25” spacer and a modified splitter. The performance of the modified, variable angle machined-steel sheaves that were used in Treatment 17 did not equal the performance of the Hydroslave stamped-steel sheaves. We assume that this difference is caused by the superior surface smoothness of the stamped-steel sheaves compared to the machined sheaves.

There was no statistically significant difference in the performance of the variable angle machined-steel sheaves compared to the performance of the Hydroslave galvanized steel sheave liners.

Figure 18. Rope samples from Treatment 19, sheaves machined to match Hydroslave variable surface angle stamped steel sheaves. The aqua colored rope is Polysteel © floating rope and the gray rope is a blended polyester and Polysteel © sinking rope.

<u>Trials with Sediment</u>

Treatments 19 through 22 were conducted with sediment and water in the simulator tank in order to compare the treatments under conditions approximating actual operating conditions. These treatments were also extended to 250 simulated hauls to avoid the possibility that differences in rope wear might not be evident without extended testing. Each sample was broken three times to increase the statistical power of the comparisons between breaking tensions. Treatment 19 utilized the modified, machined steel sheaves with a surface profile that matches that of the Hydroslave sheaves, having a continuously increasing angle from the center to the outer rim. The spacing between sheaves was 0.125. A standard steel splitter was used for Treatment 19.

Treatment 20 utilized the standard, constant 4-degree angle machined steel sheaves with a 0.03” spacer and a standard steel splitter.

This comparison was intended to demonstrate the potential for improved rope wear using the configuration represented by Treatment 19. Treatment 19, the variable angle modified sheaves, showed a statistically significant improvement in the residual breaking strengths compared to Treatment 20, the standard offshore sheaves with a constant four-degree surface angle.

Figure 19. Variable surface angle machined steel sheaves that match the surface profile of Hydroslave stamped steel sheaves. With no spacer between the sheaves, the rope rides close to the outer rim where the angle between the sheaves is widening beyond the 4-degree angle of the standard offshore sheaves.

Treatment 21 utilized a newly machined pair of standard sheaves with 0.03” spacing and a standard steel splitter. This test was intended to determine whether newly machined sheaves tend to produce more rope wear than sheaves that have been used. In the absence of a surface roughness gauge, we had no way to determine any quantitative difference in the smoothness of the sheave surfaces. Contrary to our expectations, there was no statistically significant difference in the residual breaking strengths observed with the newly machined sheaves compared to the standard sheaves that had been worn smooth through use.

Figure 20. The four samples on the left are from Treatment 19, the variable angle machined sheaves. The samples on the right are from the standard, constant 4-degree angle machined sheaves. The samples on the left have a higher residual breaking strength that is statistically significant. Contrary to appearances, the breaking strength of the floating Polysteel © (light green) samples is higher than the residual breaking strength of the blended polyester/Polysteel © sinking rope.

Figure 21. Newly machined sheaves that have been finished with a rotary grinder show the vestiges of circular machining ridges as well as the radial marks of the grinder. These surface irregularities contrast with the smooth surface of Hydroslave stamped steel sheaves that showed the best performance in terms of reduced rope wear.

Treatment 22 utilized polyurethane sheaves with a durometers of 65 Shore D, the hardest polyurethane material that we tested. These sheaves have a surface profile that matches the Hydroslave sheaves. The spacing between the sheaves was zero. The splitter was molded with 65 Shore D polyurethane. Treatment 19 utilized steel sheaves that were machined with a variable angle surface that matched the Hydroslave surface profile. There was no statistically significant difference in the residual breaking strengths observed with the 65 Shore D polyurethane sheaves compared to the machined-steel sheaves with a surface profile comparable to the Hydroslave stamped-steel sheaves.

Figure 22. Images of harder durometer (65 Shore D) polyurethane sheaves after 14 hours of simulated hauling. Treatment 19 also utilized a splitter molded with 65 Shore D polyurethane.

Most of our tests were conducted with no sediment in the simulator tank to insure that the effects that we observed were attributable to the hauler component being tested, rather than rope damage caused by sediment. We were concerned that the magnitude of the damage caused by sediment would overwhelm the effect from the hauling system, thus masking the effect that we wanted to test. After completing our series of tests on hauler components and adjustment, however, we wanted to determine whether our conclusions would hold with sediment in the tank, which would more closely simulate actual hauling conditions. Table 50 in Appendix I shows that the addition of sediment to the simulator tank reduces the residual breaking strength of sinking rope by one-third, and that the results are statistically significant with a P value of 0.00000000035, meaning that there is virtually no probability that the results occurred by random chance. Table 51 shows that there was also a 24% reduction in the residual breaking strength of floating rope when sediment was added to the tank. It should be noted that the water depth over the sediment in the simulator tank was only four inches, so the floating rope contacted the sediment when it dropped from the hauler and was pulled through sediment filled water as it travelled from one end of the tank to the other. We hope to conduct additional trials with deeper water in the simulator tank to determine a more reliable quantitative difference in the performance of floating rope compared to sinking rope.

Splitter Force Results

All lobstermen realize that the hauler knife, or splitter, is potentially a trouble spot relative to rope wear. At the same time, cursory examination of hauling equipment in the fleet, along with personal experience, tells us that fishermen often assume that their splitter is okay as long as the rope is peeling off the hauler smoothly. That assumption may not be accurate. The performance of the rope extractor, or knife, depends on the shape and adjustment of the sheaves as well as the condition and fit of the knife itself.

For this project we fitted the simulator with a load cell that measured the force with which the rope pushed against the splitter. The load cell was mounted in a bracket that was attached to the hauler frame. The splitter was mounted with one bolt, which allowed it to pivot against the load cell. The actual pivoting movement of the splitter was imperceptible. The splitter was mounted in a close fitting bracket that allowed the pivoting movement but prevented sideways movement. We used an Omega Engineering, Inc. LC302-500 submini stainless steel load cell with a 500 pound capacity. This load cell had an accuracy of +/- 0.5%, or +/- 2.5 pounds. We experienced numerous failures of the load cell. We observed that the load cell experienced noticeable drift over time. We present the load cell data here with a warning that value differences of less than 5 pounds may not indicate true differences. This problem is particularly troublesome for the splitter force readings that were observed for the variable angle sheaves, where it was impossible to tell whether a force reading of less than three pounds might actually have been zero.

It appears that the biggest determinant of splitter force is the surface smoothness of the sheaves, which also appears to be the most important factor in rope wear.

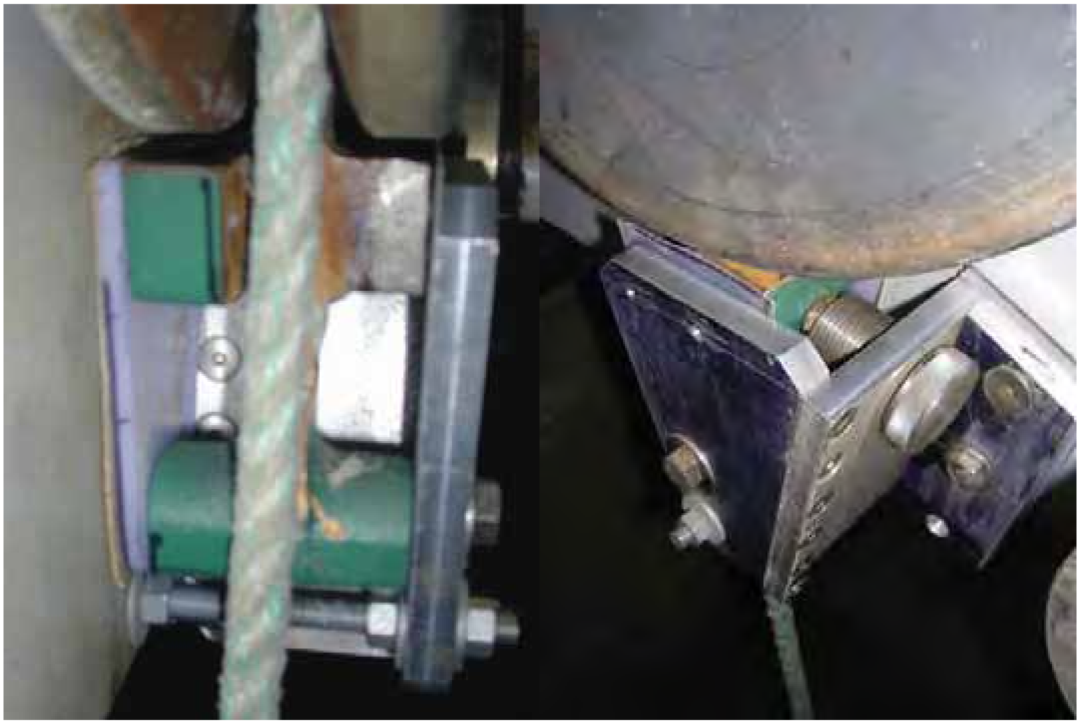


Figure 23. The picture on the left shows the rope being guided out of the hauler sheaves by the splitter. The picture on the right shows the load cell mounted behind the splitter on the hauling simulator. The knife was allowed to pivot on one bolt, exerting pressure against the load cell.

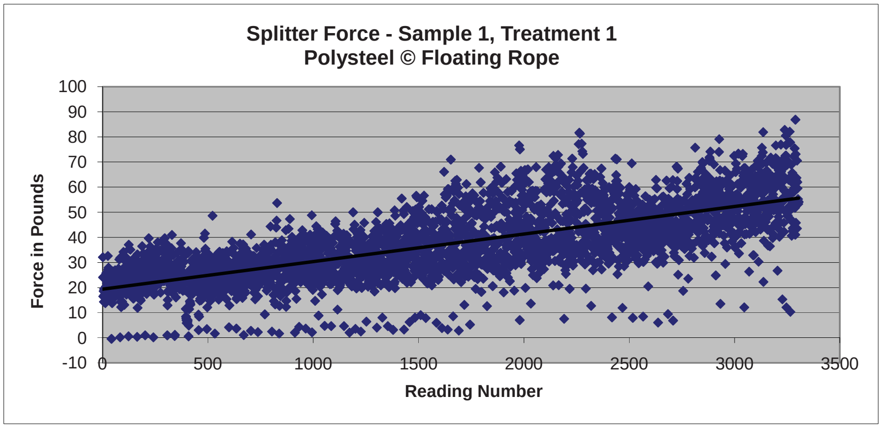
One of the most notable and visible differences between the runs with the variable angle sheaves and other hauler configurations was the lack of pressure against the splitter. Our observations of the rope peeling out of the sheaves during trials with the variable angle sheaves with no spacing indicated minimal if any pressure on the splitter. The rope did not contact the splitter within the radius of the sheaves; rather, the stiffness of the rope caused it to curl out of the sheaves with contact against the splitter outside the radius of the sheaves (Figure 24).

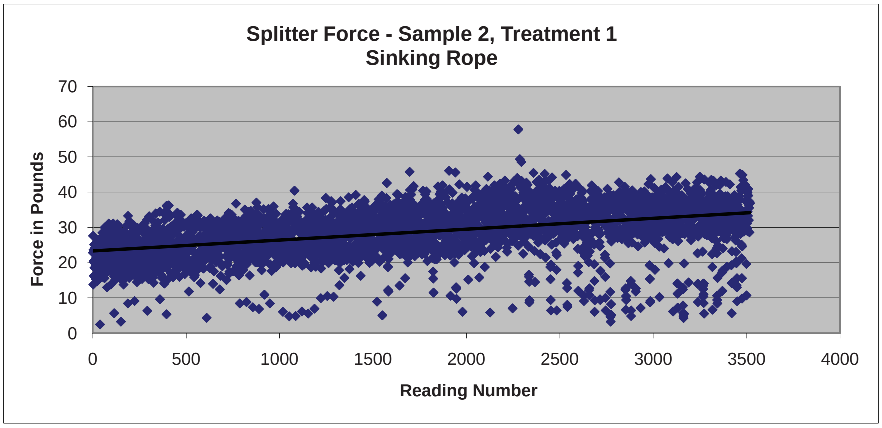
Figure 24. This picture shows clearly how the Polysteel © rope cleared the variable angle sheaves with no spacing without contacting the splitter within the radius of the sheaves.

Figure 25. Steel wedges force ropes out of the v-groove between the hauler sheaves so that the rope won't simply wind around the hauler. These rope extractors (commonly referred to as splitters or knives) are made in a variety of shapes. Splitters tend to wear rapidly, forming a groove with sharp edges. The splitter in the bottom half of this picture has a replaceable stainless steel wear plate. The condition and fitting of the splitter are critical to rope longevity.

One problem with properly sizing a load cell for this research was the unknown range of forces that we were likely to encounter. In practice we found that the force on the splitter varied from almost nothing to more than 100 pounds under normal conditions with different hauler configurations, and hundreds of pounds in excess of the 500 pound capacity of the load cell if the rope jammed in the hauler, as it did with some of our experimental configurations. Considering the indicated importance of splitter forces in determining rope wear, we will investigate more reliable load cells for this purpose for future research.

In general, we found that any rope extractor in good condition will remove the rope from the sheaves without acute damage if it fits the sheaves properly. However, we found that the force exerted on the knife by the rope is generally higher with the constant angle machined-steel sheaves than it is with the variable angle sheaves. We also found that the force against the knife often increased over the course of one run (**Figure 26**). We are not able to determine at this time whether the apparent increase is real, a function of load cell drift, or a combination of the two. Whereas the maximum drift that we noted did not exceed five pounds, any increase greater than five pounds is clearly real. Some runs did not demonstrate any increase in splitter force over the course of the run and some exhibited a slight decline.





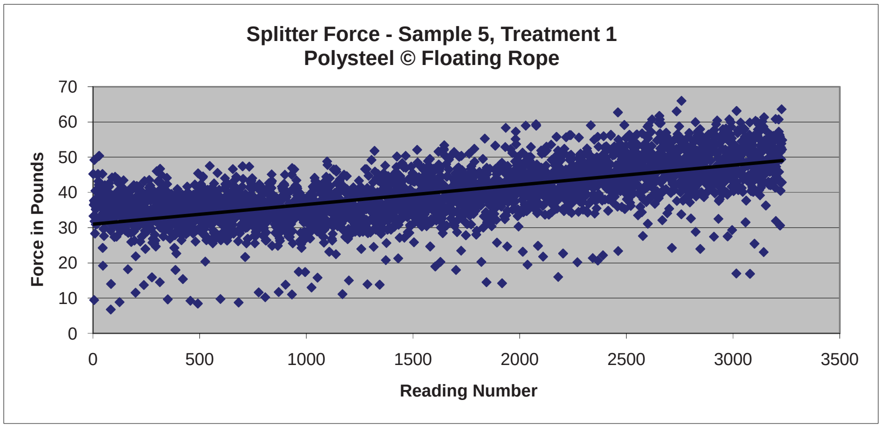
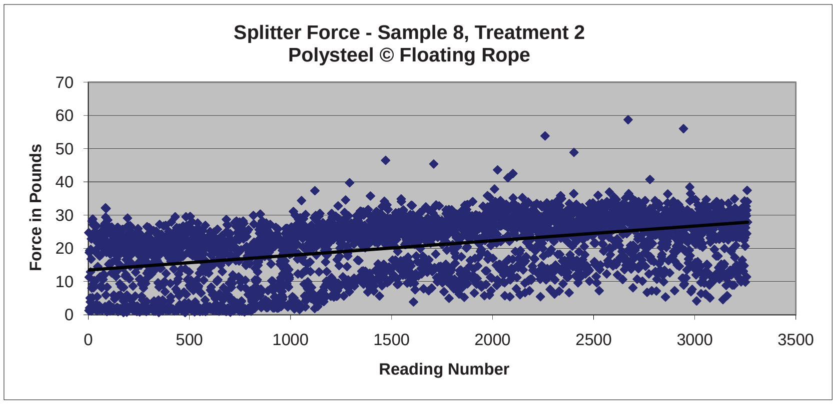
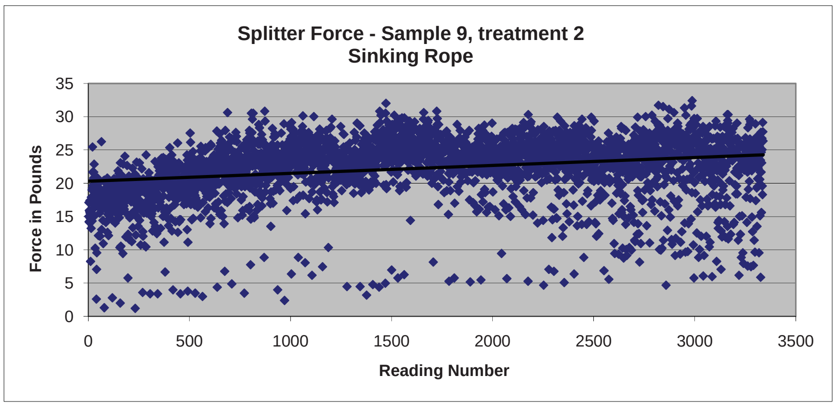


Figure 26. A graph of splitter force readings together with the trend line for the data points shows a continuous increase in the force required to push the rope out from between the sheaves over the duration of a test run of 125 hauling cycles. This data is from the runs 1, 2 and 5 (the load cell failed and the data from samples 3 and 4 were discarded). All of these runs used standard machined-steel sheaves with 0.1" spacing and a standard splitter. Note the lower starting point for run 1 compared to the others, and the steeper increase to a higher end point. Subsequent runs showed a higher mean force but with less of an increase from start to finish and a lower end point.





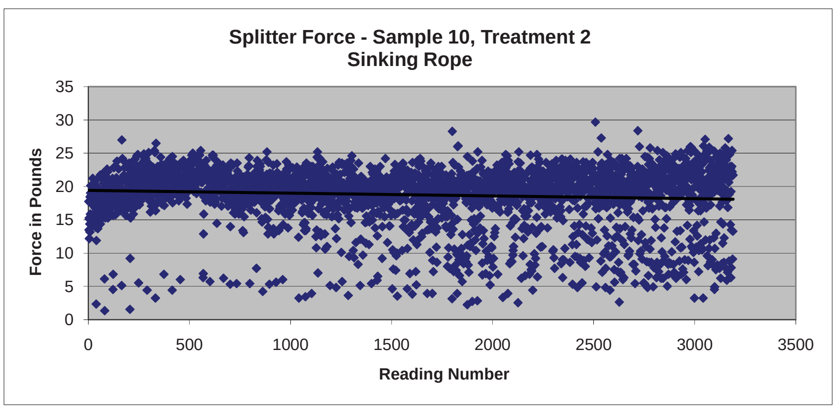


Figure 27. The mean force with which the rope pushes against the low-angle-of-incidence splitter is considerably less than that observed with the standard splitter and shows less of an inclination to increase from the beginning of a run to the end. These graphs represent data from the first three runs with the modified splitter (Treatment 2)

We assume that an increase in splitter force over the course of a run could be explained by the rope squeezing further between the sheaves as the rope wore out. The increasing roughness of the surface of the rope may have also increased the friction between the rope and the sheaves, increasing the force needed to push the rope out of the sheaves.

Higher splitter force indicates a higher propensity for rope damage, particularly as the knife wears and develops sharp edges along the wear groove. The curved profile knife showed lower load cell readings when the rope was riding deeper in the sheaves, leading to the conclusion that the curved profile knife would be friendlier to the rope under adverse conditions. Our testing was not designed to test the effect of worn splitters, but we can assume that hauler configurations that increase the force that is required to extract the rope from the sheaves will increase the potential for rope damage.

An interesting pattern of increasing force against the splitter load cell was apparently connected to the snapping of hauler bolts that occurred during the testing of sample 69 of Treatment 8, with no spacer between the Hydroslave stamped-steel variable angle sheaves. There is very little force on the splitter until the heads of the hauler bolts start snapping off. A total of three bolts snapped off, which probably allowed the sheaves to spread on one side and close up on the other, perhaps gripping the splitter in the process and increasing the reading on the load cell. Sample 69 was the last of eight runs with the same hauler set-up, which obviously created a lot of stress in the hauler bolts.

Table 5 shows a comparison of the splitter load cell readings with the rankings of the same treatments in terms of residual breaking strength. There is a clear correlation between lower splitter force readings and higher residual breaking strengths, with a few exceptions.

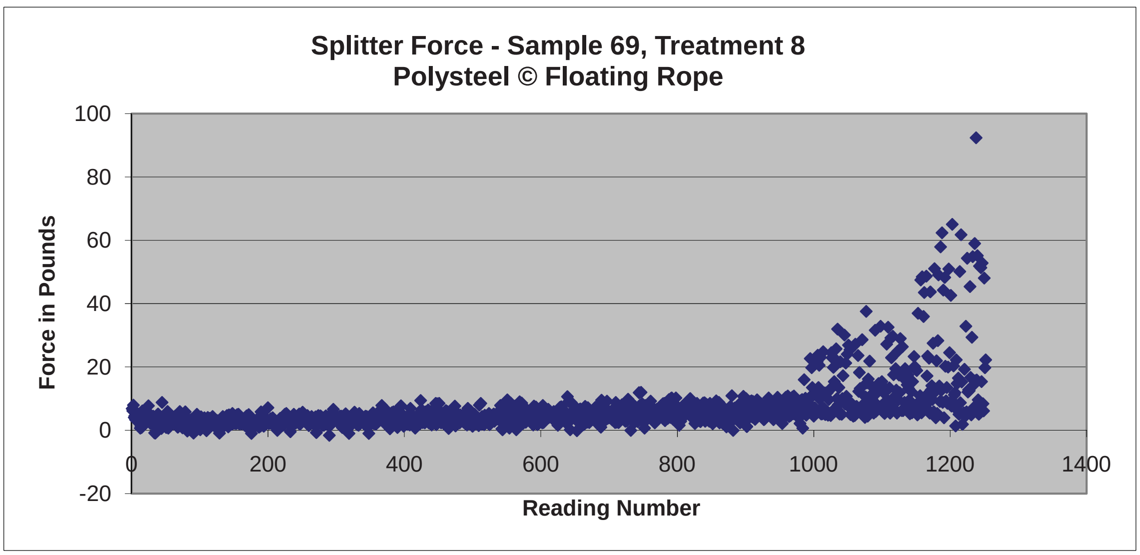


Figure 28. Sample 69 of Treatment 8 showed low splitter force readings until the heads of the hauler bolts started snapping off, at which time the splitter force readings increased dramatically with the loss of each bolt. A total of three of the eight hauler bolts snapped off during this run. Sample 69 was the last of eight runs with the same hauler set-up, which obviously created a lot of stress in the hauler bolts.

Table 5. Mean force readings for trials from which usable splitter force readings were obtained. The table is sorted in ascending splitter force. Note the low load cell readings for the closely spaced variable angle sheaves in Treatments 8, 9, and 17. We would expect that lower splitter load cell readings would indicate less potential for damage to the rope from the splitter. The breaking strength rank for these treatments generally follows the splitter force rankings, with some exceptions. All of these treatments were run through 125 hauler cycles with no sediment and rope tension of 1250 pounds. The mean breaking strength values are the combined floating and sinking rope averages for the indicated treatment.

Treatment #	Sheaves	Sheave Angle	Spacer	Splitter	Avg Splitter Force	Mean Residual Breaking Strength	Brk Strngth Rank
17	Modified Steel 2	Var	0	Std Stl HS	0.0	8068	2
8	Hydroslave 17	Var	0	Std Stl HS	5.4*	8485	1
9	Modified Steel 1	Var	0	Std Stl HS	5.8*	7817	5
5	Hydroslave 17	Var	0.3	Std Stl HS	12.7	8008	4
3	Machined Steel	4	0.3	Std Stl HS	15.6	6506	9
2	Machined Steel	4	0.1	Modified-2***	19.2	7224	6
1	Machined Steel	4	0.1	Std Stl HS**	34.7	6866	7
10	Hydroslave Liners	Var	0.11	Modified 1****	36.0	8014	3
11	Machined Steel	4	0.125	UHMWPE	38.2	6824	8
6	Modified Steel 1	Var	0.2	Std Stl HS	62.7	5571	10

* These readings may have been zero if sufficient data were available to calculate the force reading at rest

** Standard Steel Hydroslave Splitter

*** Hydroslave splitter modified to incorporate reverse curve on working surface.

**** Hydroslave splitter modified to incorporate reverse curve on working surface - thicker section.

The sheaves labeled “Modified Steel 2” were machined to match the profile of the Hydroslave stamped-steel sheaves and the surface was smoothed by sanding following the machining.

The sheaves labeled “Modified Steel 1” have a variable surface angle that does not flare as rapidly as the Hydroslave stamped steel sheaves. These sheaves were not smoothed after machining.

The label “var” indicates sheaves with a surface angle that increases from the center flat to the outer rim. The angle between the sheaves where the rope rides depends on the spacing of the sheaves – thicker spacers allow the rope to ride closer to the center where the angle is small. With no space between the sheaves the rope rides as close to the outer rim as is possible given the widening space between the sheaves with increasing radius.

Discussion

Most of our testing was done without sediment in the simulator tank because the objective was to test the impact of hauler components and adjustment on rope wear. We were concerned that the effect of sediment would mask the signal from the hauling system and would introduce an effect that might vary between floating and sinking rope. This procedure allowed us to detect differences in rope wear between floating and sinking rope that is related solely to the effect of the hauling system, rather than sediment. After completing the tests without sediment, however, we considered it useful to test both the standard hauler configuration and promising alternative configurations with sediment in the tank, so as to gain information that would be more applicable to actual hauling conditions. The testing with sediment did not change any of the conclusions that we reached based on our tests without sediment.

Testing without sediment revealed the surprising result that residual breaking strength for sinking rope samples were significantly lower than floating rope samples tested with the same hauler configuration, except for trials with variable angle sheaves with a smooth surface. Note that these results were obtained in the absence of sediment, which has commonly been assumed to be the sole cause of the shorter service life of sinking groundlines. The lower residual breaking strength of sinking rope was consistent throughout our tests, except for the tests with the Hydroslave stamped-steel hauler sheaves and the sheaves that had been machined to match the profile of the Hydroslave sheaves and smoothed after machining (Table 6). The exceptional performance observed with the Hydroslave stamped-steel sheaves did not occur in Treatment 5, which used Hydroslave sheaves with a 0.3” spacer, which allowed the rope to ride at a point where the angle between the sheaves was close to the standard 8 degrees, compared to the wider angle at which the rope rode in treatments with closer sheave spacing. The highlighted values in Table 6 indicate treatments for which the mean residual breaking strength of sinking rope was at least as high or higher than that of floating rope. **These results indicate that sinking rope is damaged more than floating rope when it is hauled through standard machined-steel hauler sheaves.**

It is easy to theorize about possible reasons for the greater loss of strength of sinking ropes compared to floating ropes when hauled through an offshore trap hauler. One possible cause could be fiber-against-fiber abrasion. Polysteel © fibers have greater elasticity than polyester fibers, which would mean that the polyester fibers in a blended rope would have stretched to a greater percentage of their maximum elongation than would the adjacent Polysteel © fibers under the same tension. This repeated stretching to a greater proportion of maximum stretch is likely to cause deterioration of the fibers. The Polysteel © fibers may also act as knives cutting into the polyester fibers as the two fibers stretch alongside each other.

It may also be the case that the polyester fibers stretch to their maximum under load, causing the fibers to break as the Polysteel © fibers continue to stretch. In other words, the fibers in the blended rope are not taking the strain evenly as are the fibers in the rope made from only one material. Additional research could test these theories by putting rope fibers under strain while being photographed at high speed. A rope testing lab could also separate the fibers from our rope samples to determine the relative loss in strength of the fibers in the blended rope.

A major problem with these theories is that they do not explain why the same superior strength retention of floating rope was not seen with the Hydroslave stamped-steel variable-angle sheaves. **The fact that the Hydroslave sheaves produced similar results with both floating rope and sinking rope leads us to conclude that the lower residual breaking strength for sinking rope that was observed with machined-steel sheaves has to do with either greater susceptibility to abrasion from the sheave surface for the sinking rope, or greater internal damage caused by the tighter squeeze placed on the rope by the narrower angle of the machined-steel sheaves.**

Further research is necessary to determine why sinking rope shows greater deterioration than floating rope when hauled with machined-steel sheaves, even in the absence of sediment, but does not show any greater deterioration than floating rope when hauled with Hydroslave stamped-steel sheaves. We are currently using National Fish and Wildlife Foundation funding to have a set of machined-steel sheaves made with a process that gives a smooth surface. These sheaves will also have a modified bevel near the outer rim to improve the grip on knots and splices compared to the Hydroslave stamped-steel sheaves or the machined-steel sheaves that we had made to match the profile of the Hydroslave sheaves. Preliminary field-testing with the sheaves that were machined to match the Hydroslave profile indicated a problem with knots and splices jumping out of the hauler.

Table 6. The highlighted cells indicate Treatments for which the residual breaking strength of sinking rope was as high or higher than floating rope. Treatment 4 used Hydroslave sheaves with 0.1" spacing, Treatment 8 used Hydroslave sheaves with zero spacing, Treatment 10 used Hydroslave galvanized sheave liners with 0.11" spacing and a modified splitter, Treatment 17 used variable angle sheaves machined to match the Hydroslave sheaves and smoothed after machining with zero spacing, and Treatment 18 used the same machined sheaves with 0.25" spacing and a modified splitter.

Treatment	Floating	Sinking
1	7142	6589
2	7325	7124
3	6606	6406
4	7856	7862
5	8104	7912
6	5762	5381
7	7544	7074
8	8417	8552
9	7945	7689
10	7954	8074
11	7344	6304
12	7439	7158
13	8111	7300
14	7872	
16		6803
17	8000	8137
18	7394	7774
19	6342	5609
20	5693	4383
21	5446	4405
22	6627	5297

Table 7. Both the one- and two-tailed t-tests show that there is a statistically significant and higher residual breaking strength for all floating rope samples compared to sinking rope samples from all of our hauler configurations other than those which used the Hydroslave stamped steel sheaves. These results are for tests done without sediment in the tank, so the difference in breaking strength is due to factors other than sediment intrusion.

All treatments without sediment and not using Hydroslave stamped steel sheaves	*Float*	*Sink*
Mean	7307.179	7037.65
Variance	524520.7	677943.5
Observations	78	80
Pooled Variance	602215.6	
Hypothesized Mean Difference	0	
Df	156	
t Stat	2.1827	
P(T<=t) one-tail	0.015277	
t Critical one-tail	1.65468	
P(T<=t) two-tail	0.030553	
t Critical two-tail	1.975287	

This research has provided additional valuable insights into the sources of rope wear that reduce the service life of offshore lobster groundlines. At the outset of the DMF/AOLA rope testing program, it was commonly assumed that the relatively shorter life of sinking groundlines was caused by sediment intrusion into the rope strands and the resulting internal abrasion. During the first phase of the rope testing project, experienced rope engineers conducted a microscopic visual examination of used groundlines (TTI 2007) and concluded that: "Damage to the inner structure of the rope strands, due to the abrasive effect of sediment was not a major contributor to damage, though it was seen …" TTI (2007) reported that "surface abrasion, both internal and external, is the dominant mechanisms [*sic*] for damage to the ropes." We would expect surface abrasion to be greater when the groundline carries sediment particles into the hauling mechanism, regardless of the degree to which the sediment finds its way into the inner structure of the rope. In this project we determined that damage from sediment caused a 33% loss in residual breaking strength of sinking rope compared to the same rope and hauler set-up run without sediment. Whereas TTI did not find a significant degree of sediment intrusion in machine-tested rope samples, we attribute the loss of breaking strength with sediment to the effect of sediment on external abrasion.

TTI (2007) also reported that "the effect of pressure is also clearly seen, particularly on inner faces of strands, where deformation and material flow can be seen. The PP filaments, with their lower melting points, were seen to be more susceptible to the effect of pressure than were the polyester filaments." A valuable conclusion that results from the testing with and without sediment is that a significant portion of the

loss in service life that results from the switch from floating rope to sinking rope may be recovered through improvements in hauler configuration. We assume that these improvements result from a combination of factors, such as reduced pressure on the rope and reduced surface abrasion caused by the hauler itself. We observed a gain of 30% in the residual breaking strength of sinking ropes tested with the Hydroslave stamped steel hauler sheaves compared to standard machined steel

hauler sheaves. When tested without sediment, the residual breaking strengths of sinking rope tested with the Hydroslave stamped steel sheaves was higher than the residual breaking strength of floating rope, although the difference was not statistically significant at the 0.05 level. Taken together, these results indicate that improvements in the hauling system have the potential to regain a portion of the service life of groundlines that would otherwise be lost in the switch from floating rope to sinking rope.

The most important results from our work include the following observations.

The smoothness of the surface of the sheaves is critically important. This is a factor that we had not considered when we developed our proposal. Essentially 100% of offshore hauler sheaves are machined from steel discs to produce the standard four-degree surface angle (eight degrees between the two discs).

The machining process leaves ridges on the surface of the steel. Some machine shops finish the surface by sanding or grinding, others do not. The smoothness of the finish on different sheaves may vary within the same machine shop. This is an issue that appears to be the subject of some confusion. One machinist remarked that the purpose of grinding the sheaves after machining was to "rough them up," apparently believing that a rough surface was necessary to insure adequate grip.

Figure 29. Standard machined-steel offshore lobster sheaves are characterized by a constant 4-degree angle across the working surface. Sheaves are likely to have a bevel of varying dimensions at the outer edge.

Our observations indicate that smooth is definitely better than rough in terms of rope wear. The only problem that we noted with rope slippage was in our attempts to move the rope to the furthest possible distance from the center of the sheaves.

Figure 30. Sheaves with a large center flat and variable surface angle develop a larger angle between the sheaves without making the opening between the sheaves too large for the rope.

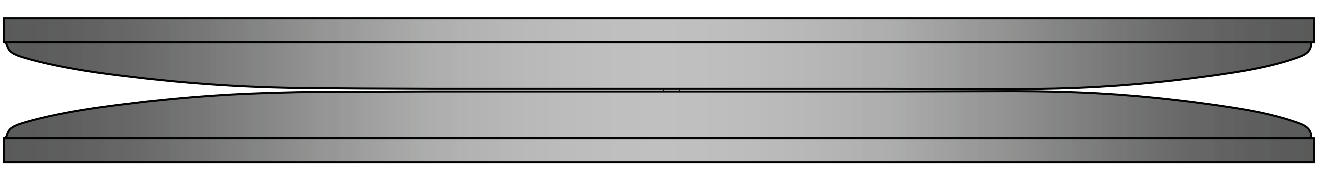


Figure 31. Sheaves with a small center flat and variable surface angle must have a shallow angle in order to avoid opening too wide for the rope at a working diameter that makes use of the diameter of the sheaves.

Generally, a wider angle between the sheaves caused less damage to the rope. A narrow angle allows the rope to squeeze further in between the sheaves. The rope yarns are scuffed against the sheaves as the rope squeezes between the sheaves under high tension. Any roughness on the surface of the sheaves causes the scuffing to be worse. The idea behind the sheave profiles illustrated in Figures 5 and 6 in our proposal (Figure 30 and Figure 31) is that the sheaves have a surface angle that becomes wider toward the outer rim of the sheaves. We determined that the sheave profile depicted in Fig. 6 of our proposal (Figure 30 above) is essentially the same profile as is available in commercially produced sheaves manufactured by the Hydroslave Hauler Company. We acquired two sets of 17-inch stamped steel Hydroslave hauler sheaves that we used in our experiments. These sheaves proved to be less damaging to the rope for two reasons: 1) the surface of the sheaves is smooth because the steel is stamped rather than machined; and, 2) we were able to maintain sufficient hauling grip on the rope with the sheaves close together, which caused the rope to ride at a point on the sheaves where the surface angle is approximately eight degrees (16 degrees between the two discs). This contrasts with standard sheaves that have a constant surface angle of 4 degrees regardless of the spacing between the discs.

The stamped steel Hydroslave sheaves are only three-eighths of an inch in thickness, compared to machined steel sheaves that measure 1 ¼" in thickness when new and are generally retired when they are still more than one-half inch thick, often showing stress cracks around the bolt holes. Based on the relatively thin steel in the Hydroslave sheaves, we question whether they can withstand the rigors of offshore trap hauling. We note, however, that representatives of the Hydroslave Hauler Company claim that their sheaves can be used for hauling lobster traps in deep water. We do not know of any true offshore shore lobster boats that use the Hydroslave sheaves, so we are unable to offer further guidance on the potential for using the stamped steel Hydroslave sheaves in deep water on large boats. Additional research is necessary to determine at what depths and on what boat sizes the Hydroslave stamped steel sheaves have been used and the fishermen's experience with them.

Figure 32. The standard 4-degree constant angle offshore sheaves cause more damage to the rope fibers than can be seen on ropes run on variable angle sheaves.

We tested the concept of the variable surface angle on a thicker sheave by having a set of solid steel discs machined to match the surface profile of the Hydroslave sheaves. We also had the discs sanded smooth. **These sheaves performed better than the standard sheaves but not as well as the Hydroslave stamped steel sheaves. We believe that additional attention paid to smoothing the surface of the machined sheaves would further improve their performance.** Preliminary field-testing of the sheaves that were machined to match the profile of the Hydroslave sheaves indicated a problem with knots and splices popping out. We believe that a modified flare toward the outer rim of the sheaves will cure this problem. We are currently in the process of having a set of sheaves machined with a CNC machining process that will produce a smooth finish and a modified bevel. We hope to obtain additional funding to test these sheaves on the simulator and in the field.

Wider spacing between the sheaves tended to increase rope wear for both floating and sinking rope used with variable angle sheaves. Wider spacing of standard machined steel sheaves produced more wear on floating rope but did not produce any significant change in the residual breaking strength of sinking rope. Wider spacing allows the rope to squeeze further into the V between the sheaves, causing the rope to scuff across the surface of the sheaves as it squeezes in and when it is forced out by the splitter. Wider spacing also causes the rope to form a tighter bend radius, which rope engineers cite as a known factor in internal rope wear.

We did not give the polyurethane splitter extensive testing because it took repeated attempts to obtain a polyurethane splitter that was stiff enough to extract the rope without bending. Treatment 11 utilized a splitter machined from Ultra High Molecular Weight Polyethylene and did not show any improvement in residual breaking strength compared to the standard steel splitter. When we did find a polyurethane formula that was stiff enough to extract the rope, we were not able to see any visible difference in the performance of the polyurethane knife compared to a steel knife. We note, however, that both the steel knife and the polyurethane knife showed significant wear after a relatively short period of hauling with sediment in the tank. In contrast to the steel knife, however, we could easily remove the wear groove and its sharp edges from the polyurethane knife with hand tools. The steel knife must be filled by welding and then ground to a smooth finish. Our experience indicates that filled steel knives may contain small pits along the edge that have the potential to damage rope when it is pushed against the knife with substantial force. Field-testing of the polyurethane knife will be required to determine whether it has sufficient durability for the offshore fleet. The durability of the knife will be less of an issue if it proves feasible to use variable angle sheaves that are adjusted to make the rope ride at a wide angle, as described below. Our tests with variable angle sheaves with close spacing showed very low splitter forces.

The reduced rope wear that was noted when the rope was riding at a point on the variable angle sheaves where the angle between the sheaves was approximately 16-20 degrees also coincided with minimal knife force readings. Visual observation confirmed that the rope was peeling out of the hauler with almost no force against the knife. All of these observations lead to the conclusion that the grip on the rope is not as great when the rope is riding at the wider angle. We did not have any problems with the rope slipping at our standard testing tension of 1250 pounds, which was chosen to be comparable to the typical hauling tension in 190 fathoms of water. We boosted the rope tension up to our maximum capability of 2200 pounds to determine if slippage would occur at that tension, and it did not. Our experience with the simulator may not represent conditions in the field with regard to rope slipping because our test samples had tapered splices and did not have gangions. Our line tension was relatively constant compared to the rapid fluctuations in line tension that occur in the field. NOAA Fisheries Gear Technologist John Kenney (Salvador and Kenney 2002) recorded a peak load of 2800 pounds in a depth of 185 fathoms. We can’t say from our experiments whether groundline, especially knots and splices, will be gripped adequately when the angle between the sheaves approaches 16-20 degrees under actual operating conditions. That leaves a question concerning the ability of the wider angle sheaves to haul consistently in deep water. At this point we simply don’t know enough about the trade-off between improved rope wear and sufficient grip. This aspect of our results will require field-testing to determine whether the wider angle sheaves have sufficient grip. We hope to preface that field-testing with additional lab testing of a variable angle machined-steel sheave with a further modified outer bevel intended to grip knots and splices better.

It should be noted that our use of the term “variable angle sheaves” refers to the surface profile of the sheaves, not the action of the sheaves in use. Sheave spacing and rope diameter determine the point at which the rope will ride on a set of sheaves. With variable angle sheaves, the angle at that point will differ depending on sheave spacing, but will be effectively fixed as long as the sheave spacing and rope diameter remain the same. If variable angle sheaves are adjusted so as to make the rope ride at a point where the sheave angle is four degrees, for example, the sheaves should perform in a similar manner to sheaves with a constant four degree angle. We would like to experiment with the concept of “cushioning” the sheaves so that the angle between the sheaves would vary according to the tension on the groundline. The idea is that the rope would ride at the wider angle when the tension was lower, thereby reducing rope wear. As the tension in the groundline increased and more grip was needed, the cushioned sheaves would spread just enough to allow the rope to ride deeper and at a narrower angle.

Offshore lobster hauler sheaves that are commonly used in the Northeast Region of the U.S. are uniform in the fact that they are all machined steel and all utilize a constant four-degree surface angle on the surface that grips the rope. For that reason, according to our results, they are all less than optimal. Beyond that factor, the performance of each individual hauler would depend on factors such as the smoothness of the surface, the spacing of the sheaves, the fit between the sheaves and the knife, and the condition of the knife. At this point in time, we believe that an appropriate way to address the problem of suboptimal haulers and hauler configurations would be to conduct an outreach program that would educate fishermen concerning the results of our experiments and assist fishermen in evaluating ways in which they could improve the performance of their haulers, such as measuring the roughness of the surface of their sheaves with an instrument designed for that purpose and working with sheave manufacturers to modify the profile of the sheaves.

The hauler that had the best results is currently not used by the primary participants in the offshore lobster fishery. The stamped steel Hydroslave hauler sheave is commonly used in the inshore lobster fishery and may be used by some smaller offshore lobster boats. Whereas the stamped steel Hydroslave sheave measures three-eighths inch in thickness, compared to 1 ¼” for new machined sheaves, we find it unlikely that offshore lobstermen will consider the stamped steel Hydroslave sheaves to be strong enough for sustained offshore use, despite the assurances of a representative of the Hydroslave Hauler Company that the 17” stamped steel sheaves have not failed in repeated deep-water use. Based on this concern about the strength of the 17” Hydroslave sheaves, we believe that offshore fishermen will prefer to have machine shops modify their approach to making sheaves for the offshore fleet.

Another alternative will be molded polyurethane sheaves that incorporate the variable surface angle and are sandwiched between standard offshore sheaves. Our experimentation with polyurethane sheaves to date has not convinced us that the polyurethane materials that we have tried so far will be durable enough to be economically feasible for the offshore fleet. We continue to experiment with materials and configurations that may make the polyurethane sheaves a feasible alternative. We believe that the added grip provided by the resilient material will reduce the likelihood that rope will slip in haulers with a wider angle between the sheaves than the current 4 degree angle.

We have expanded our outreach efforts to include the inshore lobster fleet through a partnership with the International Fund for Animal Welfare. IFAW paid for the manufacturer of polyurethane hauler sheaves and liners for 12 and 14-inch haulers, the sizes that are common in the inshore fleet. Our initial results with polyurethane sheaves for the inshore fleet were not successful because the polyurethane sheaves lacked the necessary stiffness. We subsequently manufactured and distributed polyurethane sheave liners to cooperating fishermen. The liners rely on the original steel sheaves for stiffness and provide a polyurethane hauling surface for whatever benefits may accrue. We have had good reports from the fishermen concerning the performance of the polyurethane liners.

Further outreach will be important in making the results of this research accessible to the lobster fleet. An article for Commercial Fisheries News has been submitted and will likely be published in January, 2009. We would like to produce a video for the MADMF web site that will require additional funding.

Recommendations for Further Research and Outreach

1. The hauler project that is the subject of this report utilized 3-strand blended polyester and Polysteel © sinking rope. This rope proved durable in previous trials and is readily available. Since the time that the Hauler Project was initiated, we have obtained results from field-testing that show that 4-strand blended rope is superior to 3-strand blended rope. The 4-strand rope is now readily available. We believe that the superior 4-strand blended rope should be tested on the simulator to determine the service life of the 4-strand rope when hauled with an improved hauler configuration, in comparison with straight Polysteel © floating rope. For this purpose we would increase the depth of water in the simulator to avoid sediment pickup by the floating rope, thus providing a comparison that could be expected to hold under commercial hauling conditions.

2. The current research project has tested steel hauler sheaves with different profiles and different spacing. The research on sheave profiles indicated that a modification of the commonly used offshore sheave profile would reduce rope wear. The sheave profile that reduced rope wear is commercially available in a 17-inch stamped-steel sheave made by the Hydroslave Hauler Company. Further research is needed to determine whether the Hydroslave sheaves have sufficient grip to retain knots and splices when the sheaves are mounted with no spacer between them, which was the configuration that produced the least rope wear. Further research is also needed to determine whether the Hydroslave sheaves are sufficiently strong to be acceptable to the offshore lobster fleet.

3. Machined-steel sheaves that match the surface profile of the Hydroslave sheaves showed a significant improvement in rope wear compared to the standard offshore sheaves. Preliminary field-testing of these sheaves showed that further research is necessary to obtain the correct combination of reduced rope wear and adequate grip, particularly with regard to gangions and splices. We have identified the sheave profile at the outer edge of the discs as a critical factor in this regard. We are in the process of acquiring CNC (Computer Numerical Controlled) machined sheaves with a smooth surface and a variable surface angle and modified bevel on the outer rim to improve grip on knots and splices. We would like to test these sheaves on the machine with knots and splices and then field-test them to determine the minimum sheave spacing that gives adequate grip on the rope.

4. This project demonstrated improved rope wear with a low-angle-of-incidence splitter. Field-testing of this design is necessary to determine its acceptability to

the offshore lobster fleet. We would like to acquire modified steel splitters with a reverse curve and distribute to offshore lobstermen for field-testing.

5. Further research is necessary to determine whether polyurethane splitters are more forgiving to the rope as the splitter wears. We would like to retrieve both steel and polyurethane splitters that have been worn through use by lobstermen and run rope on the machine to determine the effect of the worn splitters on rope wear.

6. We have experimented briefly with cushioned sheaves. The purpose of cushioning the sheaves arises from the fact that the most rope-friendly hauler configuration resulted from the adjustment of variable angle sheaves so that the rope rode at a point on the sheaves where the angle between the sheaves was considerably larger than the standard sheaves (8-10 degrees compared to 4 degrees). The reduced rope wear results from the reduced grip on the rope. The reduced grip was sufficient to pull rope at a tension of 2000 pounds in the laboratory, but we would expect the reduced grip to be insufficient in some field conditions. The idea behind cushioning the sheaves is to allow the sheaves to spread slightly as the tension in the rope increases. The spreading of the sheaves would allow the rope to sink deeper into the groove between the sheaves, which would position the rope where the angle between the sheaves is less and the grip is higher. If that concept proved feasible, the rope would ride at the more rope-friendly position when the tension was less and at a position with more grip when needed. This concept showed promise in laboratory trials, but requires field-testing to determine whether it will work under field conditions.

7. The durability of the polyurethane sheaves that have been tested so far is not sufficient to make them cost-effective for the offshore lobster fishery. Additional support will be necessary to continue research to determine the optimum material and material specifications for hauler sheaves. Field-testing with polyurethane inshore sheaves has indicated their improved grip on the rope compared to steel sheaves. This improved grip may be important in obtaining sufficient grip with sheaves that have a wider angle between the sheaves.

8. Research for the purpose of understanding the causes for the greater deterioration of sinking ropes compared to floating ropes when hauled with machined-steel sheaves. This research would include laboratory analysis of the differences in internal versus external strand deterioration to determine why Polysteel © groundline that shows greater visual deterioration retains higher breaking strengths than blended ropes which appear to have less deterioration.

9. There is an immediate need to provide wider dissemination of this research and related field-testing results. This research identified ways to improve offshore trap haulers so that they will cause less deterioration of groundlines. Field research has identified 4-strand sinking rope as having superior resistance to deterioration compared to other field-tested ropes, all of which were 3-strand. A broader understanding of these results will guide fishermen in their immediate purchasing decisions and will guide rope manufacturers in the development of improved groundlines.

10. Surface smoothness has been shown to be an important factor in rope wear caused by trap haulers. Virtually no information is available on the relative surface smoothness of hauler sheaves from different machine shops – no smoothness standards or specifications exist and there is apparent confusion concerning the desirability of a rough surface on hauler sheaves to improve grip. Further research and outreach is needed to establish a reasonable standard for surface smoothness and to measure the surface smoothness of existing sheaves with a surface smoothness indicator. We would like to acquire a surface smoothness instrument for this purpose.

References

Tension Technology International. "Visual and Scanning Electron Microscopy Investigation and Tensile Testing to Estimate Residual Tensile Strength of a Selection of Lobster Lines." Sussex, UK: Massachusetts Division of Marine Fisheries, 2007.

Appendix

Treatment 1 Compared to Treatment 2 – Standard Splitter Compared to Low Angle of Incident Splitter

Treatment 1 used a hauler configuration comparable to the standard steel offshore hauler sheaves with a 4-degree surface angle and with a standard steel splitter or knife sold by the Hydroslave trap hauler company. Treatment 2 used the same sheaves with a steel splitter that had been modified to reduce the angle at which the rope impinges on the splitter (Figure 11). The mean residual breaking strengths and t-test statistics[4] are shown in Table 5 for floating rope and Table 6 for sinking rope.

Table 8. The t statistic of 1.23 does not exceed the critical one-tail t value of 1.76, indicating that we can't say for sure that the modified knife is better for floating rope, even though the mean residual breaking strength for the floating rope samples from the modified splitter runs is approximately 180 pounds higher than the mean residual breaking strength from the standard splitter runs.

Floating rope	*Std Splitter1*	*Modif Splitter*
Mean	7142.125	7324.75
Variance	104083.5536	72478.78571
Observations	8	8
Pooled Variance	88281.16964	
Hypothesized Mean Difference	0	
Df	14	
t Stat	-1.229295199	
P(T<=t) one-tail	0.119611114	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	0.239222227	
t Critical two-tail	2.144786681	

[4] A note on t-tests. A t-test helps us to decide whether the difference between two sets of measurements, such as the break-test results for samples from rope runs using two hauler configurations, is significant. The danger in interpreting average values from two sets of samples with high variability within samples is that more samples might have produced a different average result, perhaps reversing the first impression. T-tests analyze the variability of the results and provide guidance on the probability that the results can be relied upon and would not be likely to change if more samples had been measured. We used Microsoft Excel to perform t-tests on our break-testing data. In the tables, if the "t statistic" is larger in absolute value than the "T critical," we can be assured that the difference in the sample means represents a true difference in the performance of the respective treatments. One-tailed t-tests are used when the researcher expects the difference to favor one treatment over the other. Two-tailed t-tests are used when the researcher has no expectations concerning the performance of one treatment compared to the other. In reporting our results, we label the t-test tables with an explanation of their practical meaning.

Table 9. T-test statistics for a one-tailed t-test indicate that we can say with a high degree of certainty that the modified splitter reduces the wear on sinking rope.

Sinking rope	*Std Splitter*	*Modif Splitter*
Mean	6589.25	7124.125
Variance	100441.0714	51593.55357
Observations	8	8
Pooled Variance	76017.3125	
Hypothesized Mean Difference	0	
Df	14	
t Stat	-3.879949199	
P(T<=t) one-tail	0.000833126	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	0.001666253	
t Critical two-tail	2.144786681	

Treatment 1 Compared to Treatment 3 – Moderate Sheave Spacing Compared to Maximum Sheave Spacing

Treatment 3 used a configuration similar to Treatment 1 except that the hauler sheaves were separated by a spacer measuring 0.3 inches in thickness, the maximum practical spacer thickness that would allow the rope to sink deeply into the sheaves without bottoming out in the V between the sheaves or catching on the tip of the splitter.

Table 10. Both the one- and two-tailed t-tests comparing the effect of closely spaced hauler sheaves to widely spaced hauler sheaves on floating rope shows that the closely spaced sheaves are better for floating rope.

Floating rope	*Treatment 1*	*Treatment 3*
Mean	7142.125	6606
Variance	104083.5536	11179.42857
Observations	8	8
Pooled Variance	57631.49107	
Hypothesized Mean Difference	0	
df	14	
t Stat	4.466487541	
P(T<=t) one-tail	0.000266146	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	0.000532292	
t Critical two-tail	2.144786681	

Table 11. A one-tailed t-test comparing the residual breaking strength for samples from the moderately spaced hauler sheaves to those from the more widely spaced sheaves does not show any statistically significant difference in the residual breaking strength after 125 simulated hauls for sinking rope.

Sinking rope	*Treatment 1*	*Treatment 3*
Mean	6589.25	6406.125
Variance	100441.0714	19241.26786
Observations	8	8
Pooled Variance	59841.16964	
Hypothesized Mean Difference	0	
df	14	
t Stat	1.49719234	
P(T<=t) one-tail	0.078273163	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	0.156546326	
t Critical two-tail	2.144786681	

Treatment 1 Compared to Treatment 4 – Standard Sheaves Compared to Hydroslave Sheaves

Treatment 4 utilized 17-inch steel Hydroslave hauler sheaves with a variable surface angle from the center to the rim (Figure 12). The Hydroslave sheaves have a curved profile when looked at from the side. Treatment 4 utilized a 0.1” spacer between the sheaves. It should be noted that the grip of the sheaves on the groundline is likely to vary with the angle between the sheaves. With variable angle sheaves, the angle at the point where the rope rides is determined by the spacer between the sheaves, which determines how deep in the sheaves the rope will ride. Treatment 1 represents our version of the standard steel offshore hauler with a 0.1” spacer.

Table 12. The one-tail t-test indicates that the Hydroslave sheaves with a 0.1” spacer produce considerably less rope wear on floating rope after 125 simulated hauls compared to standard machined sheaves with the same spacing.

Floating rope	*Treatment 1*	*Treatment 4*
Mean	7142.125	7855.75
Variance	104083.5536	159159.9286
Observations	8	8
Pooled Variance	131621.7411	
Hypothesized Mean Difference	0	
df	14	
t Stat	-3.934017034	

P(T<=t) one-tail	0.000749042
t Critical one-tail	1.761310115
P(T<=t) two-tail	0.001498084
t Critical two-tail	2.144786681

Table 13. A one-tailed t-test comparing the residual breaking strength of sinking rope after 125 simulated hauls with standard offshore machined sheaves with a constant 4-degree angle compared to Hydroslave sheaves with a variable surface angle and 0.1" spacing shows a large and statistically significant improvement in breaking strength.

Sinking rope	*Treatment 1*	*Treatment 4*
Mean	6589.25	7862
Variance	100441.0714	31027.71429
Observations	8	8
Pooled Variance	65734.39286	
Hypothesized Mean Difference	0	
df	14	
t Stat	-9.928343018	
P(T<=t) one-tail	5.10547E-08	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	1.02109E-07	
t Critical two-tail	2.144786681	

Treatment 1 Compared to Treatment 5 – Standard Hauler Compared to Widely Spaced Hydroslave Sheaves

Treatment 5 utilized the Hydroslave sheaves with a 0.3" spacer, allowing the rope to sink as deeply as practical into the V between the sheaves.

Table 14. The one-tailed t-test indicates that the residual breaking strength after 125 simulated hauls with Hydroslave sheaves with 0.3" spacing is significantly higher than the breaking strength after 125 simulated hauls with standard machined sheaves with 0.1" spacing.

Floating rope	*Treatment 1*	*Treatment 5*
Mean	7142.125	8103.625
Variance	104083.5536	119464.2679
Observations	8	8
Pooled Variance	111773.9107	
Hypothesized Mean Difference	0	
df	14	
t Stat	-	

	5.751869991
P(T<=t) one-tail	2.50392E-05
t Critical one-tail	1.761310115
P(T<=t) two-tail	5.00784E-05
t Critical two-tail	2.144786681

Table 15. The one-tailed t-test indicates that the Hydroslave sheaves with 0.3" spacing cause less rope deterioration than do the standard offshore sheaves with 0.1" spacing.

Sinking rope	*Treatment 1*	*Treatment 5*
Mean	6589.25	7911.875
Variance	100441.0714	296060.4107
Observations	8	8
Pooled Variance	198250.7411	
Hypothesized Mean Difference	0	
df	14	
t Stat	-5.94099673	
P(T<=t) one-tail	1.80158E-05	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	3.60316E-05	
t Critical two-tail	2.144786681	

Treatment 8 Compared to Treatment 5 – Hydroslave Sheaves with No Spacer Compared to Hydroslave Sheaves with 0.3" Spacer

Table 16. A one-tailed t-test tells us that the higher residual breaking strength of floating rope tested with Hydroslave sheaves with no spacer is statistically significant compared to the lower breaking strength obtained with Hydroslave sheaves with 0.3" spacing.

Floating rope	*Treatment 8*	*Treatment 5*
Mean	8417	8103.625
Variance	78258.85714	119464.2679
Observations	8	8
Pooled Variance	98861.5625	
Hypothesized Mean Difference	0	
df	14	
t Stat	1.993336446	
P(T<=t) one-tail	0.033042721	
t Critical one-tail	1.761310115	

P(T<=t) two-tail	0.066085442
t Critical two-tail	2.144786681

Table 17. A one-tailed t-test tells us that the higher residual breaking strength of sinking rope tested with Hydroslave sheaves with no spacer is statistically significant compared to the lower breaking strength obtained with Hydroslave sheaves with 0.3" spacing.

Sinking rope	*Treatment 8*	*Treatment 5*
Mean	8552.25	7911.875
Variance	102493.6429	296060.4107
Observations	8	8
Pooled Variance	199277.0268	
Hypothesized Mean Difference	0	
df	14	
t Stat	2.869034344	
P(T<=t) one-tail	0.006188134	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	0.012376267	
t Critical two-tail	2.144786681	

<u>Treatment 1 Compared to Treatment 6 – Standard Hauler Compared to Variable Angle Sheaves with 0.2" Spacing</u>

Treatment 6 utilized machined offshore sheaves that were machined with a variable surface angle, similar but not identical to the profile of the Hydroslave sheaves. The sheave spacing for Treatment 6 was 0.2". The purpose of this trial was to duplicate the profile of the Hydroslave stamped steel sheaves on a set of machined steel sheaves, expecting the rope wear to improve relative to the standard profile offshore sheave and to be comparable to the improved rope wear seen in the trials that used the Hydroslave sheaves. Contrary to our expectations, the variable angle newly-machined sheaves produced more rope wear than the either the Hydroslave sheaves or the standard sheaves. These tests reinforced our conclusion that the roughness associated with the machining process is a significant factor in rope wear. [5] Although our standard offshore sheaves

[5] We learned during this project that the surface roughness that is created in the process of machining sheaves is important to rope wear. We did not have equipment to measure surface roughness so we were unable to quantify differences in sheave surface roughness. This variable complicates comparisons that are intended to measure the difference caused by factors other than surface wear. For example, the differences in performance indicated for Treatment 6 may be caused by differences in surface roughness rather than the intended comparison between a constant surface angle and a variable surface angle. In Treatment 19 we attempted to reduce the problem associated with surface roughness by instructing the machine shop to smooth the surface of the sheaves after machining them. One machine shop indicated that their sheaves were touched up with a grinder following the machining process to "rough them up." Our experience indicated that smooth is better than rough and we expect that the grinding actually reduced the effect of the

were machined, they had been used extensively compared to the newly-machined variable angle sheaves. Machine tool marks tend to be smoothed by use, which indicates that the rope is essentially sanding the sheaves smooth as the rope is hauled. We believe that considerable rope wear occurs in this process.

Readers should also note that the results reversed when the standard sheaves were compared to the variable angle sheaves with 0.1" spacing, rather than 0.2" spacing (see Treatment 1 compared to Treatment 7, below).

Table 18. The two-tailed t-test shows that the standard offshore sheaves produce much less wear on floating rope after 125 simulate hauls than do the sheaves that have been machined with a variable surface angle and 0.2" spacing. (Surface roughness from machining may provide an alternative cause for the difference in performance, see footnote 1.)

Floating rope	*Treatment 1*	*Treatment 6*
Mean	7142.125	5761.875
Variance	104083.5536	115802.6964
Observations	8	8
Pooled Variance	109943.125	
Hypothesized Mean Difference	0	
df	14	
t Stat	8.325373244	
P(T<=t) one-tail	4.29197E-07	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	8.58394E-07	
t Critical two-tail	2.144786681	

Table 19. The two-tailed t-test indicates that standard offshore sheaves produce less wear on sinking rope after 125 simulated hauls than do the sheaves that have been machined with a variable angle and 0.2" spacing. (Surface roughness from machining may provide an alternative cause for the difference in performance, see footnote 3.)

Sinking rope	*Treatment 1*	*Treatment 6*
Mean	6589.25	5380.625
Variance	100441.0714	88967.41071
Observations	8	8
Pooled Variance	94704.24107	
Hypothesized Mean Difference	0	
df	14	

machining ridges and changed the orientation of the surface roughness from being circumferential to radial. Our observations indicated that rope suffers damage when it is scuffed across circumferential machining ridges as the rope is squeezed into the V-sheaves.

t Stat	7.85483117
P(T<=t) one-tail	8.46866E-07
t Critical one-tail	1.761310115
P(T<=t) two-tail	1.69373E-06
t Critical two-tail	2.144786681

<u>Treatment 1 Compared to Treatment 7 – Standard Hauler Compared to Variable Angle Sheaves with 0.1” Spacing</u>

Treatment 7 utilized the same machined sheaves as in Treatment 6, with a variable surface angle and a surface profile similar to the Hydroslave sheave profile. The sheave spacing for Treatment 7 was 0.1”, keeping the rope riding closer to the rim of the sheaves in Treatment 7 compared to Treatment 6. Note that the performance of the standard sheaves and the modified sheaves reversed from Treatment 6 to Treatment 7, with the only known difference being the closer sheave spacing in Treatment 7. The variable angle sheaves may also have experienced some surface smoothing through use in Treatment 6.

Table 20. The two-tailed t-test comparing the residual breaking strength of samples from the standard machined sheaves with 0.1” spacing and the variable surface angle machined sheaves with 0.1” spacing show a reversal of the performance compared to Treatment 6. Treatment 7 shows a statistically significant improvement in rope wear with the variable angle sheaves compared to the standard sheaves. This trial also demonstrates the importance of sheave spacing with variable angle sheaves – rope wear is reduced when the rope rides as close as possible to the outer rim, where the angle between the sheaves is greater.

Floating rope	*Treatment 1*	*Treatment 7*
Mean	7142.125	7544.375
Variance	104083.5536	71564.83929
Observations	8	8
Pooled Variance	87824.19643	
Hypothesized Mean Difference	0	
df	14	
t Stat	-2.714681955	
P(T<=t) one-tail	0.008383682	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	0.016767363	
t Critical two-tail	2.144786681	

Table 21. The two-tailed t-test shows that the variable angle machined sheaves cause less rope deterioration than the standard, constant angle offshore sheaves. As noted above, this reversal in performance compared to Treatment 6 may be attributed to the greater effect of surface roughness when sheaves are widely spaced and the rope scuffs across a wider rough surface before it seats tightly in the V.

Sinking rope	*Treatment 1*	*Treatment 7*
Mean	6589.25	7556.025
Variance	100441.0714	719576.0062
Observations	8	10
Pooled Variance	448704.4723	
Hypothesized Mean Difference	0	
df	16	
t Stat	-3.0426637	
P(T<=t) one-tail	0.003878398	
t Critical one-tail	1.745883669	
P(T<=t) two-tail	0.007756795	
t Critical two-tail	2.119905285	

Treatment 1 Compared to Treatment 8 – Standard Hauler Compared to Hydroslave Sheaves with No Spacer

Treatment 8 utilized the Hydroslave 17” variable surface angle sheaves with no space between the sheaves, keeping the rope riding as close to the rim as possible, given the 5/8” diameter of the rope and the angle between the sheaves.

It should be noted that Treatment 8 produced the highest residual breaking strengths of any of our hauler configurations. These impressive results must be tempered with the knowledge that the splice tended to pop out of the sheaves at times during this trial. The “pizza cutter” device kept the rope in the hauler, but it is quite likely that knots and splices would jump out of these sheaves with this close spacing under commercial use. The likelihood of slippage or popping out can be reduced by inserting spacers that widen the space between the sheaves, but trials with wider spacing showed greater rope wear (treatments 4 and 5). We believe that the grip of the sheaves on knots and splices toward the outer rim can be improved through further experimentation with the surface angle near the outer rim. The Hydroslave sheaves exhibit a radius at the outer rim that opens the angle rapidly, causing a loss of grip. A machined bevel with a shallower angle may maintain a better grip on knots and splices.

Table 22. The two-tailed t-test shows that the performance of the Hydroslave sheaves with no spacer is significantly better than the performance of the standard offshore sheaves with 0.1” spacing after 125 simulated hauls of floating rope.

Floating rope	*Treatment 1*	*Treatment 8*
Mean	7142.125	8417
Variance	104083.5536	78258.85714

Observations	8	8
Pooled Variance	91171.20536	
Hypothesized Mean Difference	0	
df	14	
t Stat	-8.444399127	
P(T<=t) one-tail	3.62912E-07	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	7.25825E-07	
t Critical two-tail	2.144786681	

Table 23. The two-tailed t-test shows that the residual breaking strength of sinking rope after 125 simulated hauls with Hydroslave sheaves with no spacer is significantly higher than the strength after 125 simulated hauls with standard offshore machined sheaves with 0.1" spacer.

Sinking rope	*Treatment 1*	*Treatment 8*
Mean	6589.25	8552.25
Variance	100441.0714	102493.6429
Observations	8	8
Pooled Variance	101467.3571	
Hypothesized Mean Difference	0	
df	14	
t Stat	-12.32500548	
P(T<=t) one-tail	3.31616E-09	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	6.63233E-09	
t Critical two-tail	2.144786681	

Treatment 1 Compared to Treatment 9 – Standard Hauler Compared to Variable Angle Machined Sheaves with No Spacer

Treatment 9 utilized the same steel sheaves that were used in Treatments 6 and 7, but with no spacer between the sheaves. The absence of a spacer causes the rope to ride as far out toward the rim of the sheaves as possible, given the diameter of the rope and the angle between the sheaves.

Table 24. The two-tailed t-test shows that the residual breaking strength of floating rope after 125 simulated hauls with machined sheaves with a variable surface angle and no spacer is significantly higher than the breaking strength after 125 simulated hauls with standard, constant angle offshore sheaves with 0.1" spacing.[6]

Floating rope	*Treatment 1*	*Treatment 9*
Mean	7142.125	7944.625
Variance	104083.5536	89166.83929
Observations	8	8
Pooled Variance	96625.19643	
Hypothesized Mean Difference	0	
df	14	
t Stat	-5.163329515	
P(T<=t) one-tail	7.1966E-05	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	0.000143932	
t Critical two-tail	2.144786681	

Table 25. The two-tailed t-test shows that the residual breaking strength of sinking rope after 125 simulated hauls with machined sheaves with a variable surface angle and no spacer is significantly higher than the breaking strength after 125 simulated hauls with standard, constant angle sheaves with 0.1" spacing.

Sinking rope	*Treatment 1*	*Treatment 9*
Mean	6589.25	7688.875
Variance	100441.0714	15835.55357
Observations	8	8
Pooled Variance	58138.3125	
Hypothesized Mean Difference	0	
df	14	
t Stat	-9.121019614	
P(T<=t) one-tail	1.44163E-07	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	2.88327E-07	
t Critical two-tail	2.144786681	

[6] Note that the opposite result obtained when the variable angle sheaves were separated by a 0.2" spacer. Note also the possible affect of surface roughness that is likely to be more pronounced when the sheaves are spaced far apart, causing the rope to scuff across a wider surface until the rope seats in the V.

Treatment 7 Compared to Treatment 9 – Variable Angle Machined Sheaves with 0.1” Spacing Compared to No Spacer

Treatment 9 used the same variable angle machined sheaves as were used in Treatment 7, but with no spacer between the sheaves. The narrower sheave spacing causes the rope to ride closer to the outer rim of the sheaves. Whereas the surface angle of the variable angle sheaves increases from the center toward the rim, rope that is riding further out toward the rim is also riding where the V between the sheaves has a wider angle.

Table 26. A one-tailed t-test shows that the higher residual breaking strength of floating rope tested with no spacer between variable angle machined sheaves compared to rope tested with the same sheaves with 0.1” spacing is statistically significant.

Floating rope	*Treatment 7*	*Treatment 9*
Mean	7544.375	7944.625
Variance	71564.83929	89166.83929
Observations	8	8
Pooled Variance	80365.83929	
Hypothesized Mean Difference	0	
df	14	
t Stat	-2.823745774	
P(T<=t) one-tail	0.006766249	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	0.013532498	
t Critical two-tail	2.144786681	

Table 27. A one-tailed t-test shows that the higher residual breaking strength of sinking rope tested with no spacer between variable angle machined sheaves compared to rope tested with the same sheaves with 0.1” spacing is statistically significant.

Sinking rope	*Treatment 7*	*Treatment 9*
Mean	7073.875	7688.875
Variance	207242.6964	15835.55357
Observations	8	8
Pooled Variance	111539.125	
Hypothesized Mean Difference	0	
df	14	
t Stat	-3.682913297	
P(T<=t) one-tail	0.001229569	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	0.002459138	

t Critical two-tail	2.144786681

Treatment 8 Compared to Treatment 9 – Hydroslave Sheaves with No Spacer Compared to Variable Angle Machined Sheaves with No Spacer

Table 28. A two-tailed t-test indicates that the higher residual breaking strength of floating rope tested with Hydroslave sheaves with no spacer is statistically significant compared to the lower breaking strength of the floating ropes tested with variable angle machined sheaves with no spacer. We assume that the difference in rope wear is caused by the presence of machining ridges on the machined sheaves and the absence of machining ridges on the stamped steel Hydroslave sheaves.

Floating rope	*Treatment 8*	*Treatment 9*
Mean	8417	7944.625
Variance	78258.85714	89166.83929
Observations	8	8
Pooled Variance	83712.84821	
Hypothesized Mean Difference	0	
df	14	
t Stat	3.265283106	
P(T<=t) one-tail	0.002819312	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	0.005638623	
t Critical two-tail	2.144786681	

Table 29. A two-tailed t-test indicates that the higher residual breaking strength of sinking rope tested with Hydroslave sheaves with no spacer is statistically significant compared to the lower breaking strength of the sinking ropes tested with variable angle machined sheaves with no spacer. We assume that the difference in rope wear is caused by the presence of machining ridges on the machined sheaves and the absence of machining ridges on the stamped steel Hydroslave sheaves.

Sinking rope	*Treatment 8*	*Treatment 9*
Mean	8552.25	7688.875
Variance	102493.6429	15835.55357
Observations	8	8
Pooled Variance	59164.59821	
Hypothesized Mean Difference	0	
df	14	
t Stat	7.099021719	
P(T<=t) one-tail	2.6726E-06	
t Critical one-tail	1.761310115	

P(T<=t) two-tail	5.34519E-06
t Critical two-tail	2.144786681

Treatment 1 Compared to Treatment 10 – Standard Hauler Compared to Hydroslave Sheaves with Stamped Steel Galvanized Liners

Treatment 10 utilized a set of Hydroslave 17” stamped steel sheave liners. These liners are commonly used with inshore trap haulers, but are seldom used in the offshore lobster fishery. The impressive performance of the Hydroslave 17” sheaves led us to experiment with the stamped steel liners to see if the liners produced more or less rope wear than did the Hydroslave sheaves without liners. We considered that knowledge to be important in advising inshore fishermen about the likely affect of hauler liners on rope wear, and in determining the future applicability of the liner concept to the offshore lobster fishery. The spacer between the liners measured 0.11” compared to 0.10” for the standard sheave spacing.

Table 30. A two-tailed t-test shows that the residual breaking strength of floating rope after 125 simulated hauls with Hydroslave stamped steel sheave liners with 0.11” spacing is significantly higher than the residual breaking strength after 125 simulated hauls with standard, constant angle machined sheaves with 0.1” spacers.

Floating rope	*Treatment 1*	*Treatment 10*
Mean	7142.125	7954
Variance	104083.5536	154399.1429
Observations	8	8
Pooled Variance	129241.3482	
Hypothesized Mean Difference	0	
df	14	
t Stat	-4.516670657	
P(T<=t) one-tail	0.000241762	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	0.000483523	
t Critical two-tail	2.144786681	

Table 31. A two-tailed t-test shows that the residual breaking strength of sinking rope after 125 simulated hauls with Hydroslave stamped steel sheave liners with 0.11" spacing is significantly higher than the residual breaking strength after 125 simulated hauls with standard, constant angle machined sheaves with 0.1" spacers.

Sinking rope	*Treatment 1*	*Treatment 10*
Mean	6589.25	8073.5
Variance	100441.0714	67107.42857
Observations	8	8
Pooled Variance	83774.25	
Hypothesized Mean Difference	0	
df	14	
t Stat	-10.25608896	
P(T<=t) one-tail	3.41166E-08	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	6.82332E-08	
t Critical two-tail	2.144786681	

Treatment 1 Compared to Treatment 11 – Standard Hauler with Standard Splitter Compared to Standard Hauler with UHMWPE Splitter

Treatment 11 utilized a splitter machined from ultra-high molecular weight polyethylene – UHMWPE, in conjunction with standard, constant angle machined sheaves with 0.125" spacing.

Table 32. A two-tailed t-test does not provide statistical support for the hypothesis that the UHMWPE splitter increases the service life of groundlines after 125 simulated hauls, compared to the standard sheave and splitter configuration. The results are based on only two samples of groundline, one floating and one sinking, tested with Treatment 11.

Combined rope types	*Treatment 1*	*Treatment 11*
Mean	6865.6875	6823.5
Variance	176957.0292	419509.6667
Observations	16	4
Pooled Variance	217382.4688	
Hypothesized Mean Difference	0	
df	18	
t Stat	0.161862603	
P(T<=t) one-tail	0.436608558	

t Critical one-tail	1.734063592
P(T<=t) two-tail	0.873217117
t Critical two-tail	2.100922037

Treatment 1 Compared to Treatment 12 – Standard Hauler Compared to 47 Shore D Polyurethane Sheaves

Treatment 12 utilized polyurethane sheaves with a hardness, or durometers, designated as 47 Shore D, which might be characterized as a medium hardness. The configuration included a standard steel splitter and zero spacing between the sheaves.

Table 33. Although the mean residual breaking strength of floating ropes tested with 47 Shore D polyurethane sheaves is 300 pounds higher than comparable ropes tested with the standard steel sheaves, the variability of the individual breaks does not lead to statistical support for the hypothesis that the polyurethane sheaves improve rope wear for floating rope.

Floating rope	*Treatment 1*	*Treatment 12*
Mean	7142.125	7438.625
Variance	104083.5536	141091.125
Observations	8	8
Pooled Variance	122587.3393	
Hypothesized Mean Difference	0	
df	14	
t Stat	-1.693682046	
P(T<=t) one-tail	0.056223683	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	0.112447367	
t Critical two-tail	2.144786681	

Table 34. A two-tailed t-test provides support for the hypothesis that the residual breaking strength of sinking rope is higher with the use of 47 Shore D polyurethane sheaves than it is with standard steel, constant angle sheaves.

Sinking rope	*Treatment 1*	*Treatment 12*
Mean	6589.25	7158.125
Variance	100441.0714	123687.2679
Observations	8	8
Pooled Variance	112064.1696	
Hypothesized Mean Difference	0	
df	14	

t Stat	-3.398704883
P(T<=t) one-tail	0.002162008
t Critical one-tail	1.761310115
P(T<=t) two-tail	0.004324016
t Critical two-tail	2.144786681

Treatment 1 Compared to Treatments 13 and 14 – Standard Hauler Compared to 52 Shore D Polyurethane Sheaves

Treatments 13 and 14 utilize polyurethane sheaves with a durometers of 52 Shore D, somewhat harder than the sheaves used in Treatment 12. These treatments lack statistical power because they polyurethane sheaves showed excessive wear early in the trial and the trial was cut short in order not to waste time and rope on a treatment that does not appear to have commercial application. Treatment 14 differed from Treatment 13 in the use of a modified steel splitter with a low angle of incidence.

Table 35. A two-tailed t-test supports the significance of the higher mean breaking strength for floating rope tested with 52 Shore D polyurethane sheaves compared to standard, constant angle machined sheaves. Treatment 14 also utilized a modified steel splitter with a low angle of incidence compared to the standard steel splitter.

Floating rope	*Treatment 1*	*Treatments 13 & 14*
Mean	7142.125	7991.25
Variance	104083.5536	22937.58333
Observations	8	4
Pooled Variance	79739.7625	
Hypothesized Mean Difference	0	
df	10	
t Stat	-4.910418698	
P(T<=t) one-tail	0.000306766	
t Critical one-tail	1.812461102	
P(T<=t) two-tail	0.000613533	
t Critical two-tail	2.228138842	

Table 36. A two-tailed t-test supports the statistical significance of the higher mean breaking strength for sinking rope tested with 52 Shore D polyurethane sheaves compared to standard, constant angle machined sheaves. Treatment 14 also utilized a modified steel splitter with a low angle of incidence compared to the standard steel splitter.

Sinking rope	*Treatment 1*	*Treatment 13 & 14*
Mean	6589.25	7300.25
Variance	100441.0714	251764.9167

Observations	8	4
Pooled Variance	145838.225	
Hypothesized Mean Difference	0	
df	10	
t Stat	-3.040312898	
P(T<=t) one-tail	0.006227962	
t Critical one-tail	1.812461102	
P(T<=t) two-tail	0.012455924	
t Critical two-tail	2.228138842	

Treatment 1 Compared to Treatment 17 – Standard Hauler Compared to Machined Steel Sheaves that Match Hydroslave Variable Angle Profile

Treatment 17 utilized machined steel sheaves that were machined to match the profile of 17" Hydroslave sheaves. The purpose for machining sheaves to match the Hydroslave sheaves was to increase the strength of the sheaves for offshore use. 17" Hydroslave sheaves are approximately ½" thick. Standard offshore sheaves start their life with a thickness of 1 ¼". They are usually retired when re-surfacing reduces their thickness to an inch or less. By that time they typically suffer from stress cracks around the bolt holes. This experience leads us to believe that the thinner Hydroslave sheaves are not likely to stand up to continuing use on the offshore lobster grounds. Representatives of the Hydroslave Hauler Company claim that their 17" sheaves have been used successfully in deep water without any problems with stress cracks. Our assumption that the stamped steel sheaves would not be adequate for sustained use in the offshore lobster fishery led us to have a set of steel sheaves machined to match the surface profile of Hydroslave sheaves that appears to extend the service life of groundlines. Treatment 17 differed from Treatments 6, 7, and 9 in greater care taken to match the profile of the Hydroslave sheaves and surface grinding to smooth the ridges left by the machinist's lathe. Treatment 17 used zero spacing between the sheaves based on earlier tests that showed the best performance of Hydroslave sheaves with no spacer. Treatment 17 used a standard steel splitter.

Table 37. A two-tailed t-test shows that the higher residual breaking strength calculated for floating rope samples tested on steel sheaves machined to match the surface profile of Hydroslave sheaves is statistically significant compared to testing with standard, constant angle machined sheaves. The machining ridges on the modified sheaves were also smoothed with a grinder prior to testing.

Floating rope	*Treatment 1*	*Treatment 17*
Mean	7142.125	8000.25
Variance	104083.5536	24147.58333
Observations	8	4
Pooled Variance	80102.7625	
Hypothesized Mean Difference	0	

df	10
t Stat	-4.951208027
P(T<=t) one-tail	0.00028875
t Critical one-tail	1.812461102
P(T<=t) two-tail	0.000577499
t Critical two-tail	2.228138842

Table 38. A two-tailed t-test shows that the considerably higher residual breaking strength for sinking rope samples tested on steel sheaves that were machined to match the surface profile of Hydroslave sheaves is statistically significant compared to testing with standard, constant angle machined sheaves. The machining ridges on the modified sheaves were also smoothed with a grinder prior to testing.

Sinking rope	*Treatment 1*	*Treatment 17*
Mean	6589.25	8136.5
Variance	100441.0714	9652.333333
Observations	8	4
Pooled Variance	73204.45	
Hypothesized Mean Difference	0	
df	10	
t Stat	-9.338478355	
P(T<=t) one-tail	1.4828E-06	
t Critical one-tail	1.812461102	
P(T<=t) two-tail	2.96559E-06	
t Critical two-tail	2.228138842	

Treatment 1 Compared to Treatment 18 – Standard Hauler Compared to Machined Steel Sheaves that Match Hydroslave Variable Angle Profile and Modified Steel Knife

Treatment 18 utilized the modified steel sheaves with a surface profile that matches the Hydroslave sheaves. The sheave spacing for Treatment 18 was 0.25” and the splitter was modified to reduce the angle at which the rope impinges on the splitter.

Table 39. A two-tailed t-test does not show demonstrate a statistically significant improvement in rope wear for floating rope tested with the modified steel sheaves with 0.25” spacing and the modified splitter compared to the standard steel sheaves with 0.1” spacing and a standard steel splitter.

Floating rope	*Treatment 1*	*Treatment 18*
Mean	7142.125	7394
Variance	104083.5536	186992.6667

Observations	8	4
Pooled Variance	128956.2875	
Hypothesized Mean Difference	0	
df	10	
t Stat	-1.145376237	
P(T<=t) one-tail	0.139362394	
t Critical one-tail	1.812461102	
P(T<=t) two-tail	0.278724788	
t Critical two-tail	2.228138842	

Table 40. A two-tailed t-test indicates that the higher residual breaking strength of sinking rope tested with modified steel sheaves, 0.25" spacing, and a low angle of incidence splitter is statistically significant compared to ropes tested with standard, constant angle machined sheaves with 0.1" spacing and a standard steel splitter.

Sinking rope	*Treatment 1*	*Treatment 18*
Mean	6589.25	7774.25
Variance	100441.0714	77594.91667
Observations	8	4
Pooled Variance	93587.225	
Hypothesized Mean Difference	0	
df	10	
t Stat	-6.325493758	
P(T<=t) one-tail	4.30989E-05	
t Critical one-tail	1.812461102	
P(T<=t) two-tail	8.61977E-05	
t Critical two-tail	2.228138842	

<u>Treatment 8 Compared to Treatment 17 – Hydroslave Sheaves Compared to Machined Steel Sheaves that Match Hydroslave Variable Angle Profile</u>

Treatments 8 and 17 showed the highest residual breaking strength for sinking rope. Treatment 8 utilized the 17" Hydroslave sheaves with zero spacing. Treatment 17 utilized steel sheaves that had been machined to match the surface profile of the Hydroslave sheaves. The spacing between the sheaves was zero. Both treatments used a standard steel splitter.

Table 41. A two-tailed t-test indicates a statistically significant and higher residual breaking strength for floating rope tested with 17" Hydroslave sheaves with zero spacing compared to machined

sheaves with a surface profile that matches the Hydroslave profile. It seems likely that the difference in performance between the Hydroslave sheaves and the machined sheaves relates to surface smoothness. Although the machined sheaves were smoothed with a grinder, they were still much rougher than the surface of the Hydroslave sheaves.

Floating rope	*Treatment 8*	*Treatment 17*
Mean	8417	8000.25
Variance	78258.85714	24147.58333
Observations	8	4
Pooled Variance	62025.475	
Hypothesized Mean Difference	0	
df	10	
t Stat	2.732592835	
P(T<=t) one-tail	0.01054965	
t Critical one-tail	1.812461102	
P(T<=t) two-tail	0.021099299	
t Critical two-tail	2.228138842	

Table 42. A two-tailed t-test indicates a statistically significant and higher residual breaking strength for sinking rope tested with 17" Hydroslave sheaves with zero spacing compared to machined sheaves with a surface profile that matches the Hydroslave profile. It seems likely that the difference in performance between the Hydroslave sheaves and the machined sheaves relates to surface smoothness. Although the machined sheaves were smoothed with a grinder, they were still much rougher than the surface of the Hydroslave sheaves.

Sinking rope	*Treatment 8*	*Treatment 17*
Mean	8552.25	8136.5
Variance	102493.6429	9652.333333
Observations	8	4
Pooled Variance	74641.25	
Hypothesized Mean Difference	0	
df	10	
t Stat	2.485004458	
P(T<=t) one-tail	0.01613255	
t Critical one-tail	1.812461102	
P(T<=t) two-tail	0.0322651	
t Critical two-tail	2.228138842	

Treatment 8 Compared to Treatment 10 – Hydroslave Sheaves Compared to Hydroslave Sheaves with Stamped Steel Galvanized Liners

Treatment 8 was the treatment with the highest residual breaking strength for sinking rope. It utilized the Hydroslave sheaves with no spacer. Treatment 10 recorded the third highest residual breaking strength for sinking rope, after Treatment 8 and Treatment 17. Treatment 10 utilized the stamped steel Hydroslave sheave liners with 0.11" spacing.

Table 43. A two-tailed t-test shows that the higher residual breaking strength recorded for floating rope tested with the unlined Hydroslave sheaves compared to the lined sheaves is statistically significant. The only observable differences between the unlined sheaves and the lined sheaves are the radial grooves in the liners and the galvanized surface of the liners compared to a smooth steel surface on the unlined sheaves.

Floating rope	*Treatment 10*	*Treatment 8*
Mean	7954	8417
Variance	154399.1429	78258.85714
Observations	8	8
Pooled Variance	116329	
Hypothesized Mean Difference	0	
df	14	
t Stat	-2.714982217	
P(T<=t) one-tail	0.008378749	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	0.016757499	
t Critical two-tail	2.144786681	

Table 44. A two-tailed t-test shows that the higher residual breaking strength recorded for sinking ropes tested with the unlined Hydroslave sheaves compared to the lined sheaves is statistically significant. The only observable differences between the unlined sheaves and the lined sheaves are the radial grooves in the liners and the galvanized surface of the liners compared to a smooth steel surface on the unlined sheaves.

Sinking rope	*Treatment 10*	*Treatment 8*
Mean	8073.5	8552.25
Variance	67107.42857	102493.6429
Observations	8	8
Pooled Variance	84800.53571	
Hypothesized Mean Difference	0	
df	14	
t Stat	-3.288058114	
P(T<=t) one-tail	0.002694409	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	0.005388819	

t Critical two-tail	2.144786681

Treatment 10 Compared to Treatment 17 – Hydroslave Sheaves with Galvanized Liners Compared to Machined Sheaves with Variable Angle Profile to Match Hydroslave

Table 45. A two-tailed t-test does not indicate a statistically significant difference in the residual breaking strength of floating rope tested with lined Hydroslave sheaves compared to machined steel sheaves with a surface profile that matches the Hydroslave sheaves.

Floating rope	*Treatment 10*	*Treatment 17*
Mean	7954	8000.25
Variance	154399.1429	24147.58333
Observations	8	4
Pooled Variance	115323.675	
Hypothesized Mean Difference	0	
df	10	
t Stat	-0.222401067	
P(T<=t) one-tail	0.414239112	
t Critical one-tail	1.812461102	
P(T<=t) two-tail	0.828478224	
t Critical two-tail	2.228138842	

Table 46. A two-tailed t-test does not indicate a statistically significant difference in the residual breaking strength of sinking rope tested with lined Hydroslave sheaves compared to machined steel sheaves with a surface profile that matches the Hydroslave sheaves.

Sinking rope	*Treatment 10*	*Treatment 17*
Mean	8073.5	8136.5
Variance	67107.42857	9652.333333
Observations	8	4
Pooled Variance	49870.9	
Hypothesized Mean Difference	0	
df	10	
t Stat	-0.460682073	
P(T<=t) one-tail	0.327441219	
t Critical one-tail	1.812461102	
P(T<=t) two-tail	0.654882438	
t Critical two-tail	2.228138842	

Trials with Sediment

Treatment 19 Compared to Treatment 20 – Sheaves Machined to Match Hydroslave Variable Angle Profile Compared to Standard Constant Angle Offshore Sheaves

Treatments 19 through Treatment 22 were conducted with sediment and water in the simulator tank in order to compare the treatments under conditions approximating actual operating conditions. These treatments were also extended to 250 simulated hauls to avoid the possibility that differences in rope wear might not be evident without extended testing. Each sample was broken three times to increase the statistical power of the comparisons between breaking tensions. Treatment 19 utilized the modified, machined steel sheaves with a surface profile that matches that of the Hydroslave sheaves, having a continuously increasing angle from the center to the outer rim. The spacing between sheaves was 0.125. A standard steel splitter was used for Treatment 19.

Treatment 20 utilized the standard, constant 4-degree angle machined steel sheaves with a 0.03" spacer and a standard steel splitter.

This comparison is intended to demonstrate the potential for improved rope wear using the configuration represented by Treatment 19.

Table 47. A two-tailed t-test indicates a statistically significant improvement in the residual breaking strength of floating rope tested with the modified, variable angle machined sheaves compared to the standard, constant angle machined sheaves. Testing simulated 250 hauls with sediment in simulator tank.

Floating rope	*Treatment 19*	*Treatment 20*
Mean	6342.333333	5692.666667
Variance	103989.4667	127267.4667
Observations	6	6
Pooled Variance	115628.4667	
Hypothesized Mean Difference	0	
df	10	
t Stat	3.309168095	
P(T<=t) one-tail	0.003945198	
t Critical one-tail	1.812461102	
P(T<=t) two-tail	0.007890397	
t Critical two-tail	2.228138842	

Table 48. A two-tailed t-test indicates a a statistically significant improvement in the residual breaking strength of sinking rope tested with the modified, variable angle machined sheaves compared to the standard, constant angle machined sheaves. Testing simulated 250 hauls with sediment in simulator tank.

Sinking rope	*Treatment 19*	*Treatment 20*
Mean	5609.166667	4382.833333

Variance	159719.7667	53967.36667
Observations	6	6
Pooled Variance	106843.5667	
Hypothesized Mean Difference	0	
df	10	
t Stat	6.498228399	
P(T<=t) one-tail	3.45546E-05	
t Critical one-tail	1.812461102	
P(T<=t) two-tail	6.91092E-05	
t Critical two-tail	2.228138842	

Treatment 20 Compared to Treatment 21 – Standard Steel Sheaves Compared to Newly Machined Standard Steel Sheaves

Treatment 21 utilized a newly machined pair of standard sheaves with 0.03” spacing and a standard steel splitter. This test was intended to determine whether newly machined sheaves tend to produce more rope wear than sheaves that have been used. In the absence of a surface roughness gauge, we had no way to determine any quantitative difference in the smoothness of the sheave surfaces.

Table 49. A one-tail t-test does not support the hypothesis that newly machined sheaves will cause more rope wear and a lower residual breaking strength for floating rope compared to standard steel sheaves that have been smoothed somewhat by continued use.

Floating rope	*Treatment 20*	*Treatment 21*
Mean	5692.666667	5445.5
Variance	127267.4667	53657.5
Observations	6	6
Pooled Variance	90462.48333	
Hypothesized Mean Difference	0	
df	10	
t Stat	1.423364976	
P(T<=t) one-tail	0.092536308	
t Critical one-tail	1.812461102	
P(T<=t) two-tail	0.185072616	
t Critical two-tail	2.228138842	

Table 50. A one-tail t-test does not support the hypothesis that newly machined sheaves will cause more rope wear and a lower residual breaking strength for sinking rope compared to standard steel sheaves that have been smoothed somewhat by continued use.

Sinking rope	*Treatment 20*	*Treatment 21*

Mean	4382.833333	4405.333333
Variance	53967.36667	52935.06667
Observations	6	6
Pooled Variance	53451.21667	
Hypothesized Mean Difference	0	
df	10	
t Stat	-0.168563813	
P(T<=t) one-tail	0.434750192	
t Critical one-tail	1.812461102	
P(T<=t) two-tail	0.869500384	
t Critical two-tail	2.228138842	

Treatment 22 Compared to Treatment 19 – Hard Durometer Polyurethane Sheaves with a Surface Profile that Matches Hydroslave Sheaves Compared to Machined Sheaves with a Surface Profile That Matches Hydroslave Sheaves

Treatment 22 utilized polyurethane sheaves with a durometers of 65 Shore D, the hardest polyurethane material that we tested. These sheaves have a surface profile that matches the Hydroslave sheaves. The spacing between the sheaves was zero. The splitter was molded with 65 Shore D polyurethane. Treatment 19 utilized steel sheaves that were machined with a variable angle surface that matched the Hydroslave surface profile.

Table 51. A one-tailed t-test does not support the hypothesis that the residual breaking strength of floating rope will be higher when tested with 65 Shore D polyurethane sheaves compared to variable angle machined steel sheaves.

Floating rope	*Treatment 19*	*Treatment 22*
Mean	6342.333333	6626.833333
Variance	103989.4667	68804.96667
Observations	6	6
Pooled Variance	86397.21667	
Hypothesized Mean Difference	0	
df	10	
t Stat	-1.67645933	
P(T<=t) one-tail	0.062290974	
t Critical one-tail	1.812461102	
P(T<=t) two-tail	0.124581948	
t Critical two-tail	2.228138842	

Table 52. A one-tailed t-test does not support the hypothesis that the residual breaking strength of sinking rope will be higher when tested with 65 Shore D polyurethane sheaves compared to variable angle machined steel sheaves.

Sinking rope	*Treatment 19*	*Treatment 22*
Mean	5609.166667	5297.166667
Variance	159719.7667	154720.1667
Observations	6	6
Pooled Variance	157219.9667	
Hypothesized Mean Difference	0	
df	10	
t Stat	1.362891778	
P(T<=t) one-tail	0.101408199	
t Critical one-tail	1.812461102	
P(T<=t) two-tail	0.202816397	
t Critical two-tail	2.228138842	

Treatment 1 Compared to Treatment 21 – Standard sheaves with no sediment in simulator tank compared to standard sheaves with sediment in tank

Most of our tests were conducted with no sediment in the simulator tank to insure that the effects that we observed were attributable to the hauler component being tested, rather than rope damage caused by sediment. We were concerned that the magnitude of the damage caused by sediment would overwhelm the effect from the hauling system, thus masking the effect that we wanted to test. After completing our series of tests on hauler components and adjustment, however, we wanted to determine whether our conclusions would hold with sediment in the tank, which would more closely simulate actual hauling conditions. Table 50 shows that the addition of sediment to the simulator tank reduces the residual breaking strength of sinking rope by one-third, and that the results are statistically significant with a P value of 0.00000000035, meaning that there is virtually no probability that the results occurred by random chance. Table 51 shows that there was also a 24% reduction in the residual breaking strength of floating rope when sediment was added to the tank. It should be noted that the water depth over the sediment in the simulator tank was only four inches, so the floating rope contacted the sediment when it dropped from the hauler and was pulled through sediment filled water as it travelled from one end of the tank to the other.

Table 53. A one-tailed t-test provides strong support to the expectation that sinking rope tested with sediment in the simulator tank will have lower residual breaking strength than when tested without sediment in the tank.

Sinking rope	*No Sediment*	*Sediment*

Mean	6589.25	4405.333333
Variance	100441.0714	52935.06667
Observations	8	6
Pooled Variance	80646.90278	
Hypothesized Mean Difference	0	
df	12	
t Stat	14.23963368	
P(T<=t) one-tail	3.51745E-09	
t Critical one-tail	1.782287548	
P(T<=t) two-tail	7.0349E-09	
t Critical two-tail	2.178812827	

Table 54. A one-tailed t-test supports the expectation that the residual breaking strength of floating rope will be lower when tested with sediment in the simulator tank. The water in the simulator is shallow enough for the floating rope to pick up sediment as it travels from one end of the tank to the other.

Floating rope	*No Sediment*	*Sediment*
Mean	7142.125	5445.5
Variance	104083.5536	53657.5
Observations	8	6
Pooled Variance	83072.69792	
Hypothesized Mean Difference	0	
df	12	
t Stat	10.8996689	
P(T<=t) one-tail	7.0061E-08	
t Critical one-tail	1.782287548	
P(T<=t) two-tail	1.40122E-07	
t Critical two-tail	2.178812827	