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Evaluation of the Time Tension Line Cutter (TTLC) as a whale-safe fishing gear option

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EVALUATION OF THE TIME TENSION LINE CUTTER (TTLC) AS A WHALE-SAFE FISHING GEAR OPTION

BY

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THESIS

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ABSTRACT

EVALUATION OF THE TIME TENSION LINE CUTTER (TTLC) AS A WHALE-SAFE FISHING GEAR OPTION

by

Timothy Pickett

University of New Hampshire, December, 2009

The Time Tension Line Cutter (TTLC) is a device designed to limit the severity of entanglement of whales, the critically endangered North Atlantic Right Whale (NARW) in particular, in passive fishing gear. In this study, an evaluation of the performance of the TTLC was conducted using a series of lobster trawl tows, as well as a pilot study to test the durability and fishability of the TTLC in real fishing situations.

The trawl tow test data were collected for 5, 10, and 20 trap trawls, consisting of end line loading and trap elevation measurements. The time to cut (TTC) was measured on the TTLC employed in these tows, while the trap elevation and end line loading were used to understand gear behavior in an entanglement scenario. Additional numerical and controlled physical testing was conducted to verify the results of the tow tests. The pilot study employed 50 TTLCs procured by Blue Water Concepts of Eliot ME, which were distributed to fisherman for testing. Data collected consisted of pre- and post-deployment TTC calibrations, as well as a log sheet filled out by the fisherman.

CHAPTER I

INTRODUCTION

I.1 Background

Commercial fishing has been a staple of the economy of New England for its entire history, from early Nordic explorers to present-day commercial fishermen. Whales have also, in a similar way been involved in the history of commercial fishing in New England. North Atlantic Right Whales (NARW) in particular were very important to the New England whaling effort being named so because they were the "Right" whale to kill because they floated when dead. The average size for a mature whale is around 50 feet in length and weighs 60 tons, with adult females being slightly larger than adult males. This, coupled with their lethargic nature and high blubber yield made them the choice of whalers during the peak of the whaling effort of the 19th century.

The exploitation of these animals led to a severe decline in their population numbers which have yet to show significant signs of recovering. Since the population of NARW has struggled so much to recover, even decades after the abolition of whaling, a great deal of effort has been to identify the major threats to their survival, and ultimately, the populations' ability to recover. Ship strikes and fishing gear entanglements warrant the most investigation regarding their respective dangers to the species (Lippsett, 2005). The topic of fishing gear entanglements, particularly those involving vertical lines lobster gear in the northeast, is the concern of this investigation.

Much like whaling in the earlier part of the history of New England, the lobster fishing industry is a very important staple in the economy of the area. According to the National Marine Fisheries Service (NMFS), the 2007 lobster landings were valued at approximately $350,000,000. The most productive waters for the lobster fishery also happen to be the favored waters of NARW, thereby creating a conundrum regulating the co-existence of the fishery and the whales.

Passive fishing gear is any type of gear that is not actively tended by the fisherman. This gear is most commonly resting on the bottom and marked by surface floats affixed to a vertical line, which is attached to the gear and is used to haul and check the gear. This type of passive technique is typical of both the lobster and gillnet fisheries that take place in the natural range of NARW. Figure 1.1 depicts a typical lobster trawl as an example of how such gear is fished, and is the reference used when discussing the NARW entanglement mechanism. Since fishing gear poses a threat to the endangered NARW, there is an initiative to assess the entanglement issue in an effort to prevent fatal entanglements. These efforts can be divided into two major categories- the avoidance of whale/gear encounters, and, should an entanglement occur, limiting the harmful effects on the animal by the ensnaring gear.

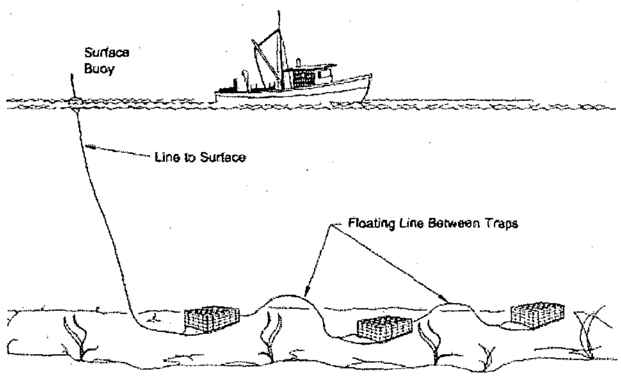

Figure 1.1: Passive fishing gear
Diagram of a typical passive fishing gear setup (lobster gear in this case). (Fried, 2000)

Avoidance of entanglements involves either the adaptation of the fishing gear in a way that limits the potential encounter of the whale and the gear, or moving the gear away from the documented paths of the whales, or, in most cases, a combination of the two. Moving gear away from known concentrations of whales limits the fisherman's ability to fish where and when he wants to. This leads to potential conflicts between the best season for catching a particular species, and the migrations of whales through the fishing grounds. In response to the risk of concentrations of whales encountering concentrations of fishing gear, NMFS has employed Dynamic Area Management (DAM) zones, that require certain gear modifications in an effort to limit life-threatening entanglements.

Limiting the severity of entanglements deals with the post-gear-encounter reaction of both the whale and the gear, and actions that could be taken to free one from the other. Essentially, the tangling mechanisms of the whale would need to be studied, enabling conscious decisions to be made regarding the best adaptations possible for the gear. However, in both avoidance and severity limiting attempts, adapting gear has other consequences, such as ability to fish effectively, compromises in the safety of the gear in operation, cost to implement, and practicality of operation. These design criteria are what separate some designs from others.

I.2 Previous Attempts:

Several attempts at designing whale-safe gear have been made with well documented results. First, eliminating the chance for a whale's encounter with passive fishing gear, in effect, fishing outside the seasonal range of NARW would make the most sense because it would eliminate the need to study the entanglement mechanism, and rely on strategic placement of the gear. However, this is not necessarily feasible, because the natural range for NARW is in the nearshore waters of the Gulf of Maine, which is consistent with some of the most concentrated commercial fishing efforts in the entire country. It would cause an economic crisis if fishing were to be stopped for any length of time in the Gulf of Maine.

So, if relocation of fishing gear is not an option, then the next step in gear avoidance would be to somehow alter the present configuration of the fishing gear to eliminate the gear's presence in the water column. In the passive gear fisheries, the problematic members in traditional rigging are the end lines rigged with surface floats, and floating ground lines. Both of these elements are suspended in the water column and could pose a threat to whales that are actively feeding in the area. The use of sinking ground lines has already been made law and all fisherman must be compliant by 4/5/09 (NMFS Fed Reg). This eliminates the arcing profile in the water column, however, problems with entangling gear on the bottom, the main reason for using floating ground lines in the first place, are sure to arise. The use of sinking ground lines has actually been implemented recently in areas of high whale traffic, namely in Massachusetts Bay, and in areas of the coast of Maine (Fried, 2000).

After eliminating floating ground lines from the water column, vertical end lines pose a separate threat. Eliminating vertical lines all together creates the problem of being able to locate and retrieve gear because it isn't marked at the surface. This also makes gear invisible to other fisherman in the area, who could set their gear, unknowingly over other fisherman's gear, resulting in a tangled mess. A potential solution to this problem is to use acoustic end line releases, where an acoustic signal is sent from the fisherman to an acoustic release at the end of the gear, which would release a float attached to the end line. Once the release is activated, the float is released, and it rises to the surface, carrying the submerged end line with it. Figure 1.2 below shows how an acoustic release would work to eliminate the presence of an end line in the water column.

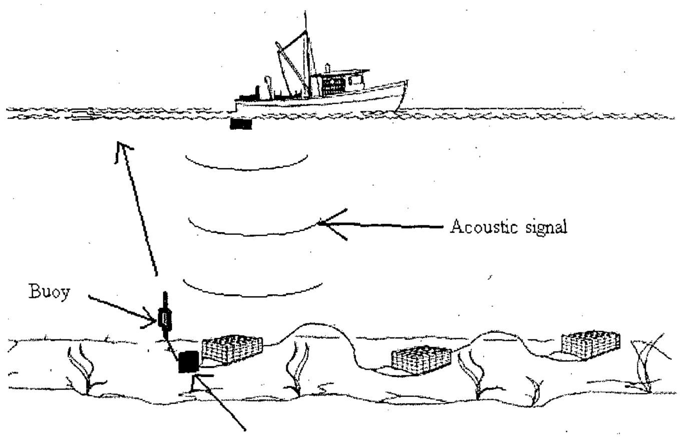

Figure 1.2: Acoustic Release

Diagram of how an acoustic release mechanism might be employed to promote avoidance of contact with whales.(Adapted from Fried, 2000)

Assuming the methods for eliminating end lines from the water column prove unrealistic, the next step in limiting the severity of the entanglement of whales lies in post-entanglement intervention, essentially enabling the whale to free itself from ensnaring gear. In the ideal scenario, the ensnaring end line would separate from the bottom gear, which could allow the whale to free itself from the end line because it is no longer being loaded by the dragging gear. The problem in the entanglement mechanism which is harmful to the whale is when a line becomes wrapped around the whale while under tension, thereby damaging the skin, and creating a potential site for infection. If the end line can somehow release from the bottom gear, the tension in the end line is relaxed, reducing the potential for scarring of the animal, or allowing the now loosely ensnaring lines to unravel.

There are two main classifications of breakaway end line techniques, these are the utilization of a weak link in the end line, or the use of a time-tension line cutter (TTLC). A weak link is a part of the gear with a known (lower than normal) breaking strength designed to part under the load of an entangled whale. Weak links can take three general forms, either as a store bought unit (typically a plastic link with nominal breaking strength), a series of hog ring crimps to form a loop connection in the line, or using an entire end line comprised of line with a nominal breaking strength (Cite NMFS poster). Figure 1.3 below illustrates how a store bought weak link could be employed. The use of a weak link in fixed gear was implemented in much of the Northeast. Nominal breaking strength requirements (from 600-1100lbs) are dependent on the area fished as well as the type of gear being fished, again this is regulated using DAM zones (Cite NMFS fed regs).

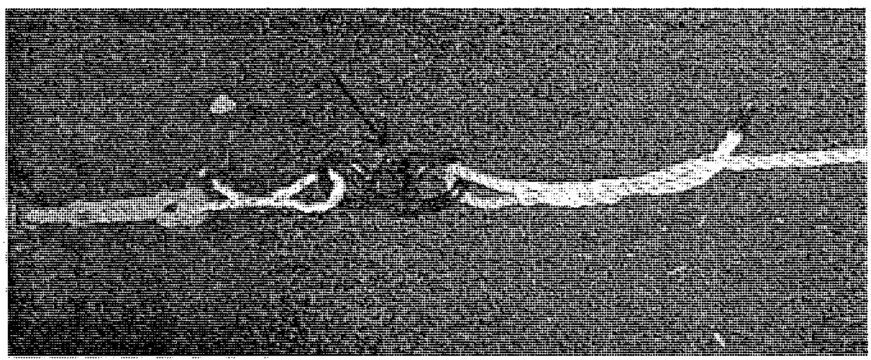

Figure 1.3: 600 Lb Weak Link
Typical configuration of store-bought 600lb swiveling weak link (Photo courtesy of Maine DMR)

A similar alternative to a discrete weak link is the use of a continuous weak element such as Whale Safe Rope (WSR). The advantage to using WSR, rather than discrete weak elements is that a continuous weak element can part at the highest concentration of stress in its length. For a weak link to break, the stress needs to be applied at the link its self. However, the same problem in quantifying the appropriate tensile strength arises with WSR as it did with discrete weak links. This is perhaps even more appropriate in terms of WSR because there is a greater chance for fatigue and wear because the rope must constantly be cycled through the hauling apparatus.

McGillicuddy(2005) developed a testing protocol for determining the breaking strength of Whale Safe Rope (WSR), developed by Dr. Norm Holy and Bob Ames of Seaside, Inc. WSR uses barium sulfate mixed in varying amounts into the polypropylene base material as a way of regulating (reducing) the breaking strength. A standardized testing protocol was developed based upon criteria set forth by the Cordage Institute (CI) to both assign engineering properties to the WSR, as well as compare its properties to industry-standard Polypropylene. In comparing the "dry" test results for WSR to that for the control Polypropylene, it was shown the average breaking strength for the WSR was 1019.5lbs as compared to 2784.2lbs for Polypropylene.

Although these results are extremely robust in terms of the consistency of the testing procedure, no results were collected for rope that had been used, to evaluate the change in characteristics of the rope over a period of time exposed to real conditions. The concern with not doing this type of a follow up calibration is that the rope being exposed to fishing situations might have the breaking strength compromised. This exposure could make the breaking strength low enough to be unsafe for use in lobster trawl hauling, resulting in lost gear or injury to fisherman without warning.

I.3 The TTLC:

A time-tension line cutter (TTLC) is a device that was developed by Ben Brickett of Blue Water Concepts (BWC) in Eliot M.E. whose goal was to eliminate the problems associated with alternative solutions to the entanglement problem (Figures 1.4, 1.5). The TTLC, uses a cutting blade whose position relative to the line is controlled by a hydraulic piston and a spring. The spring prevents the hydraulic piston from compressing within the unit, however, once a load is applied the hydraulic piston begins to force fluid from one side of the piston to the other via a small orifice. Once all of the fluid is transferred from one side to the other, the blade is engaged and the line is cut. The time to cut (TTC) is a function of the size of the hydraulic orifice, so, ideally, the fisherman could haul his gear at full strength, as long as it was within the time threshold. However, a whale would not have to encounter a disturbing load for an extended period of time, provided it could keep tension above the threshold of the spring (BWC, pers. com.). Figure 1.4 shows the internal working parts of the TTLC.

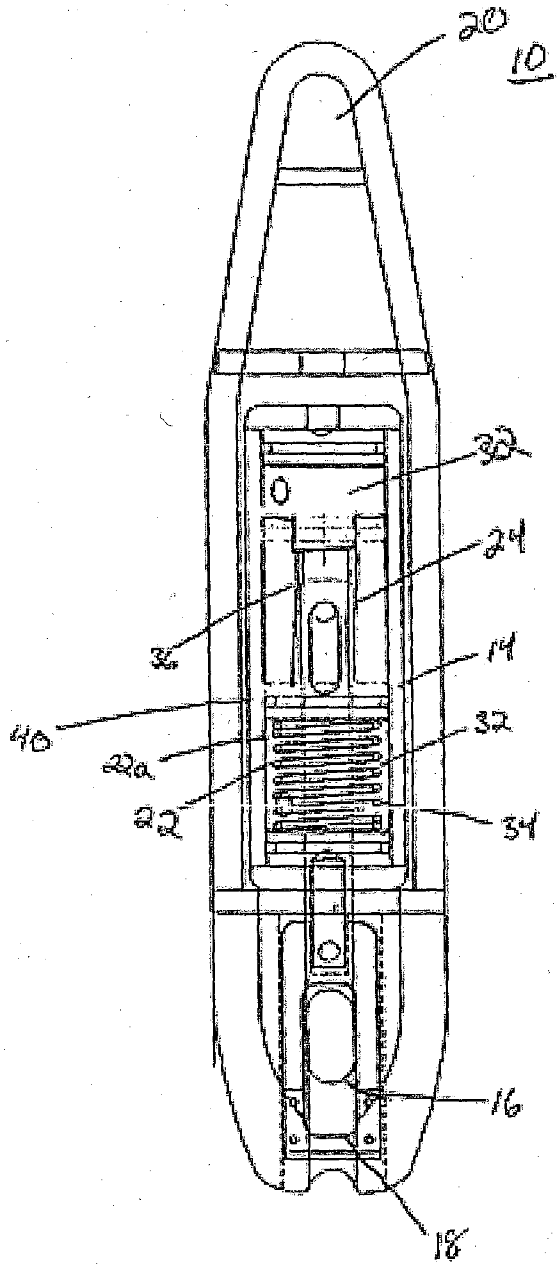

Figure 1.4- TTLC patent drawing
Drawing of the mechanical components of the TTLC. The Flow is initiated by compressing the spring (32), and driving hydraulic fluid through the restrictive orifice (36, 24), and into the secondary fluid resivior (32). This advances the blade (16) into the line, and cuts it.

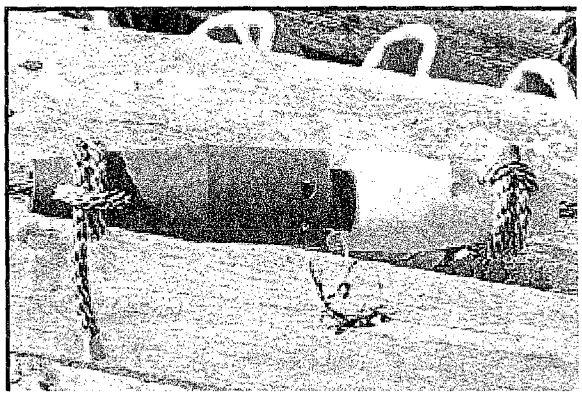

Figure 1.5: The TTLC
The gap between the two main pieces of the plastic housing correspond to the amount of hydraulic fluid displaced, which correlates to the proximity of cutting time. (Photo courtesy of Blue Water Concepts, Eliot M.E.)

The decision to continue with a more thorough evaluation of the TTLC as a device to limit the severity of entanglements of whales in passive fishing gear was based upon the results of a preliminary evaluation of the TTLC done by Baldwin and Landino (2007). In this study, the repeatability of the TTLC was tested by determining the consistency of the TTC of several different TTLCs' with different TTCs'. The results showed that the TTLC was capable of being consistent and predictable in terms of its' repeatability in the cutting process (Table 1.1). Data were also collected to investigate the time-to-cut with a change in temperature, which would change the viscosity of the hydraulic operating fluid, and thereby changing the ultimate TTC. The results from that test showed that after long term exposure to a much colder temperature (40°F vs. ~70 °F), the time-to-cut would roughly doubles (Table 1.2). The consistency of the data merited further exploration in terms of real gear testing, as well as a pilot study to test the TTLCs' ability to be fished effectively, while also evaluating their overall robustness.

Table 1.1 Summary of repeat cyclic testing from Baldwin and Landino(2007)

Serial #	NA 15	NA 20	NA 28
Time, Test 1	15m 53s	15m 48s	24m 18s
Rest Time, test 1	12m 12s	14m 28s	19m 58s
Time, Test 2	15m 33s	17m 37s	21m 48s
Rest Time, test 2	11m 42s	12m 42s	16m 42s*
Time, Test 3	36m 48s	18m 20s	28m 36s
Rest Time, test 3	29m 38s*	13m 7s	20m 31s

Table 1.2 Long term cold exposure results from Baldwin and Landino(2007)

S/N	NA 20	NA 28
Time static	~12m	~20m
Time Cold	23m 47s	41m 41s

I.4 Entanglement Characteristics

The testing that was completed in the summer of 2007 as a part of the New England Aquarium research entailed the use of a full-scale NARW flipper and side-section (Figure 1.6) to model full-scale flipper interactions with fishing gear. The flipper and belly section were designed from measurements taken from photographs and necropsy reports, and through using boat-building software Rhino-3D, a scale replica was constructed. The model was covered in neoprene "blubber" and a rubber "skin" to best represent the flesh of the whale, as well a provide as realistic a response as possible when a line is tangled around it. The flipper-line interactions were characterized by the foreward-backward angle θ, as well as the distance from the body at which the interaction occurred.

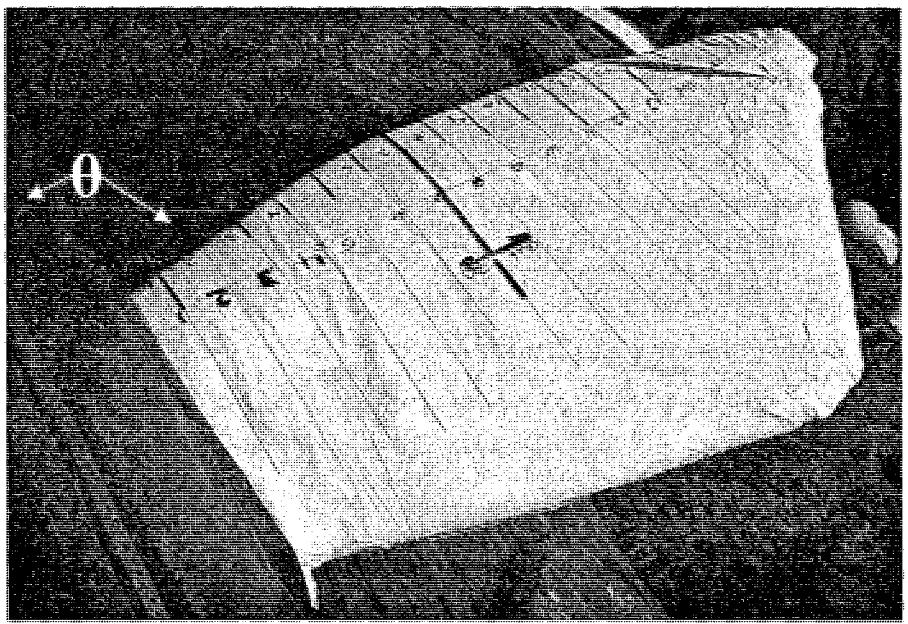

Figure 1.6: NARW Flipper
Photo of full scale NARW flipper and body section. Scale (written in black) represents 10cm per mark.

Variables tested included the angle of attack of the flipper, WSR vs. polypro, as well as including TTLCs on several of the tows. Figure 1.7 below shows load output from a run made using WSR and a TTLC on a five trap trawl. After the line became entangled around the flipper, the load was significant enough to cycle the TTLC after the prescribed time and cut the line while the WSR never broke. The load observed on the flipper never exceeded the breaking strength of the WSR. This is interesting because the load measured in these tests was the loading on the frame of the flipper, and indicated the increase in load when the gear snagged, however the specific geometry of the configuration was not recorded, and therefore exact line tension could not be measured.. There should have been an increase in stress at the junction of the flipper and the line, where the WSR should have parted under the loading of the traps in tow, if these stress concentrations were high enough. However, direct measurements of line tension or line stress were not taken in this study.

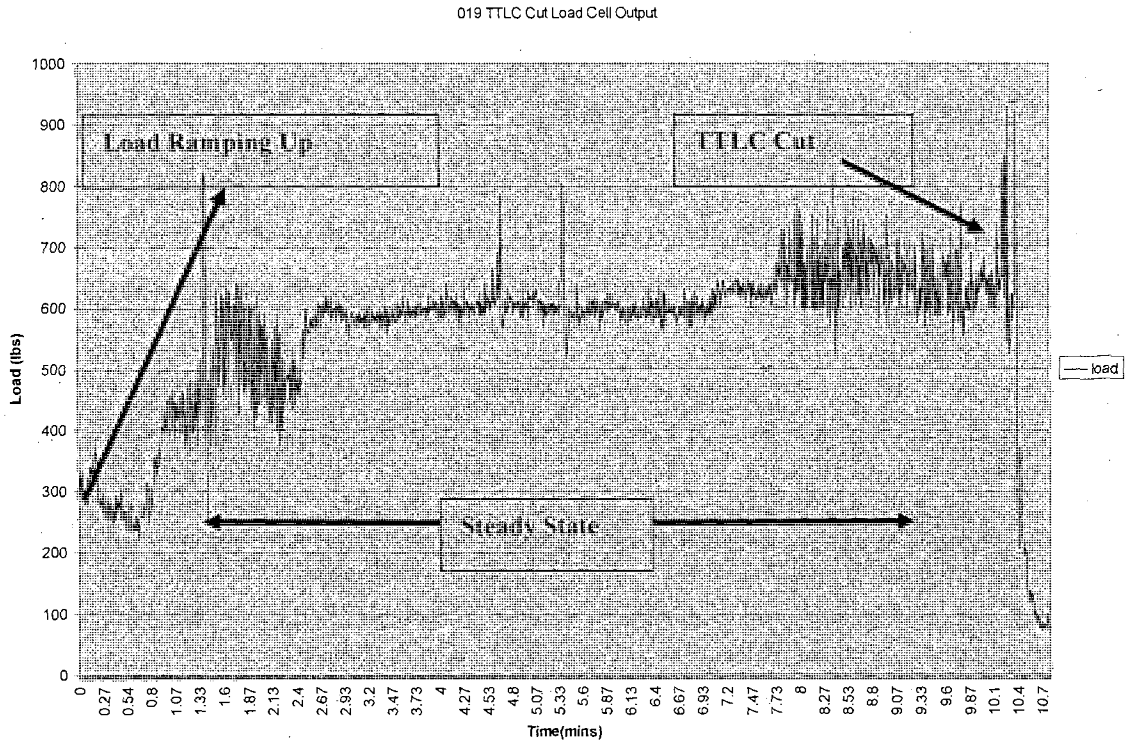

Figure 1.7: Flipper Load vs. Time
Plot of load vs. time for one flipper/gear interaction. Notice the load on the flipper, after accounting for ambient drag is ~300lbs, which was enough after ~8mins to trigger the TTLC to cut, and not enough to break the WSR of the end line.

This series of observations lead to the development of the towing experiment discussed in this paper. Since no data were collected within the trawl of traps, the altitude profile of the trawl was unknown, and the loading on the end line could have been either the hydrodynamic drag of the traps through the water, or the drag of the traps on the bottom, or a combination of both. By measuring the altitude profile of the traps while taking load measurements of a trawl in tow, the individual contributions to the load can be extracted. End line loading will be directly measured as well to provide an accurate representation of the line tension actually "felt" by an entangled whale. This will allow for better understanding on the whole of what happens to the gear when it is towed by an entangled whale, thereby allowing for a more consistent evaluation of not only the TTLC, but of whale-safe fishing methods in general.

The present study will further investigate the use of the TTLC as a disentanglement device. This will be done by using a series of trawl tows to quantify the conditions surrounding a lobster trawl under tow (in a simulated entanglement). A direct measurement of the end line tension will allow for a more representative end line tension value than the flipper measurements. The trap elevation data will also provide additional insight as to how the traps in a trawl behave while under tow, as well as if end line scope has any bearing on the trap's altitude profile under tow. Finally a pilot study will assess the TTLC as a piece of fishing gear in terms of longevity and fishability.

CHAPTER II

METHODOLOGY

II.1 Introduction

After completing flipper study in the summer of 2007, it was apparent that additional information regarding the behavior of a lobster trawl in tow was needed. Specifically, end line tension needed to be directly measured, and the altitude of the traps under tow needed to be investigated. The end result would be a simulated entanglement in which the operating conditions of the TTLC could be quantified.

II.2 Tow Testing

In the summer of 2008, data were collected to characterize the dynamics of a trawl of lobster gear in tow. This was done to simulate the behavior of the trawl after becoming entangled with a traveling whale. The data that were collected consisted of pressure readings from 5 Star-Oddi self-recording pressure sensors (to measure water column elevation), and end line loads collected using an Omega LC 203-2.5K, 2500lb capacity load cell. Variables that were tested were the water depth, number of traps in the trawl, and relative scope of the end lines (tow lines).

II.2.1 Gear Used

The traps used in these tests were 4', four-brick traps, which are typical of the nearshore lobster fishery. They were attached to a ground line with a 1 fathom gangion (Figure 2.1, L2), with the spacing between traps of 7 fathoms (Figure 2.2, L1). The heads of the traps were removed and the openings wired shut to ensure that the traps were completely un-fishable. This ground line was then attached to a short (~1 fathom) section of line to which the bottom of the TTLC would attach. From this short piece, a longer safety line was spliced in order to stay attached to the traps once the TTLC would cut the line. The end line was then attached to the top (cutting end) of the TTLC, and the longer safety line was spliced above that. Loops were tied in the end of the end lines to facilitate easy fastening to the load cell via a shackle.

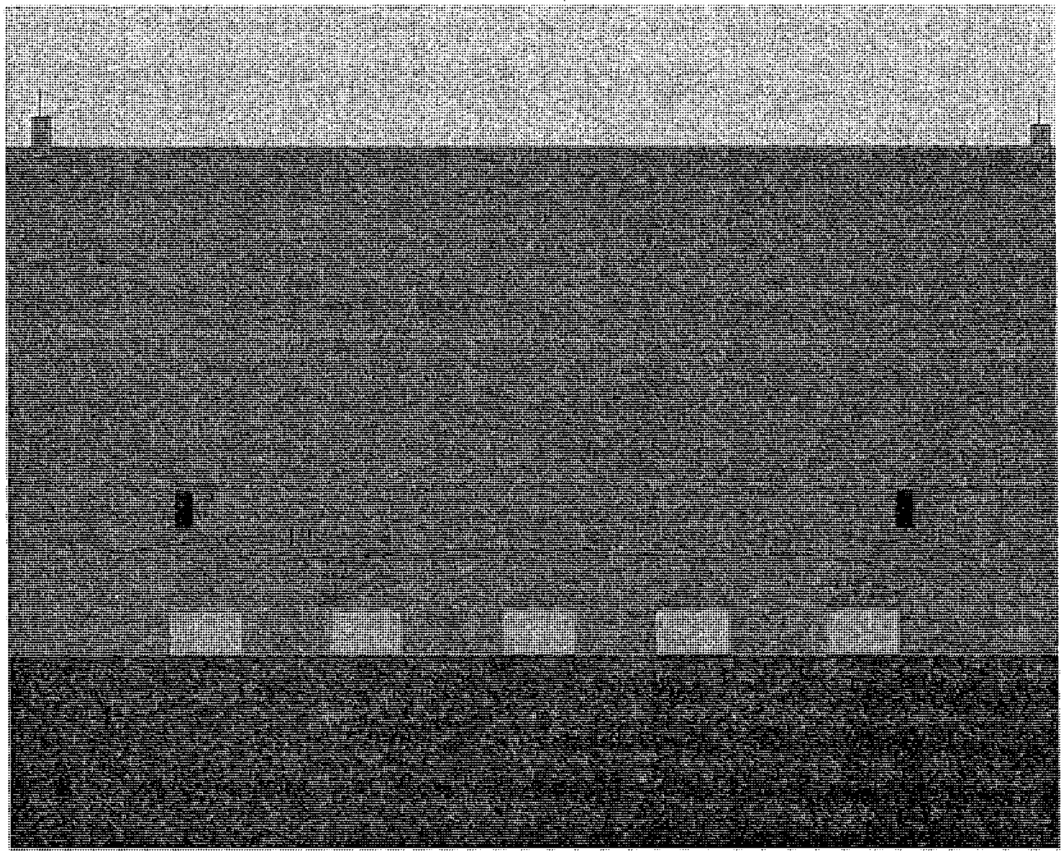

Figure 2.1: Diagram of towed gear configuration.
1. End line from buoy at surface to TTLC at the bottom. 2. Safety "jumper" keeps end line connected to ground line after the TTLC is cut (under normal fishing circumstances, this would not be attached to the end line above the TTLC). 3. The TTLC. L1 is the distance between gangions, ~7Fa, L2 is the gangion length ~1Fa.

II.2.2 Star-Oddi

The pressure sensors used in this testing procedure were Star-Oddi DST Milli self recording pressure/temperature loggers (Figure 2.2, Left). These were mounted in traps on the gear trawl to characterize the elevation of any given trap in the trawl, while in tow. These loggers were programmed, and the data subsequently downloaded via a communication box which was connected to a PC running the Star-Oddi software SeaStar (Figure 2.2, Right). The loggers could be set to record both temperature and pressure in terms of any specified unit, and could also pre-convert pressures into corresponding depths. Sampling rate, and start time could also be preset by the user via the communication box.

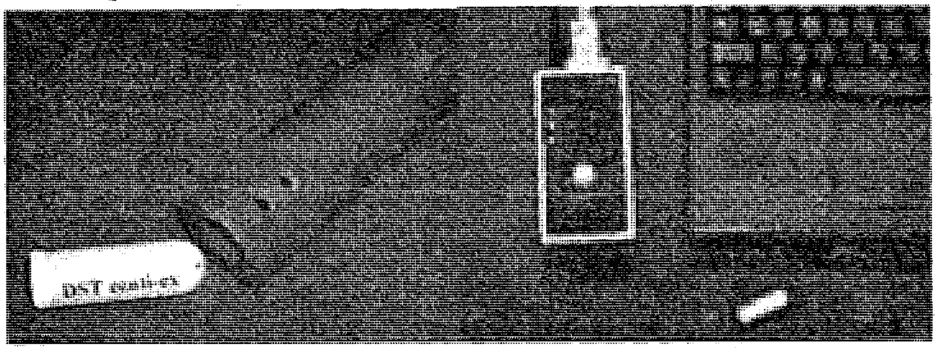

Figure 2.2: Star-Oddi and Communication Box
Images of a Star-Oddi mini logger with the protective housing, as well as the communication box that allows the loggers to be controlled (turned on, off, adjusted etc.) through a laptop while in the field. (Photo Courtesy of Star-Oddi)

Once unplugged, the loggers were placed into perforated rubber sleeves before being tied into the wire mesh of traps. The purpose of the sleeve was to protect the fragile components of the loggers as well as providing a secure method of attaching the loggers to a trap. After a series of tests were completed, the loggers were removed from their respective traps and placed back into the communication box to download the data and be turned off. The data were in the form of a .txt file that could easily be used for processing in either Matlab or Excel.

II.2.3 Load Cell

The purpose for monitoring the load on the end line in this testing was twofold- first, the load vs. time series could be used to evaluate the performance of the TTLCs, and secondly to provide a relationship between the Star-Oddi trap-elevation data vs. tension in the end line. The load cell that was used was an

Omegadyne Omega LC 203-2.5K, 2500lb capacity load cell. The output voltage from the load cell was amplified using an Omega DMD-465 signal amplifier whose gain was adjusted to scale the sensitivity of the output voltage of 0-10V to 0-2500lbs. This 0-10V output voltage was then fed through a National Instruments NI USB-6009 analog-digital converter, which was fed into a computer via USB cable. This signal was then processed by a LabView Program that converted the output voltage to load in pounds using the calibrated sensitivity (Baldwin and Landino, 2007).

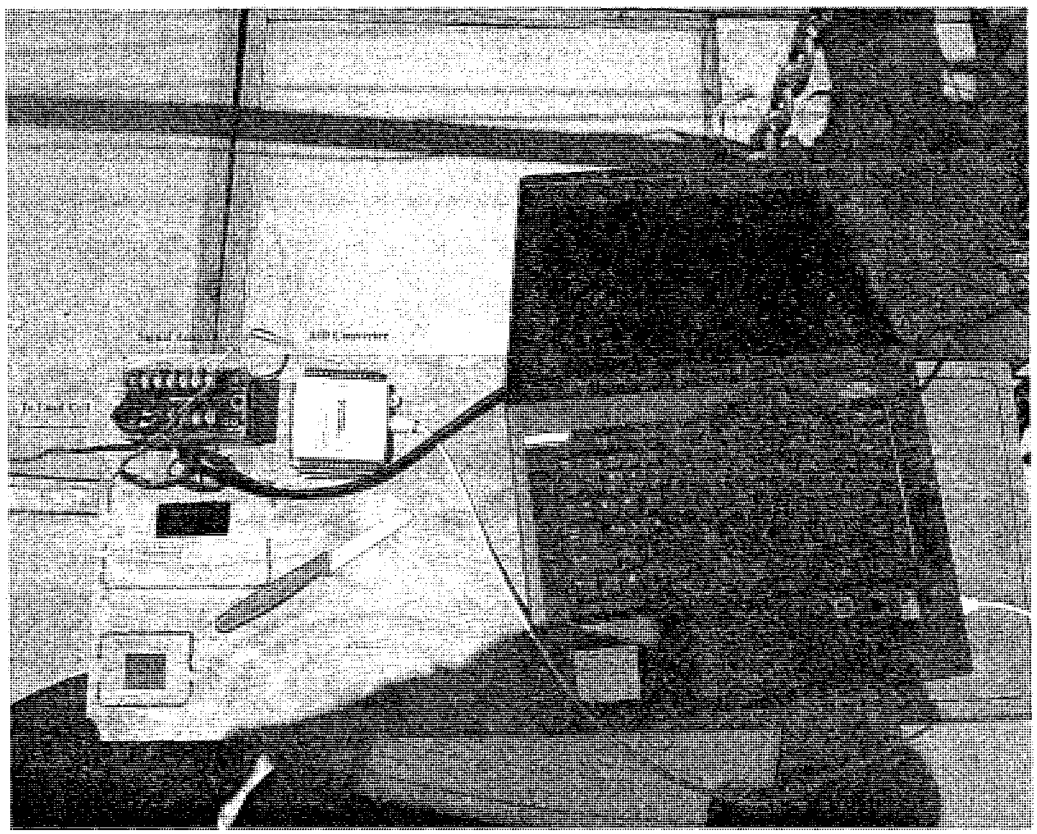

Figure 2.3: Setup to record load cell on the Jesse B
The wire on the left hand side of the picture is coming from the load cell. It then enters the signal amplifier (black box) and then is sent through an A-D board (white box) and then to the laptop running the LabView Software.

II.3 Testing Setup

The testing platform for this series of experiments was the *Jesse B* owned and operated by Blue Water Concepts of Eliot ME. The Jesse B was outfitted with a movable gin pole which could be moved up and out of the way while the boat was underway, and down into the "tow" position when a tow was being made. The load cell was fixed to the end of the pole when it was in the tow position using a shackle. Next, the end line was tied to the load cell. The idea behind lowering the pole down from the upright position was to have the point of pulling as close to the water as possible to mimic the angle at which an entangled whale would be pulling the gear, while maintaining maneuverability of the vessel. The Star-Oddi loggers were placed in different traps depending on the number of traps in the test trawl. Since there were 5 loggers, on a 5 trap trawl, a logger was placed in every trap, whereas on a 10 trap trawl, loggers were placed in traps 1, 3, 5, 8, and 10. On the 20 trap trawl, loggers were placed in the same configuration as a 10 trap trawl, which meant that either the first or last 10 traps in the trawl had loggers in them, depending on which end line was being pulled.

In this case the scope (length of line to depth of water ratio) of the end line was varied on each line, from short to long, rather than just having one end line being short and one being long, as was done in all of trawls smaller than 20 traps. The definition of "short" scope was taken as 1.33 times the depth of the water, and "long" scope was defined as 2.4 times the depth of the water. These values were held constant throughout the whole experiment, to ensure that the values of scope were consistent when the test site (ie. water depth) was changed.

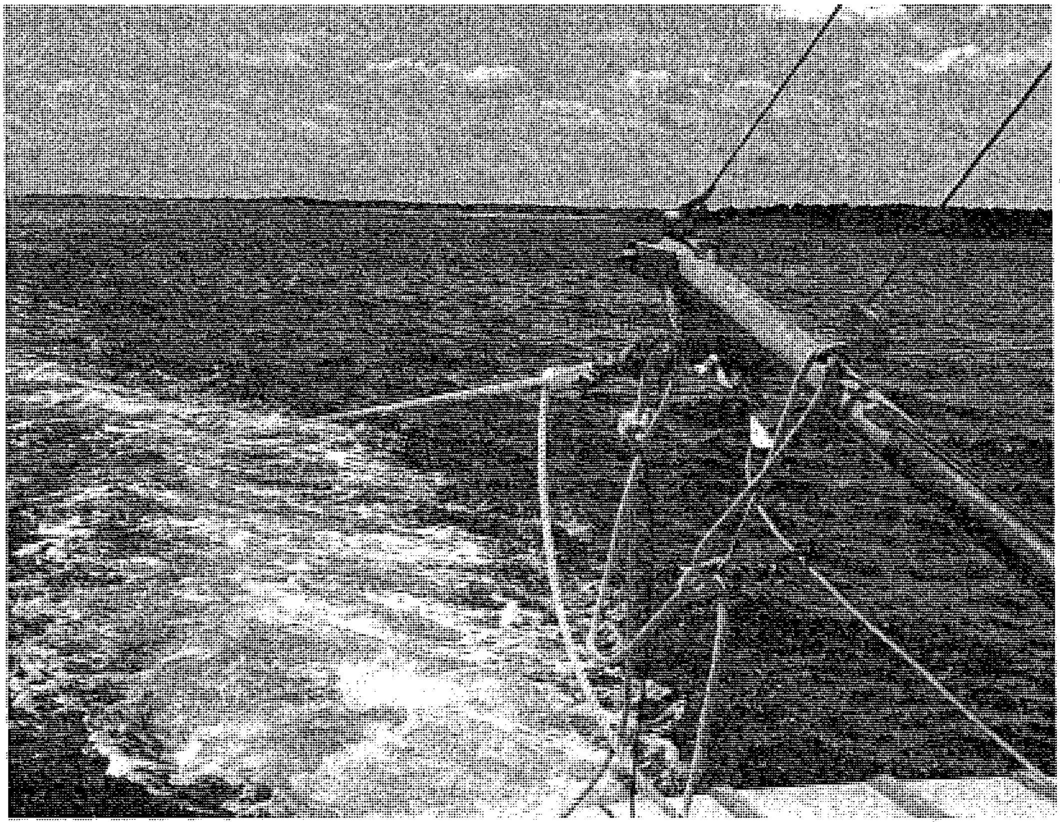

Figure 2.4: Gin pole on Jesse B in the testing position.
The load cell is at the connection point between the pole and the end line being towed.

II.4 Pilot Study

Starting in the summer of 2008, a pilot study was initiated in order to test the robustness and "fishability" of the TTLC in near shore lobster fishery in the GOM. Fifty TTLCs were assembled by Blue Water Concepts of Eliot ME in mid summer and were available for initial TTC testing by late summer. Each unit was threshold tested before being given to the fisherman for at-sea testing. This baseline testing was preformed to gauge the operation of the TTLC, find the initial TTC of each unit. This also insured that the TTC was adequate enough to fish safely.

II.4.1 Calibration

Threshold testing was done in the engineering tank at the Chase Ocean Engineering Laboratory at UNH. This was done by using the same load recording apparatus used for the tow testing to measure the load and TTC. A section of steamer chain (450lb submerged weight) was used as a deadweight to apply the amount of force required to initiate the cutting sequence of the TTLC. The TTLC was attached to the chain via short piece of line at the bottom of the unit, and then attached at the top (cutting end) via another section of line coming from the load cell. The load cell was then attached to the crane, which would allow the chain to be picked up off of the floor, and placed in the tank, thereby applying the load (weight) of the chain on the mechanism of the TTLC, initiating the cutting process. A safety line was attached from the chain to the crane to prevent the chain from sinking to the bottom of the tank after the line connecting the TTLC to the crane was cut. A diagram of this setup can be seen in Figure 2.5.

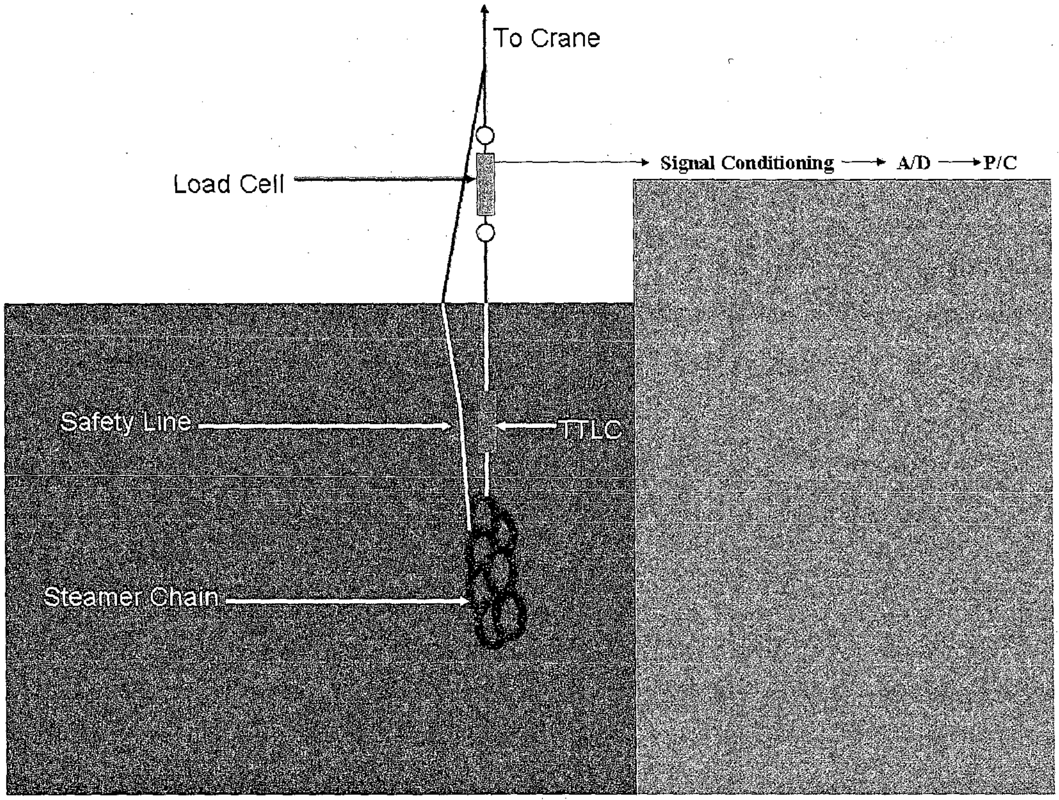

Figure 2.5: Diagram of calibration setup

The aluminum sleeve containing the moving parts of the TTLC was also marked in ¼" increments corresponding to the advancement of the blade in the cutting process (Figure 2.6). These increments were painted to correspond with how close the TTLC was to cutting the line with green being the least time elapsed, then yellow, then orange being the closest to a cut. This was done to allow the fisherman have a warning of when the TTLC was going to cut, as well as allowing for an easy way to measure the gap on the TTLC when it was being hauled.

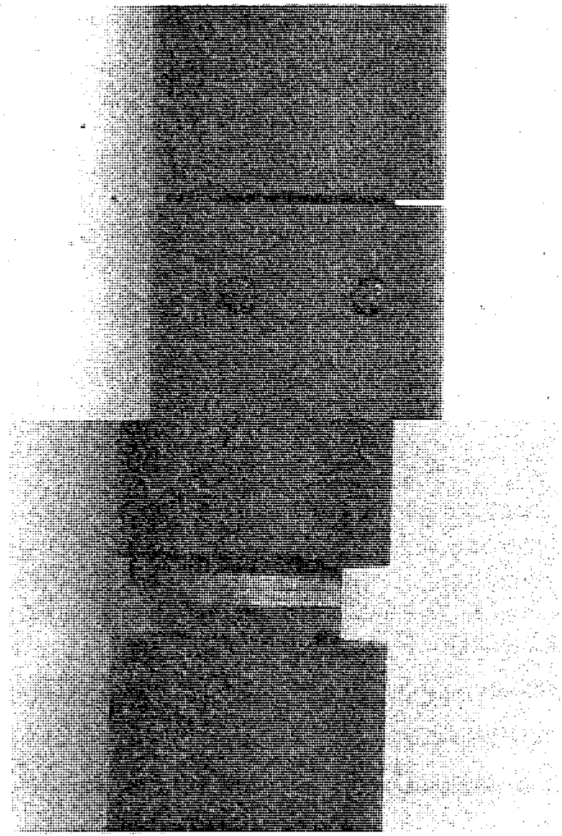

Figure 2.6: TTLC before and after cut
(left) Picture of gap in TTLC with no pressure applied, notice the lack of a gap between the upper and lower plastic housing pieces. (right) Picture of TTLC after reaching TTC, notice green, yellow, and orange time indicator bands.

II.4.2 Identifying fisherman

It was initially proposed to identify 10 fisherman from MA, NH, and ME to each fish 5 TTLCs, while periodically sending the units back to UNH for re-calibration. However, due to several factors regarding availability of candidates for this study (to be elaborated upon later), it was decided that having 5 boats fish 10 units apiece would be more feasible, and hopefully create a more robust data set in terms of having the units fished as much as possible in the timeframe of the study.

II.4.3 Suggested Rigging

When the units were being distributed, each candidate fisherman was provided with a description of how the device worked, as well as suggested rigging techniques, although the rigging methods undertaken are ultimately the decision of the fisherman. Since the TTLC is somewhat non-compliant (as compared to the rest of the end line), the unit must bypass the hauling mechanism rather then simply being cycled through. Figures 2.7 and 2.8 show the suggested rigging of the TTLC, and how this rigging would be used to haul gear. Figure 2.7 shows the TTLC approaching the block on the hauling davit with the jumper line trailing the TTLC which would be used to bypass the TTLC when hauled. At this time, the jumper line and end line would be swapped in the hauler, removing the tension from the TTLC and allowing it to bypass the block and hauler much like a trap on a trawl (figure 2.8).

Figure 2.7: Rigging method
This image shows the author's suggested rigging method as fished on the F/V *Rough Times* of Portsmouth NH. (1) The hydraulic plate-style hauler. (2) End line above and below TTLC. (3) The block hanging off of the davit on the starboard side of the vessel. (4) The TTLC. (5) The "jumper" spliced into the bottom of the end line, used to bypass the TTLC around the hauling apparatus.

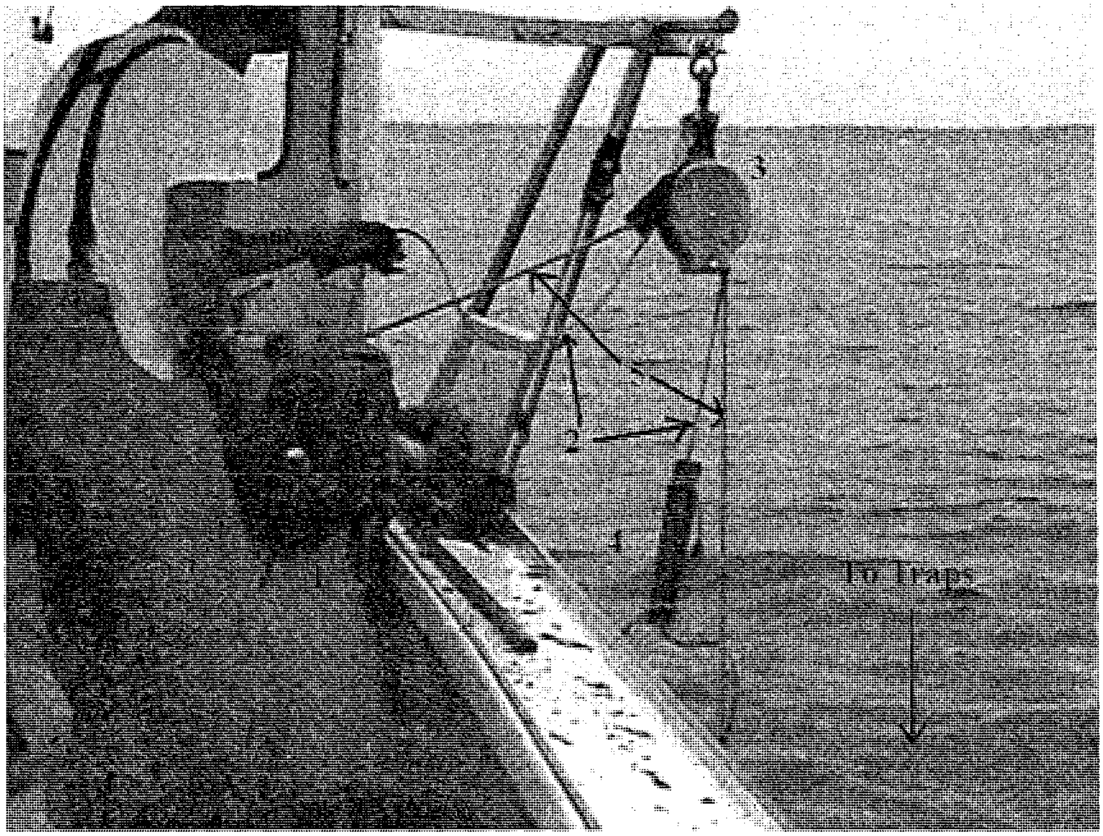

Figure 2.8: Jumping the block
This image shows the hauling procedure for the TTLC. At this instant, the end line (2) is being swapped with the jumper line (5) removing tension in the TTLC by switching the load from the end line to the jumper, the TTLC (4) is then bypassed around both the block (3) and the hauler (1).

CHAPTER III

DATA COLLECTION/REDUCTION

III.1 Introduction

This chapter presents the data collection and reduction for the two components of this study. The tow test data were collected electronically, using the pressure sensors and the load cell, while the pilot study data consisted of the log sheets filled out by the fisherman in the study, and the subsequent TTC evaluation.

III.2 Tow Test

The data were collected during the summer of 2008 from late June to early August aboard the *Jesse B*. The base station for the majority of the tests was the Blue Water Concepts Pier in Eliot ME, while two other test days were staged out of the NH State Pier in Hampton NH. Three different test sites were selected, all with different water depths, for their accessibility, and the lack of gear present (to avoid tangles, and molesting resident gear).

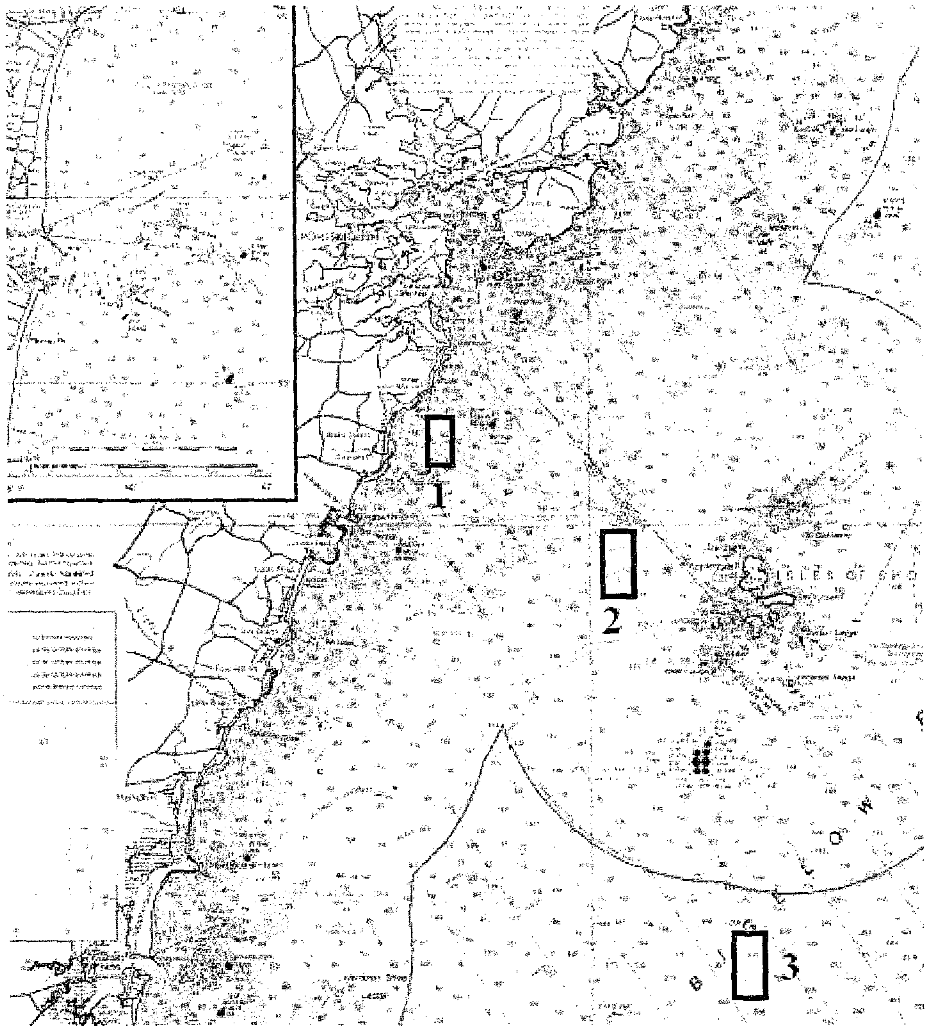

Figure 3.1: NOAA Chart 13278 highlighting testing locations.
(1) In front of Wallis Sands Beach, Rye NH ~13m. (2) Between Portsmouth NH and Isles of Shoals ~36m. (3) SE of Whaleback, ~8nm E of Hampton Harbor NH, ~73m.

Throughout the testing, a log was kept to ensure that any anomalies observed during testing would be taken into account during data processing, as well as to note any qualitative observations of each tow. While tow speed was available from a GPS it and had to be manually recorded. Engine RPMs were noted at a specific speed and kept constant throughout any given day of testing. The objective was to provide enough power to simulate a whale pulling the gear at ~2kts, by keeping the engine RPMs consistent throughout a day's testing.

III.2.1 Data reduction-Tow Test

The data for the tow test came in two forms, the data from the Star-Oddi loggers regarding depth (pressure) of the towed traps and the line tension data from the load cell. The Star-Oddi data were converted into a .txt file when they were downloaded from the loggers to the PC via the communication box at the end of each testing day. Each logger was assigned to measure depth (in meters) rather than pressure (pressure units were converted internally to corresponding depths), to eliminate a step in data processing. The data file contained a date and time stamp for each temperature and depth measurement. This time stamp made synchronizing events in the time series possible. Each logger had an offset that was corrected for by subtracting the average of the first 100 samples (when the logger was idle, and had not been submerged), thereby allowing the loggers to be "zeroed" with respect to one another, that is, scaling all depth (pressure) values to correspond to zero before being deployed. Also, since the logger output measured pressure as a positive value, thereby corresponding to a positive depth, the negative value of these depths were used to better illustrate the elevations (when plotted) of the traps off the bottom.

This final set of depth numbers was then used to provide insight into the movement of the traps while under tow. The most important thing was to identify the sections of the data set in which the traps were being towed, then finding the average elevation of the trap relative to it's starting elevation (on the bottom). This was difficult in some instances, particularly with larger trawls, because some of the traps never came off of the bottom. Also, it was necessary to make the procedure with which the data were treated consistently from data set to data set, to enable direct evaluation of the contributions of the desired unknowns.

First, it was necessary to identify each tow (run) within the data set for each logger. This was done by correlating the start time for each run in the log notes with the presence of a change in the measurement of a logger (Figure 3.2, Table 3.1). This change in depth of the logger due to towing was, understandably, more pronounced on the first trap in the series than the subsequent traps, in all cases, however in trawls in shallower water and containing fewer traps, the data was more straightforward.

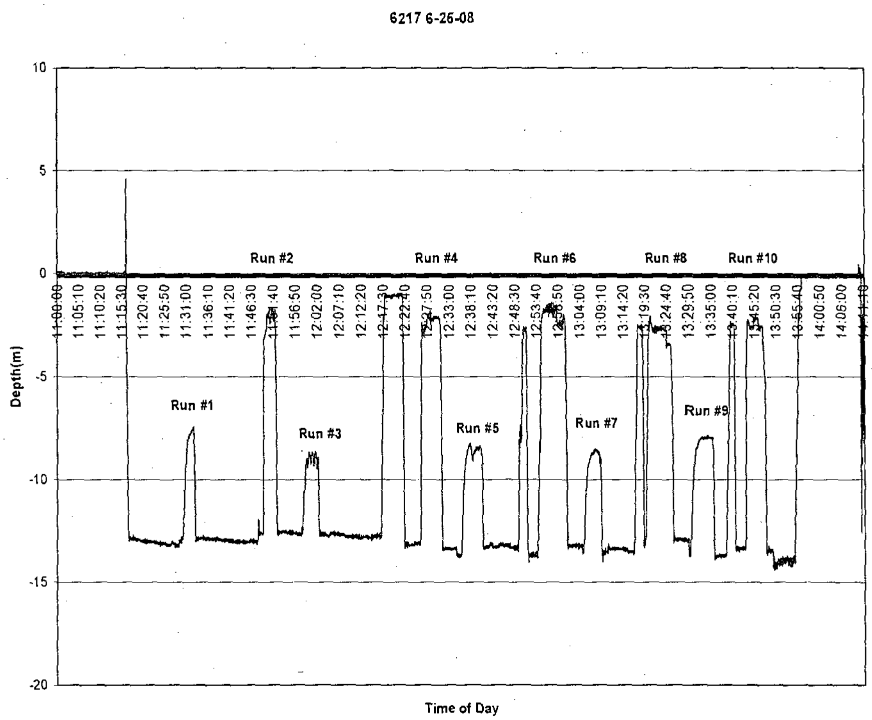

Figure 3.2: Sample Star-Oddi plot
Raw data plot for Star-Oddi logger (SN 6217) with labels corresponding to run numbers. Odd numbered runs were pulled with a long scope with this logger being the last in line out of 5, and even run numbers were pulled using the short scope, with this logger being the fist trap in line.

Table 3.1: Star-Oddi raw data sample
Star-Oddi logger data sample (SN 6217) of the last logger in a 5-trap-trawl on 6/25/08. This section of data shows the trap depth transition at the beginning of a tow test. Notice how the depth changes from being fairly consistent while the traps are on the bottom (~13m), to approaching the surface when the tow is started at ~11:30.00

Time	Uncorrected depth(m)	Corrected depth(m)	Negative depth(m)
11:30:00	11.056	14.88	-13.09932817
11:30:02	11.056	14.88	-13.09932817
11:30:04	11.056	14.67	-12.88932817
11:30:06	11.025	14.61	-12.82932817
11:30:08	11.025	14.72	-12.93932817
11:30:10	11.025	14.72	-12.93932817
11:30:12	11.025	14.67	-12.88932817
11:30:14	11.025	14.51	-12.72932817
11:30:16	11.025	14.51	-12.72932817
11:30:18	11.056	14.51	-12.72932817
11:30:20	11.088	14.41	-12.62932817
11:30:22	11.088	14.15	-12.36932817
11:30:24	11.119	14.05	-12.26932817
11:30:26	11.182	13.95	-12.16932817
11:30:28	11.307	13.8	-12.01932817
11:30:30	11.526	13.45	-11.66932817
11:30:32	11.589	13.25	-11.46932817
11:30:34	11.682	13.1	-11.31932817
11:30:36	11.744	12.89	-11.10932817
11:30:38	11.807	12.69	-10.90932817
11:30:40	11.9	12.43	-10.64932817
11:30:42	11.993	12.28	-10.49932817
11:30:44	12.055	12.13	-10.34932817
11:30:46	12.117	11.93	-10.14932817
11:30:48	12.148	11.67	-9.889328165
11:30:50	12.179	11.51	-9.729328165
11:30:52	12.21	11.41	-9.629328165
11:30:54	12.241	11.31	-9.529328165
11:30:56	12.272	11.15	-9.369328165
11:30:58	12.272	11.05	-9.269328165
11:31:00	12.302	11	-9.219328165

Once these events were isolated, an average was taken of 30 consecutive data points at what was observed to be steady-state depth for the tow for the first trap in the trawl. Since the loggers were synched with respect to time, this time period could be used throughout the rest of the loggers to represent the average steady state of the trawl for the specific tow (Table 3.2). In addition to this average measurement of the elevation of the traps during the tow, a similar average of the pre-tow depth was gathered, again being consistent in time throughout the series of loggers, to define the pre-tow bottom (Table 3.3). This was necessary to compare the elevation of the traps with respect to the pre-tow water depth.

Table 3.2: Finding average steady state trap depth
Star-Oddi logger data sample (SN 6217) of the last logger in a 5-trap-trawl on 6/25/08. This section of data shows the average (in red) of 30 samples (in bold) taken during the steady state at the start of the tow test. These values could then be compared to the pre-tow trap bottom values to determine if the traps came off the bottom or not.

Time	Uncorrected depth(m)	Corrected depth(m)	Negative depth(m)	
11:31:34	12.672	9.67	**-7.889328165**	
11:31:36	12.672	9.61	**-7.829328165**	
11:31:38	12.703	9.77	**-7.989328165**	
11:31:40	12.703	9.61	**-7.829328165**	
11:31:42	12.703	9.61	**-7.829328165**	
11:31:44	12.733	9.56	**-7.779328165**	
11:31:46	12.764	9.62	**-7.839328165**	
11:31:48	12.764	9.62	**-7.839328165**	
11:31:50	12.764	9.57	**-7.789328165**	
11:31:52	12.764	9.57	**-7.789328165**	
11:31:54	12.795	9.62	**-7.839328165**	
11:31:56	12.795	9.52	**-7.739328165**	
11:31:58	12.795	9.52	**-7.739328165**	
11:32:00	12.795	9.52	**-7.739328165**	
11:32:02	12.795	9.52	**-7.739328165**	
11:32:04	12.795	9.52	**-7.739328165**	**-7.686896**
11:32:06	12.795	9.46	**-7.679328165**	
11:32:08	12.795	9.41	**-7.629328165**	
11:32:10	12.795	9.41	**-7.629328165**	
11:32:12	12.795	9.46	**-7.679328165**	
11:32:14	12.795	9.41	**-7.629328165**	
11:32:16	12.825	9.36	**-7.579328165**	
11:32:18	12.825	9.41	**-7.629328165**	
11:32:20	12.795	9.41	**-7.629328165**	
11:32:22	12.795	9.36	**-7.579328165**	
11:32:24	12.795	9.31	**-7.529328165**	
11:32:26	12.795	9.36	**-7.579328165**	
11:32:28	12.795	9.26	**-7.479328165**	
11:32:30	12.825	9.26	**-7.479328165**	
11:32:32	12.795	9.26	**-7.479328165**	
11:32:34	12.795	9.26	**-7.479328165**	

Table 3.3: Finding pre-tow bottom depth

Star-Oddi logger data sample (SN 6217) of the last logger in a 5-trap-trawl on 6/25/08. This section of data shows bottom prior to a tow test. The value in red is the average of 30 samples (in bold) to define the pre-tow bottom depth.

Time	Uncorrected depth(m)	Corrected depth(m)	Negative depth(m)	
0.47771	10.962	14.82	**-13.03932817**	
0.47773	10.962	14.92	**-13.13932817**	
0.47775	10.962	14.87	**-13.08932817**	
0.47778	10.962	14.87	**-13.08932817**	
0.4778	10.962	14.87	**-13.08932817**	
0.47782	10.962	14.92	**-13.13932817**	
0.47785	10.962	14.92	**-13.13932817**	
0.47787	10.962	14.92	**-13.13932817**	
0.47789	10.962	14.92	**-13.13932817**	
0.47792	10.962	14.87	**-13.08932817**	
0.47794	10.962	14.92	**-13.13932817**	
0.47796	10.962	14.92	**-13.13932817**	
0.47799	10.962	14.87	**-13.08932817**	
0.47801	10.962	14.92	**-13.13932817**	
0.47803	10.962	14.92	**-13.13932817**	
0.47806	10.962	14.92	**-13.13932817**	
0.47808	10.962	15.08	**-13.29932817**	**-13.1645**
0.4781	10.962	14.92	**-13.13932817**	
0.47813	10.962	14.87	**-13.08932817**	
0.47815	10.962	15.03	**-13.24932817**	
0.47817	10.962	15.08	**-13.29932817**	
0.47819	10.962	14.97	**-13.18932817**	
0.47822	10.962	14.92	**-13.13932817**	
0.47824	10.962	15.03	**-13.24932817**	
0.47826	10.962	15.03	**-13.24932817**	
0.47829	10.962	14.92	**-13.13932817**	
0.47831	10.962	14.97	**-13.18932817**	
0.47833	10.962	15.03	**-13.24932817**	
0.47836	10.962	14.97	**-13.18932817**	
0.47838	10.962	15.03	**-13.24932817**	
0.4784	10.962	15.08	**-13.29932817**	

After producing the averages for both the bottom and trap elevation for the first trap in the tow, an Excel program was developed to carry over the time periods (corresponding to rows in the spreadsheet of each respective logger output) over which the values for trap depth were averaged, and find the averages for a different logger's output over the same time period. In the end, a value for the starting water depth, and the mean elevation for each trap (with a logger) was extracted. These data were then plotted using Excel (Figure 3.3).

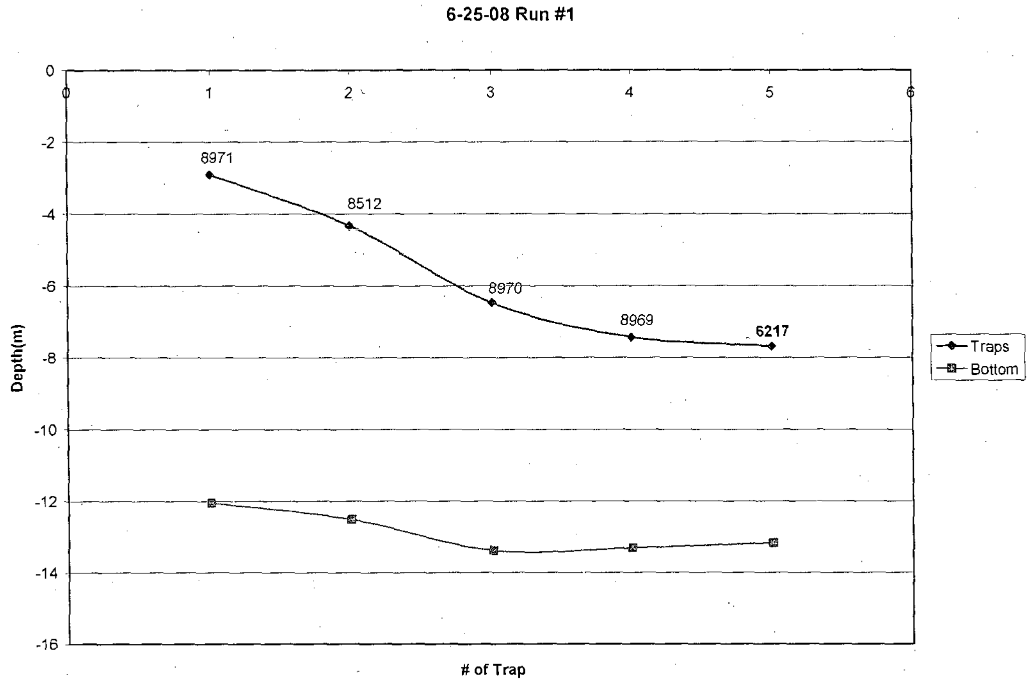

Figure 3.3: Sample trap elevation plot
Plot of run #1 on 6-25-08, using a long-scoped end line. The blue line corresponds to the traps under tow, while the pink line denotes the starting bottom depth. The logger 6217, highlighted in red is the logger for which the sample data reduction was preformed for above.

The load cell data for the tow tests were processed using Matlab code loadplotter.m (see Appendix C). This code returned the average load under tow, the maximum load during the tow, and the TTC.

III.3 Pilot Study

The data collected for the pilot study took two forms- determining the consistency of the TTC of the TTLCs as they were exposed to a fishing environment, and the qualitative data obtained from the fisherman on the TTLC Pilot Study Log Sheets (Appendix D). Before all of the TTLCs were given to fisherman, they were threshold tested as described previously. This ensured that each of the TTLCs were functioning properly, and also provided a TTC to compare the "used" units to after they were returned.

The log sheet was used to gage the performance of the TTLCs from the point of view of the fisherman, as well as provide some insight to their operating conditions. The fisherman were asked to fill out these sheets every time they hauled their TTLC-equipped gear, and fill in the matrix corresponding to each particular unit. This matrix contained selections for bottom type, depth of water, and "gap" distance (color showing).

Once the TTLCs were returned by the fisherman after the first round of testing at sea, they were returned to the lab for testing to evaluate their performance compared to the initial calibration values. This re-calibration was done under the same conditions and using the same setup as the initial calibration. The blades in the TTLC were not changed for re-calibration, however new blades will be installed in the TTLCs before they are calibrated at the termination of the pilot study, to account for discrepancies in the blade performance due to repeated cutting (chips in blade, rolled over blade, blade corrosion, etc.).

III.3.2 Data Processing- Pilot Study

Processing for the calibration data, and subsequent re-calibration data was done with the same loadplotter.m Matlab code used to process the load cell data from the tow tests. Log sheets were read and comments from fisherman were taken into consideration as to the "fishability" of the units.

Table 3.4: TTLC Recalibration

Example of TTLC recalibration as compared to original calibration TTC. The percent change refers to the increase in the TTC over the original calibration values. This re-calibration occurred after 10 hauls, without changing the blade (each blade had cut at least once before during initial calibration, and before re-calibration).

TTLC #	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ
New	6.53	5.36	5.55	7.53	7.86	5.10	10.44	10.76	7.15	5.33
Used	11.97	14.32	6.32	16.32	23.42	7.28	16.08	16.39	15.00	10.27
%change	**83.16**	**166.98**	**13.73**	**116.83**	**197.99**	**42.81**	**53.95**	**52.36**	**109.79**	**92.50**

CHAPTER IV

RESULTS

IV.1 Introduction

This chapter presents the results of the tow test, pilot study, and lab testing necessary to understand the operation of the TTLC. Each component of the study is presented separately beginning with the tow experiments, followed by the pilot study. Details pertinent to each component are presented along with the data to help clarify the results.

IV.2 Results- Tow Test

A total of seven days of tow testing data were collected, with varying water depth, bottom type, end line scope, and number of traps. A summary of the number of data sets collected in terms of the number of traps and the depth of water can be seen in Table 4.1.

Table 4.1: Tow Summary
The number of tows completed at each water depth and for each length (number of traps) trawl.

Number of Traps	~13m	~36m	~73m	Total
5	10	12	0	22
10	0	10	12	22
20	0	9	0	9
Total	14	31	12	**53**

The choice to do this type of distribution of the data were to accurately reflect fishing effort in each depth regime, that is, match the type of gear, quantity of traps on a trawl, with the depth it is commonly fished.

IV.1.1 Results- Trap Movement

The data that were extracted from the Star-Oddi loggers was formed into plots which showed the average elevation of the traps while under tow. These data was then broken down into two sets within each testing day- the tows utilizing a long end line (hawser) and those using a short end line.

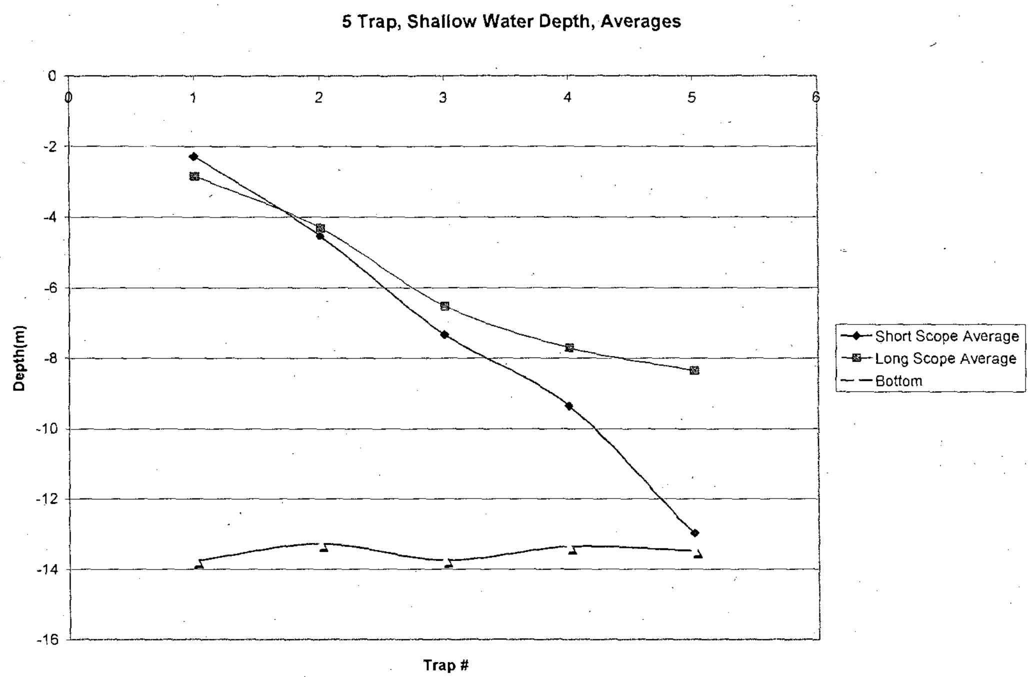

Figure 4.1: Five trap shallow water averages
This plot shows the average of all of the tow tests made with five traps in shallow water depth. Long and short scope results as well as a representative bottom are included

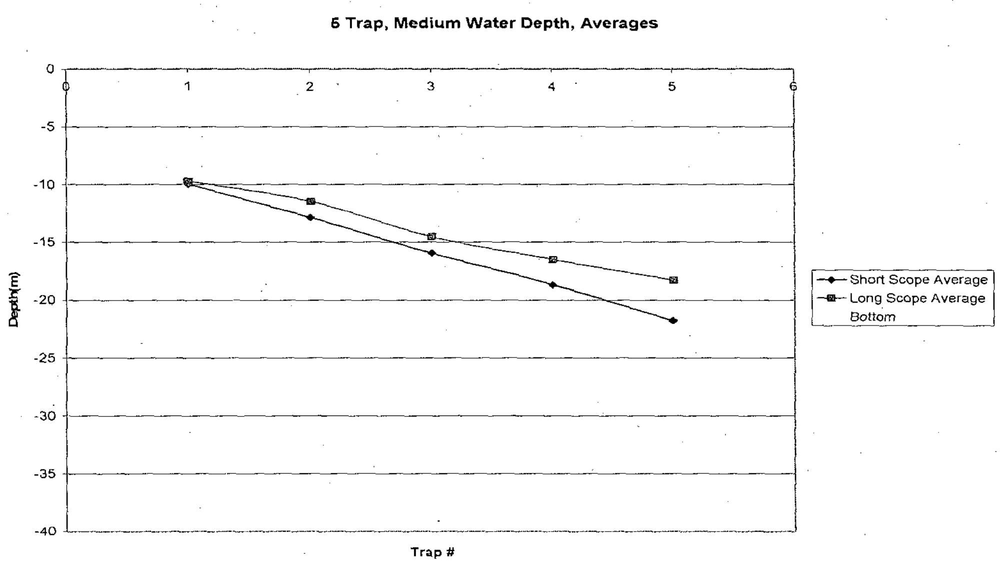

Figure 4.2: Five trap medium water averages
This plot shows the average of all of the tow tests made with five traps in medium water depth. Long and short scope results as well as a representative bottom are included

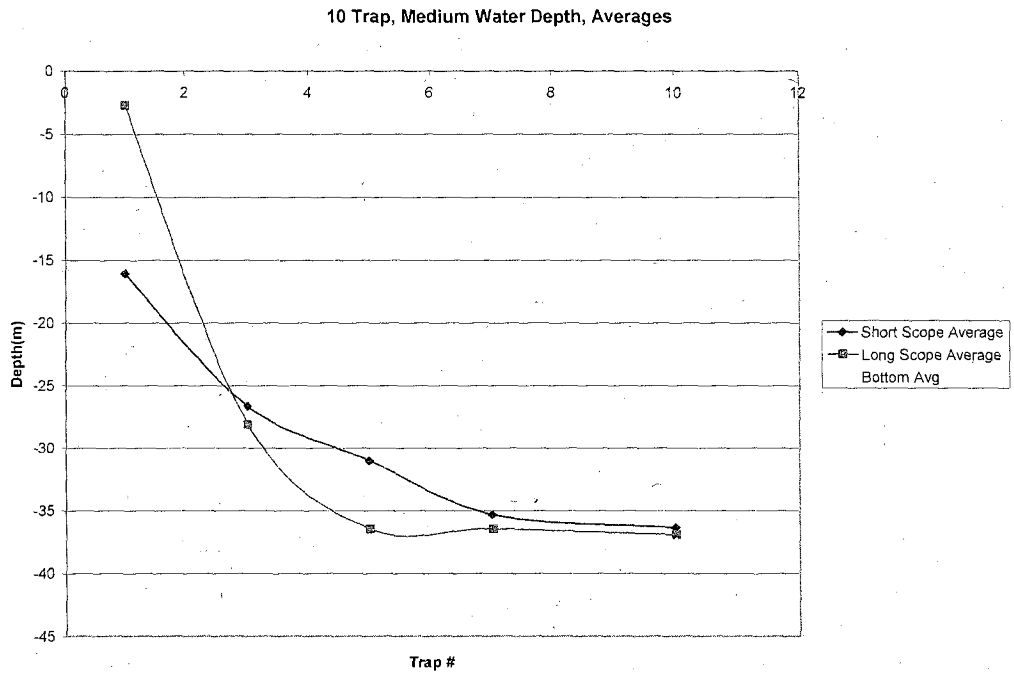

Figure 4.3: Ten trap medium water averages
This plot shows the average of all of the tow tests made with ten traps in medium water depth. Long and short scope results as well as a representative bottom are included

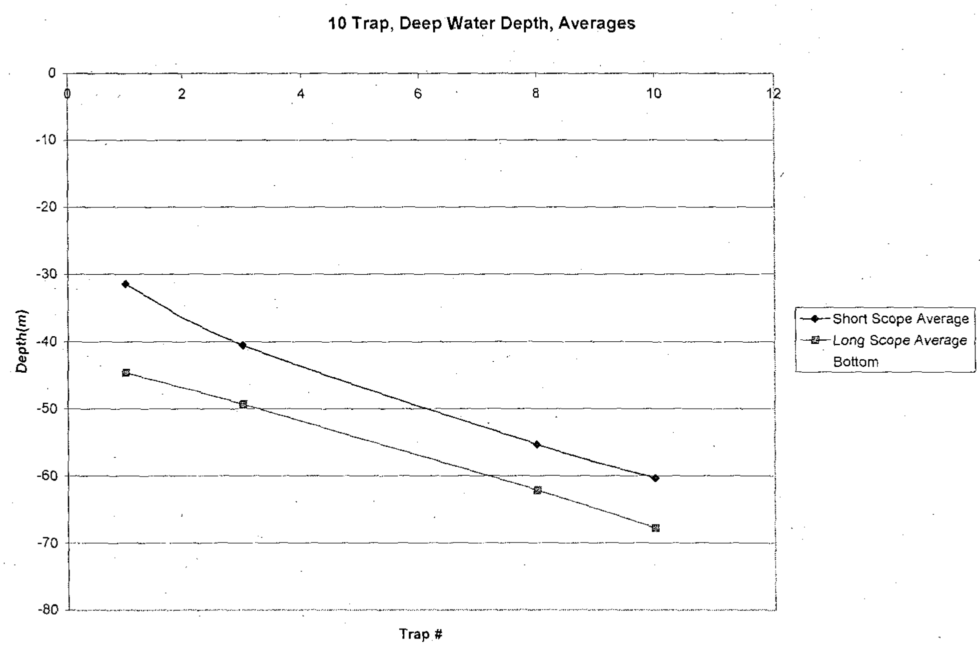

Figure 4.4: Ten trap deep water averages
This plot shows the average of all of the tow tests made with ten traps in deep water depth. Long and short scope results as well as a representative bottom are included

IV.1.2 Results- Trap Movement, Load Cell

Load cell data were taken from the Omegadyne 2.5K strain gage load cell, rigged from the gin pole on the Jesse B. This loading represents the tension in the end line (towing hawser), which represents both the force on the whale by the trailing gear, as well as the force on the TTLC at the bottom of the end line. Tables 4.2-4.4 shows a summary of the load results.

Table 4.2: Five trap load data
Summary of load cell and TTLC cut time data for all five trap trawl tow tests
The loading data shown is the average towed load, and the maximum load during the tow. This average load was taken from the start of the tow until the tow was finished or the TTLC was cut. Blade chips occurred when "blade" was noted.

6/25/2008 (5 traps, shallow water)										
run	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
avg(lbs)	565.8	572.2	564.6	527.0	570.8	570.0	587.5	491.5	581.4	492.8
max(lbs)	633.3	642.5	654.6	666.6	722.2	742.3	746.7	711.8	741.6	796.6
ttc(min)	3.0	no ttlc	4.2	4.5	5.1	6.0	4.4	5.7	5.8	4.6
6/27/2008 (5 traps, medium water)										
run	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**		
avg(lbs)	486.4	433.5	495.8	451.2	451.2	502.2	495.7	451.9		
max(lbs)	707.0	764.2	633.9	559.8	596.7	562.4	646.6	575.4		
ttc(min)	6.4	10.1	7.2	blade	8.0	blade	5.5	blade		
7/9/2008 (5 traps, shallow water)										
run	**1**	**2**	**3**	**4**						
avg(lbs)	372.1	404.4	439.2	489.1						
max(lbs)	468.6	482.3	546.5	625.6						
ttc(min)	6.7	tangle	7.9	18.2						

Table 4.3: 10 trap load data

Summary of load cell and TTLC cut time data for all 10 trap trawl tow tests The loading data shown is the average towed load, and the maximum load during the tow. This average load was taken from the start of the tow until the tow was finished or the TTLC was cut.

7/2/2008 (10 traps, medium water)

run	1	2	3	4	5	6	7	8	9	10
avg(lbs)	508.8	628.1	572.6	537.6	541.8	595.7	548.6	629.8	611.3	626.8
max(lbs)	693.3	1119.2	837.0	1016.9	896.7	905.3	908.2	803.9	935.8	1056.9
ttc(min)	6.5	4.6	5.7	6.1	6.2	6.1	6.2	4.8	5.3	5.0

7/16/2008 (10 traps, deep water)

run	1	2	3	4	5	6	7	8
avg(lbs)	590.2	531.0	540.1	585.5	584.7	539.4	604.1	526.4
max(lbs)	795.3	648.2	688.2	931.0	708.9	789.6	1003.2	731.5
ttc(min)	11.9	11.5	6.0	12.5	5.0	15.0	11.3	broke line

7/17/2008 (10 traps, deep water)

run	1	2	3	4
avg(lbs)	561.8	603.4	605.1	675.8
max(lbs)	713.7	774.0	983.5	1045.5
ttc(min)	8.0	6.2	17.3	15.2

Table 4.4: 20 trap load data

Summary of load cell and TTLC cut time data for all 20 trap trawl tow tests The loading data shown is the average towed load, and the maximum load during the tow. This average load was taken from the start of the tow until the tow was finished or the TTLC was cut.

8/13/2008 (20 traps, medium water)

run	1	2	3	4	5	6	7	8	9
avg(lbs)	947.4	1015.3	1046.8	929.7	874.9	937.3	947.0	830.4	673.2
max(lbs)	1251.7	1338.5	1212.0	1438.3	1138.6	1221.8	1372.2	1143.7	1219.0
ttc(min)	no record	11.4	7.5	engine	7.1	2.5	tangle	tangle	tangle

IV.3 Results: Pilot Study

F/V *Rough Times*, Capt. Chris Adamaitis:

Ten TTLCs (SN AA through AJ) were distributed to Mr. Adamaitis in midsummer 2008 and were fished aboard his boat *Rough Times* out of Portsmouth NH throughout the Fall of 2008 and Spring of 2009. The 10 TTLCs were fished on one end line of 10 trawls, all but one of which were 10 trap trawls. These

TTLCs were rigged as shown previously in Figure 2.7, being fished at the bottom of the end line, and being rigged as they would in a normal fishing situation. Only one TTLC was used per trawl, with the other end line remaining intact, in case of TTLC malfunction, enabling the gear to be hauled in a standard method as well.

After spending ~ 1 month exposed to fishing conditions and completing 10 hauls of the test gear using the TTLCs, as prescribed, and filling out the provided log sheets, the TTLCs were returned to UNH for re-calibration using the same setup described in Figure 2.5. The data for this re-calibration can be found in Table 4.5, The TTLCs were then given back to Mr. Adamaitis for another iteration of testing beginning in the late fall of 2008 and continuing the spring of 2009, after the gear had been hauled out for the winter.

At the conclusion of the testing, Mr. Adamaitis expressed no concerns about the durability of the TTLC, nor did he hint as to any difficulty in the fishability of the TTLC. He had no significant problems with hauling his gear other than "getting used" to using a jumper to bypass the TTLC around the block during hauling. Once he became familiar with the procedure, he claimed that fishing with the TTLCs was not unsafe, and didn't add significant time to his hauling routine, which were the major concerns for many fisherman when previously shown the TTLC.

The only concern in terms of the fishability of the TTLC expressed by Mr. Adamaitis was that the line would chafe around the attachment points of the TTLC over time, thereby weakening the line and potentially allowing it to break during a storm or in the hauling process. He suggests that since the TTLC sinks, it could roll around the bottom, thereby chafing the line at the attachment points. Also, he expressed a concern that when the TTLC would sink, it would allow the inclusion of sediment in the line, thereby abrading the line as a whole when cyclically loaded, and working the grains of sediment against the individual strands of line. His solution to the problem would be to somehow either float the TTLC or to make the TTLC itself buoyant so as to eliminate the bottom sediment interaction with the line. He also noted that the TTLC without modification could be used effectively if the user took note of any chafing of the line and simply advanced the line through the TTLC periodically and eliminated the chafed portion of line. Table 4.5 contains the return data for the first return of the TTLCs' after 10 hauls.

Table 4.5: F/V Rough Times return data

TTLC #	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ
New	6.53	5.36	5.55	7.53	7.86	5.10	10.44	10.76	7.15	5.33
Used	11.97	14.32	6.32	16.32	23.42	7.28	16.08	16.39	15.00	10.27
%change	**83.16**	**166.98**	**13.73**	**116.83**	**197.99**	**42.81**	**53.95**	**52.36**	**109.79**	**92.50**

F/V *Island Lady*, Capt. Bob Bryant:

Ten TTLCs (SN AK through AT) were given to Mr. Bryant to fish on his boat the *Island Lady* out of Portsmouth NH, in September of 2008 and fished through November of 2008 for a total of 10 hauls of the gear. The TTLCs were rigged as suggested, as shown in Figure 2.7. Overall, Mr. Bryant expressed no concern with the fishability or durability of the TTLCs he was given. Table 4.6 contains the return data for the first return of the TTLCs' after 10 hauls.

Table 4.6: F/V Island Lady return data

TTLC #	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT
New(min)	7.5	5.3	6.0	12.7	9.3	6.8	7.0	3.6	8.3	4.2
Used(min)	20.7	21.9	16.0	25.0	11.8	16.4	12.3	6.4	21.7	6.1
%change	**275.7**	**413.8**	**265.6**	**196.8**	**126.7**	**240.1**	**177.0**	**177.0**	**261.0**	**145.0**

Capt. Eliot Thomas:

Ten TTLCs were given to Mr. Thomas in late August 2008 to be fished for 10 hauls during the fall season aboard his vessel out of Yarmouth ME. When the units were delivered to Mr. Thomas, he was informed of the suggested method of rigging and hauling the TTLCs, and he seemed confident that his testing of the units would go off without a hitch. Also, he was provided with the author's contact information (email and phone number) in case there was a problem with the testing. After several months, the author attempted contacting Mr. Thomas via e-mail, and later phone, at which time Mr. Thomas informed him that he had fished one TTLC for one haul back and deemed the device "Unsafe due to having to jump the block, especially for a fisherman who fishes alone". When asked to arrange a time to pick up the devices to be returned to UNH for re-evaluation and to be sent out with another fisherman, he informed the author that he had given the units to Patrice McCarron of the Maine Lobesterman's Association (MLA), despite the fact that the MLA had no affiliation with the project.

The units were finally returned, after making arrangements with Ms. McCaron, on February 6th 2009, and were in essentially unused condition. Also, the log sheets given to Mr. Thomas were absent, and were substituted with the MLA report on the TTLC, which included an MLA log sheet filled out by Mr. Thomas entailing his experience with the UNH TTLCs, which were not intended to be a part of an MLA study, as the TTLCs provided for that study were part of a completely different study, using older generations of the TTLC. In short, the

MLA was included in this study in a capacity that was not consistent with its' objectives, and it was apparent that there was no intentions to follow the guidelines of the study, as Mr. Thomas simply echoed the general attitude of the MLA in reference to the TTLCs both in their statements made in meetings, as well as their conclusions in their own research.

F/V *Patty-B*, Capt. Dale Blatchford:

Ten TTLCs were given to Mr. Blatchford in September of 2008 for testing during the late fall/winter of 2008. The units were tested throughout the fall and winter, and were returned in the spring of 2009. Unfortunately, the TTLCs were not rigged as they were intended to be used, but instead, rigged beneath the bouy as if they were a weak link. This was unfortuate from the standpoint of assessing the hauling strategies employed by Mr. Blatchford, in that there was no need for him to jump the block with the TTLC while hauling. However the amount of exposure time to the ocean elements, while having also be exposed during the winter makes the data set all the more robust.

F/V *Patricia Lynn*, Capt. Josiah Derringer:

Ten TTLCs were given to Mr. Derringer in July of 2009 for testing during the summer of 2009 for 10 hauls. Although results are not yet available, as the testing is concurrent at the time of this paper, preliminary comments from Mr.

Derringer are available. Of particular interest is his style of rigging the TTLCs on his gear, which is unlike all of the other participants in the study. He is using, and fishing the TTLC without using a jumper line beneath the TTLC to bypass the TTLC around the block. He is instead manually pulling the TTTLC around the block because he felt it unnecessary to install a jumper, and has, thus far, experienced no problems.

CHAPTER V

DATA ANALYSIS

V.1 Tow Test Analysis

The objective of the tow tests were to understand the behavior of lobster gear while being towed by an entangled, traveling whale. The quantitative data collected were in the form of pressure transducer data to measure the depth of the traps relative to the surface, and in turn their height off the bottom while under tow, and load cell data to both quantify the load felt by the animal due to the ensnaring gear, as well as providing a simple way of identifying the TTC of the TTLC.

V.1.1 Pressure Transducer (Trap Elevation) Analysis

Of the seven days at sea testing, two were completed using only four of the five because one of the transducers (SN 8970) was lost during one of those days. However, the remaining four transducers were intact and recording reliably. A replacement Star-Oddi was obtained to complete the testing. One of the variables in this test was the dependence of the scope of the end line on the trawl elevation profile while under tow. It was found that the scope of the end line changed the depth profiles of the traps, however differently as the depth and number of traps changed.

For the five trap trawl tows in shallow water, the trawls towed from a shorter-scoped end line tended more towards the bottom than those with the longer scope (Figure 4.1). In this case the difference between the averages for the shallow water testing and the deep water testing were also quite dramatic. In the shallow water test, the long-scoped had all five traps consistently off of the bottom and the profile of the traps was fairly smooth, with traps 3, 4, and 5, on average, lying within two meters of each other in the water column. However, for the short scoped end line tests in the same water depth, the profile is quite different, with the traps all tending more to the bottom in a more linear fashion, with traps 3, 4, and 5 not leveling out like they did in the long scope tows.

In the medium water depth (Figure 4.2), the trap profiles for both the short and long scoped end lines more closely resembled the shallow water profile of the long scope tests. Again, the short scoped profile tended to be generally deeper than that of the long scope profiles, but not nearly as drastic as those for the shallow water tests, but the traps, as a whole were deeper than that for the shallow water tests. All of the 5 trap trawl tests had all 5 traps in the trawl completely off the bottom with the exception of a few of the shallow water, short scope tows, in which case the 5^{th} trap in line sometimes was on the bottom while under tow.

In terms of the 10 trap trawls, in the medium water depth (Figure 4.3), both the long and short scoped tows tended near the bottom with traps 3-10 consistently within 10m of the bottom. The most noticeable of the differences between the long and short scoped tows for the medium water depth were that the long scoped tows had the first two traps significantly higher in the water column than the short scoped tows, the 3rd trap was at the same relative elevation, but subsequent traps tended more towards the bottom, until the 7th-10th traps were both the long and short scoped data sets showed the traps at or near the bottom.

The 10 trap deep water tows (Figure 4.4) were significantly different than the 10 trap tows in medium water depth. The profiles were less dramatic than the medium water depth, and were much like the profiles of the 5 trap trawl in medium water depth, however the short scoped tows were consistently higher off the bottom than the long scope tows.

V.1.2 Tow Test- Sources of Error

Naturally, as with any experiment, there were unforeseen sources of error that need to be qualitatively taken into consideration while analyzing the data. First, the actual velocity of the tows were approximate and taken as the average speed over ground (SOG) taken from the GPS on the *Jesse B*. This speed was simply noted periodically throughout the tow and was written down in the log for the tow. Also, engine RPMs were noted, and were, as close as possible, held consistent for a series of tests. These precautions were taken to try and eliminate speed as a variable, and keep the speed consistent at 2-3 knots for each test. This was difficult to regulate with extreme accuracy because of the tradeoff between basing the test on SOG or on engine RPMs. Since the engine RPMs were the easiest to regulate, and provided a consistent pulling force, rather than speed, the engine RPM were held consistent for a series of tests. Another concern with using

SOG rather than engine RPMs is that SOG doesn't take into consideration the influence of ocean currents. The inclusion of the local currents during a test is important because it influences the relative velocity of the flow field around the traps, and since the traps are supposed to be towed at 2-3 knots, the exclusion of ocean currents on the results could not be neglected, and hence, SOG becomes an inaccurate metric of measuring speed.

Even with using engine RPMs as a way of quantifying and keeping tests consistent, there still is some uncertainty in the consistency of the results in terms of the actual velocity of the flow field encountered by the traps. This discrepancy would influence not only the elevation profile of the traps, but would influence the loading data as well. This could be remedied in future tow tests by employing an ADCP while conducting the tow tests, as well as a GPS that could record position and SOG in real time. This would allow for a correlation between the current magnitude, and direction, which could correct the ship's SOG into a real velocity felt by the traps, thereby allowing for more thorough interpretation of the trap profile and loading data.

Sea state and weather were noted daily in the log, and were fairly consistent, as only days with calm sea conditions were used for testing, this was done to ensure the accuracy of the data, as well as to ensure the safety of the vessel and equipment.

The largest discrepancy in the entire test was with the data for the 20 trap trawl test. Since only five pressure transducers were available, it was decided to place the transducers in the first 10 traps, in the same configuration as they would be in a 10 trap trawl. The idea behind this type of configuration, is that the trawl could be pulled first by the end with the transducers closer to the tow line, and then again with the transducers being far away from the end line. This could be done using both a short and long scoped end line, with the end result being appearing as though 10 transducers had been distributed throughout the trawl. The results, however, were difficult to interpret.

Another source of error was that the *Jesse B* could not, at times, muster enough power to move the entire trawl, without "stalling out" (propeller moving, but no forward progress being made), or overheating the keel-cooled engine and transmission. Also, at some point during the test, the towed trawl became ensnared in some unmarked, abandoned, lobster gear. This was an added variable that undoubtedly effected the results, as the exact time of the entanglement in the abandoned gear was unknown, and the extent to its effect on the test remains unknown. However, this event could simulate what could actually happen if a whale became entangled in a trawl of lobster gear, that is an ensnaring trawl gathering additional gear as it was being towed. The TTLC in this case still preformed as designed, and cut the end line after a period of time in all four instances in which the TTLC was used.

V.1.3 Tow Test- TTLC Performance

Overall, the TTLCs preformed as designed, with cuts occurring on the majority of tests, within their calibrated timeframe. The largest deviation in time consistency seemed to stem from the blades in the TTLC becoming chipped or otherwise damaged (edge rolled over, etc.) due to repeated cutting. In a real scenario, however, the blade in the TTLC would be in pristine condition because repeated cuts would not ocurr under operating conditions, as they did throughout the tow testing. A more in-depth look at the contribution of blade fatigue on the variance of the time to cut was investigated as part of the pilot study section.

V.2. Pilot Study

In terms of the consistency of the calibration results, a controlled testing procedure was strictly followed, and kept consistent throughout the calibrations of the TTLCs throughout the pilot study. There were some discrepancies in TTC between the original TTC and the "used" (after 10 hauls of exposure) TTC. Using table 4.5 data from the first retest of the TTLCs deployed aboard the F/V *Rough Times*, it is apparent that all of the TTLCs yielded a longer TTC after being deployed, with the percent change in times varying between 13.73% and 197.99%. It is impossible at this time to determine whether or not the discrepancies in time are a result of the degradation of the mechanical process of the TTLC, or are simply a function of blade fatigue due to repeated cutting. The simplest way to eliminate the blade fatigue issue as a variable would be to replace the blades after having completed a cut. This has not been tested at the moment, but will be discussed under future work, in Chapter VII.

V.2.1 Pilot Study- Fisherman feedback analysis

The qualitative feedback from the fisherman participating in the pilot study was quite promising in terms of their ability to be fished effectively. There were, however several concerns were expressed by the fisherman about improvements that could be made to make the units be more "fishable". One general concern, across the board was with the fact that the units sink when deployed, thereby allowing for the units and their connecting lines to interact with the bottom. This is of particular concern when fishing on hard bottom because the TTLC could roll across the bottom and be lodged between rocks, making retrieval of the gear difficult. Several of the fisherman indicated that adding some type of flotation, or by making the unit itself buoyant would be preferable over the existing design and deployment. Compounding the issue of the sinking TTLC is the fact that they are round and could roll across the bottom, increasing its ability to hang on the bottom. A suggested fix to this problem would be to have the plastic housing of the TTLC have square edges, which would make the units less likely to roll along the bottom, and therefore less likely to find a hang.

CHAPTER VI

LAB WORK

6.1: Further Investigation/Lab Work

After performing the tow tests on the Jesse B, it was apparent that additional insight into the mechanics of the towed traps was needed to better correlate the contributions of each individual component of the gear in tow to better understand the trap profiles and end line loading data generated during the tow test.

Since the end line loading at steady state (traps all being off the bottom) is essentially a measure of the drag force of the gear due to the oncoming water (tow) velocity. The two factors that contribute -to this hydrodynamic drag are the lines (both the end line and ground line) and the traps. Equation 6.1 (Fridman, 1986) estimates the drag force on a towed line in terms of water (tow) velocity, line diameter, line length, and angle of attack.

$$R_x = C_x * L * D * q \qquad \text{Equation (6.1)}$$

Where,

$$q = \frac{\rho * V^2}{2} \qquad (6.1.1)$$

Where R_x is the line drag force, C_x is the coefficient of drag, L and D are the length and diameter of the line, respectively, and q is the hydrodynamic stagnation pressure. C_x is dependent on the angle of attack (α) between the line and the approaching water velocity. Fridman (1986), relates C_x and α with Table 6.1 based upon data collected using 16mm steel rope. This estimation also neglects the dependence of C_x on the magnitude of the Reynolds number, however the table provided allows for baseline estimate for C_x.

Table 6.1: Cx dependence on α (Fridman, 1986)

α(deg)	C_x	α(deg)	C_x
0	0.12	50	0.70
10	0.20	60	0.90
20	0.32	70	1.12
30	0.41	80	1.25
40	0.56	90	1.30

Since C_x is dependent on the angle of attack of the line in the flow, and the angle of each line in each test was highly variable, even within data sets (particularly between traps), a Matlab code was written to extract the angle of the both the end line and the ground line in between traps. The code line_drag_calc.m loads the average trap elevation data from a set of tow tests, and calculates α of each line segment in the trawl. Figure 6.1 shows how the code extracts the angles (α1,α2) from lengths (L1,L2) and trap depths (D1, D2), using simple trigonometry. The code then interpolates the data from Table 6.1 for a value of C_x, and uses this value in Equation 6.1 to calculate the drag for each segment of line. The sum of these line segment drags is the net drag on the whole trawl due to the line.

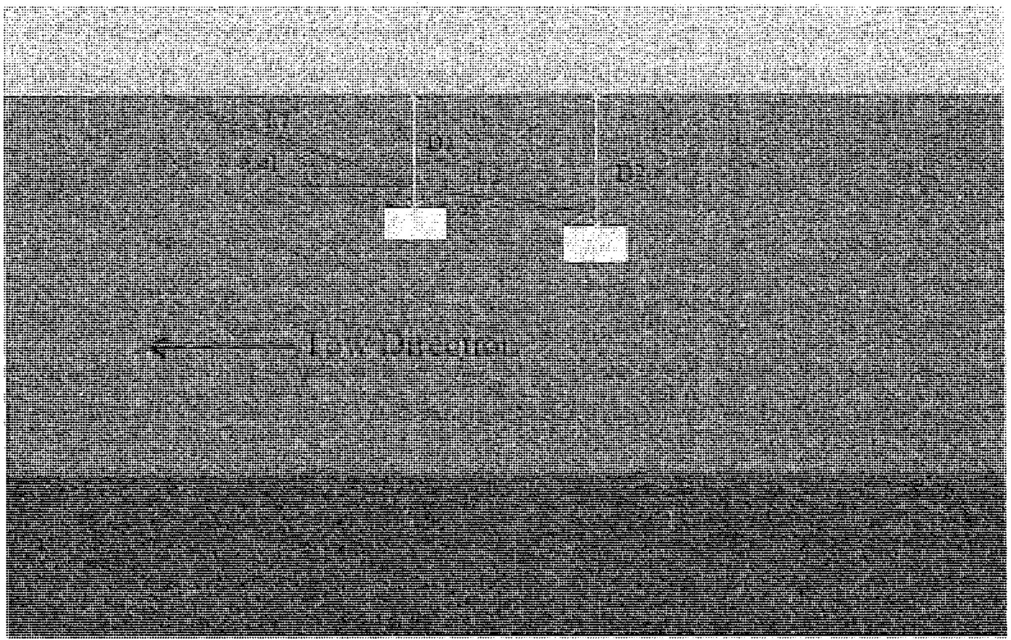

Figure 6.1: Model definition
Diagram of tow setup showing resultant angles ($\alpha 1$,$\alpha 2$) as a relation to lengths (L1,L2) and trap depths (D1, D2) relative to the tow direction which is opposite of the incident flow. Since the angle of the line connecting each trap as well as the angle of both end lines differ from each other, these angles need to be calculated independently for each line segment, yielding a different drag coefficient and therefore a different drag force for each line segment.

Since D remained constant for all tests, and L only varied with changing trap configurations, only C_x and q were variable from test to test, in terms of the drag force contributions of the line. Once the code extracted these individual drag contributions of the line segments of the trawls for each average testing scenario, it could be compared to the measured values for line tension in the tow to provide insight as to the contribution of line drag to the total tension value in the end line. This could then be combined with an analytical estimation of the amount of drag force exerted by a trap to form a complete model of the end line tension in terms of the static (weight) and dynamic (drag) contributions of the line and the traps.

However, due to the complex geometry of a lobster trap, finding a generic value for a drag coefficient (C_{xtrap}) from a chart or a table was difficult. The simplest and most accurate method for evaluating C_{xtrap} of the trap was to perform a series of tow tests at a controlled velocity in order to back out a consistent value for C_{xtrap}. Equation 6.2 is used to back out this C_{xtrap} given the measured drag force via a load cell in a towing experiment, projected area of the trap, known water density, and tow velocity.

$$R_x = \frac{1}{2} C_{xtrap} * \rho * A * V^2 \qquad (6.2)$$

Where R_x is the resultant drag force of the trap being towed, C_{xtrap} is the drag coefficient of the trap, ρ is the density of water, A is the projected area of the trap exposed to the flow, and V is the tow (fluid) velocity. One interesting variable in this equation, particularly in how it applies to this specific problem is the definition of the projected area A. To simplify the calculation it was assumed that the front face of the trap comprised the projected area normal to the flow. This area was chosen because of the dominance of the contribution of the parallel (to the flow) faces of the trap, and also because the inclusion of the trailing face of the trap would have to include the presence of shadowing from the leading face of the trap, which is exceedingly computationally intensive for this investigation. Then C_{xtrap} could be extracted using the known towing velocities, the constant water density, the constant projected area of the trap, and the measured value of the resultant drag force.

6.2: Tow Tank Test

The UNH tow tank consists of a 100'x12'x8' deep tank with a cable driven tow carriage to which the towed structure is attached. In this case, since hydrodynamic drag was the desired quantity to be measured, the drag force needed to be isolated so it could be directly measured with the load cell attached to the carriage. The setup was adapted from Risso(2007) in which the towing apparatus was used to test net panels for scaling use in aquaculture applications. Similarly, in the case of the net panels, hydrodynamic drag was the desired quantity, and was measured using a swiveling mount of the net panel to allow for lateral movement in the direction of the flow (drag) while inhibiting vertical movement of the panel (lift), in order to measure the purest possible component of the drag force.

The setup for this experiment consisted of two vertical, and one horizontal sections of 80/20 Inc. aluminum stock attached to a swiveling assembly made of 1.5" pipe (Figure 6.2). This mount was attached to the trailing side of the carriage, while an aluminum beam holding the load cell was attached to the leading side of the carriage. In this case, once a bridle line was lead from the trap to the load cell, and a tow was started, the trap would swivel on its mount about the axis of the horizontal pipe, allowing the load cell to record the horizontal resistivity of the trap against the oncoming flow (hydrodynamic drag). The load cell that was used was a Sentran 50lb S-beam load cell with an output voltage capacity of 0-10V and was captured using the in-house Labview software on the tow carriage computer

(Figure 6.3). The data was then processed in Matlab using steady_state_v3.m to return the average loading and to plot the load cell output.

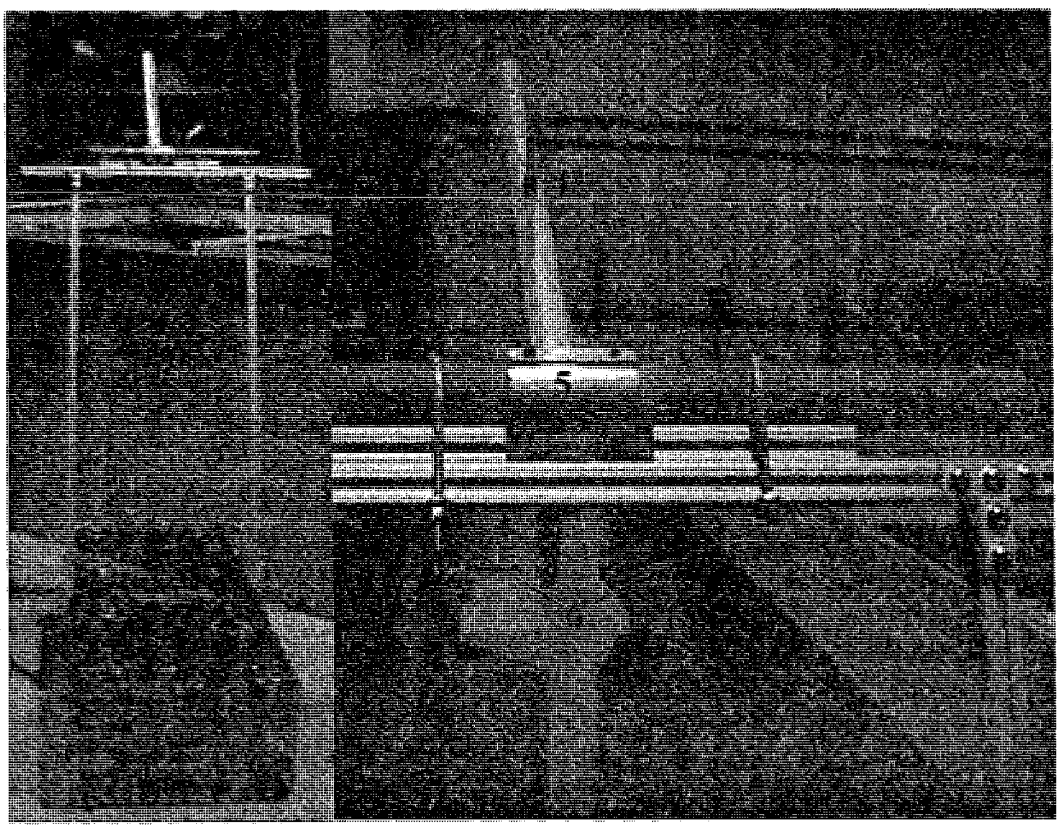

Figure 6.2: Tow carriage mount
Photos of mounting apparatus used to perform tow test in UNH tow tank to extract drag data. The components of the mount are as follows: (1) Standard 4', 3 brick lobster trap. (2) 80/20 extruded aluminum stock and connectors used for uprights and cross member. (3)1.5" OD steel pipe. (4)1.5" OD aluminum pipe used to attach the mount to the tow carriage; holes were added to provide elevation adjustment. (5) Pipe connection with ID slightly higher than the OD of the vertical and horizontal pipes. This connector was tightened on the vertical pipe, and left loose on the horizontal pipe, allowing the mount to swivel about the axis of the horizontal pipe. (6) U-bolts and 80/20 spacers attached the horizontal pipe to the 80/20 cross member, while allowing for the swiveling pipe connection to rotate.

Figure 6.3: Load cell and bridle
The towing setup attached to the tow carriage, with the load cell attached to a vertical beam aligned with the leading edge of the trap. A bridle is rigged from the outside edges of the trap, and reduced to one line leading to the load cell.

6.3: Results of the model

Data were collected using the computer aboard the tow carriage, which was controlled using the computer on the control station above the tow tank. Data that were collected were the output voltage of the load cell vs. elapsed time for three different velocities (0.5, 0.75, and 1m/s), with three repetitions at each velocity. These data were plotted (Figure 6.4) using Excel and a polynomial equation was fit to the data to enable a prediction for drag force at velocities different than those completed in the test.

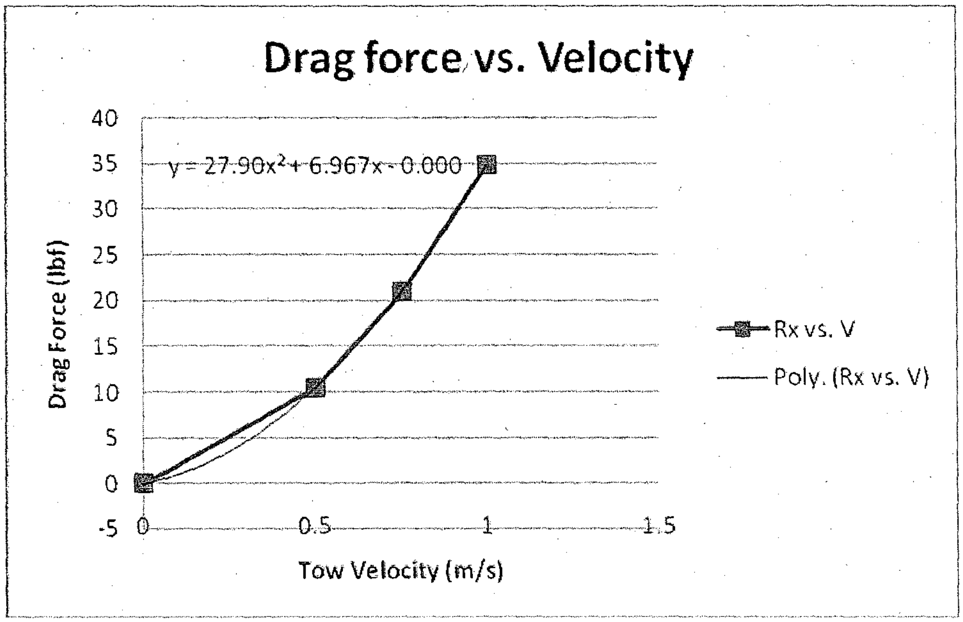

Figure 6.4: Drag force vs. tow velocity
Plot of Drag force vs. tow velocity for one lobster trap being towed in the UNH tow tank. The trend line represents the polynomial curve fit to the data, assuming that drag varies as V^2.

The culmination of this experiment and series of calculations were to develop a method for predicting the end line tension of a series of traps in tow. In comparing the results of this numerical/lab testing to the field study results, values for the loading are similar in magnitude, albeit not terribly accurate, but certainly representative. Table 6.2 shows the analytical data based upon the drag calculations and tow tank tests. The average of the loading data from the field tow test, shown in Table 6.3, are generally less than the analytical.

Table 6.2: Numerically derived drag values
Sample of numerically derived line drag forces with and without the measured drag of a trap from the tank tow test. These values were based upon a 2kt simulated towing speed, and all values are measured in pounds.

Depth	Shallow	Shallow	Medium	Medium	Deep	Deep
Scope	Short	Long	Short	Long	Short	Long
5(line only)	134.13	106.96	207.99	202.4	N/A	N/A
10(line only)	N/A	N/A	355.63	482.43	774.69	842
5(traps inc)	520.08	492.91	593.94	588.35	N/A	N/A
10(traps inc)	N/A	N/A	1127	1254	1546	1614

Table 6.3: Load averages for field tow tests.
Load averages for the field tow tests broken down in the same fashion as the theoretical prediction data in table 6.2. Loads are in pounds.

Depth	Shallow	Shallow	Medium	Medium	Deep	Deep
Scope	Short	Long	Short	Long	Short	Long
5 traps	530.68	574.06	546.71	455.37	N/A	N/A
10 traps	N/A	N/A	556.62	603.56	580.81	567.92

The difference between the field data and the analytical data is much less for the five trap trawl then for the 10 trap trawl, for several potential reasons. One reason is that there was significantly less bottom influence on the five trap trawl field data because the traps were almost always off of the bottom, whereas with the 10 trap trawl this was not always the case. Also, as previously mentioned, the lack of a reliable metric for measuring the oncoming water velocity during a field tow (taking into account boat speed coupled with currents, etc) makes for a difficult comparison in terms of what analytical velocity with which to compare the field results.

Perhaps the most interesting variable that was neglected in the analytical approach is that of lift in the traps as they are towed, which may alleviate some of the force imparted by the trap drag component. Lift in the towed trap was not measured in the tow tank tests, but would have, and most likely did occur during the field tow tests. Since the traps in the towed trawls were not rigidly connected to the ground line, they could pivot, making the trap at an angle, rather than completely normal to the incident flow. This would make the trap act much like an airfoil, creating a lift component, making the trap travel up in the water column, and alleviating some of the end line tension. Since the analytical model did not account for this lift term, 10 trap trawls have a much more significant end line load than does a five trap trawl. However, in the field experiment, although the 10 trap trawls experienced a higher load than the five trap trawl, the difference was not as significant, meaning that another force (lift) was potentially alleviating some of the end line tension that would not normally occur in a purely drag scenario.

CHAPTER VII

FUTURE WORK/CONCLUSIONS

VII.1 Future Work

In terms of the field tow test, improvements in the testing protocol regarding an accurate measurement of the trawl speed, as a function of recording the vessel speed as well as other contributing factors, would make the data that much more consistent in terms of controlling the speed variable. Also, using an attitude sensor to measure the angle at which a trap lies naturally while being towed on a trawl could prove to be useful, especially in terms of tailoring a future controlled tank test to determine the lift contribution of a towed trap.

Continuing the pilot study is also very important in terms of evaluating not only the robustness of the TTLC, but also to see if the comfort level of the fisherman using the device will increase with time as well. There are currently one set of 10 TTLCs' still being fished, and two sets of 10 awaiting recalibration at the writing of this report. There is concern, however, with the increase in TTC as the units had been cycled a number of times. This is most likely due to blade degradation, rather than a failure in the cutting mechanism of the TTLC, as visible blade failures did occur. The simplest way to test for this discrepancy is to replace the blade in each TTLC after it is returned from its final deployment in the pilot study. If the TTC for a thoroughly used unit with a new blade is comparable to the first time it was initially calibrated, the problems with the variance in the TTC between calibrations could be attributed to the blades.

The analytical approach to modeling the trap movement, using a numerical model and a tow tank test also has some room for improvement. The inclusion of a lift measurement in the tow test could prove to be valuable and may yield results closer to that of a field tow test. This would be accomplished by holding the trap at a variety of angles and using a load cell that could be rigged in a way to measure lift as well as drag. This, coupled with the data from an attitude sensor in a trap during a field tow test and correlating the natural tow angle with the lift force generated using a tank tow at that same angle to get a more representative analytical approach.

VII.2 Conclusion

The field tow testing and pilot study were completed in an effort to test the TTLC as a whale safe fishing alternative. Also, an analytical model was developed in hopes to verify the results of the field testing portion of the project.

The data collected in the field testing were useful in determining the behavior of lobster trawls in tow, as they could be in an entanglement scenario. The trap profiles showed a dependence on water depth, end line scope, and the number of traps in the trawl. Nevertheless, the TTLC preformed as designed for any type of configuration, under the common loading scenarios, and anomalies in the cut times were commonly attributed to the blade in the unit deteriorating over a series of cuts.

The pilot study was useful in that feedback was obtained from fisherman about how the units would handle once they were deployed in a real fishing situation. It was also valuable to be able to test used units for their repeatability after being used. The units all functioned when they were returned after being fished, with most of them having a longer TTC than they did before they were deployed. This is likely due to blade fatigue as a result of multiple cuts with the same blade. This also is consistent with the findings of Baldwin and Landino 2007.

The analytical model proved to be an interesting complement to the field testing in that it verified some numbers (particularly with the 5 trap trawl data), and most importantly, identified the contributing forces acting on the end line in an entanglement. A more robust model would allow for an accurate prediction of end line tension, and could be used to develop a whale-safety threshold for differing gear configurations.

Continuing the pilot study, and obtaining additional feedback from fisherman, as well identifying the blade fatigue problem as the culprit in the increased TTC of the returned pilot study TTLCs, are important in assessing the TTLC as both a whale-safe device, as well as a piece of fishing equipment. The data collected in this study, however, was significant in that end line loading and trawl depth profiles in an entanglement scenario are better understood, and can be predicted to a certain degree.

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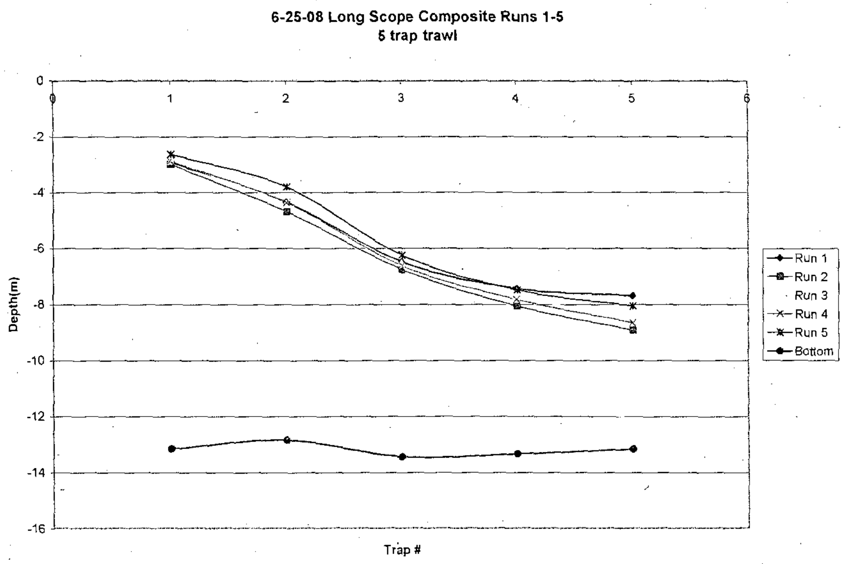
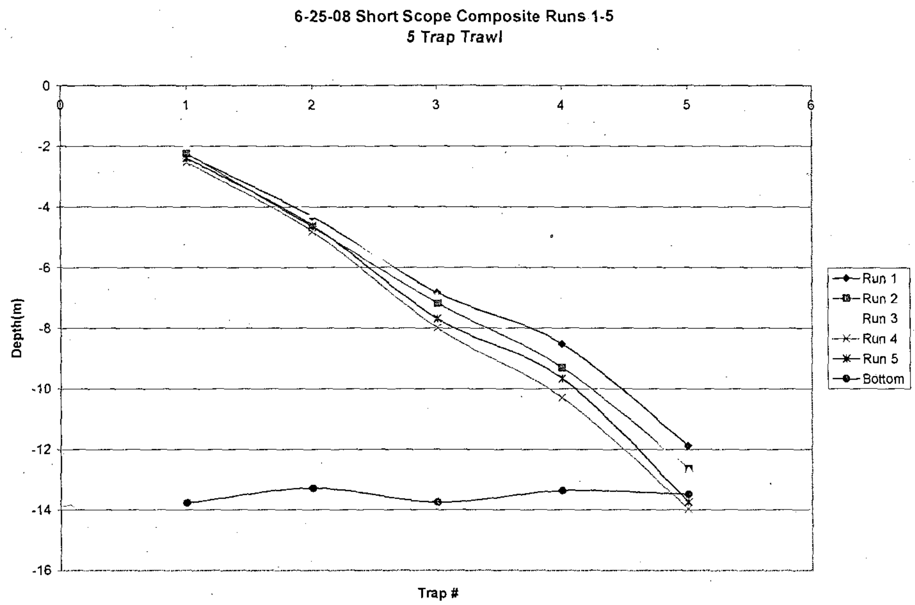
APPEDICIES

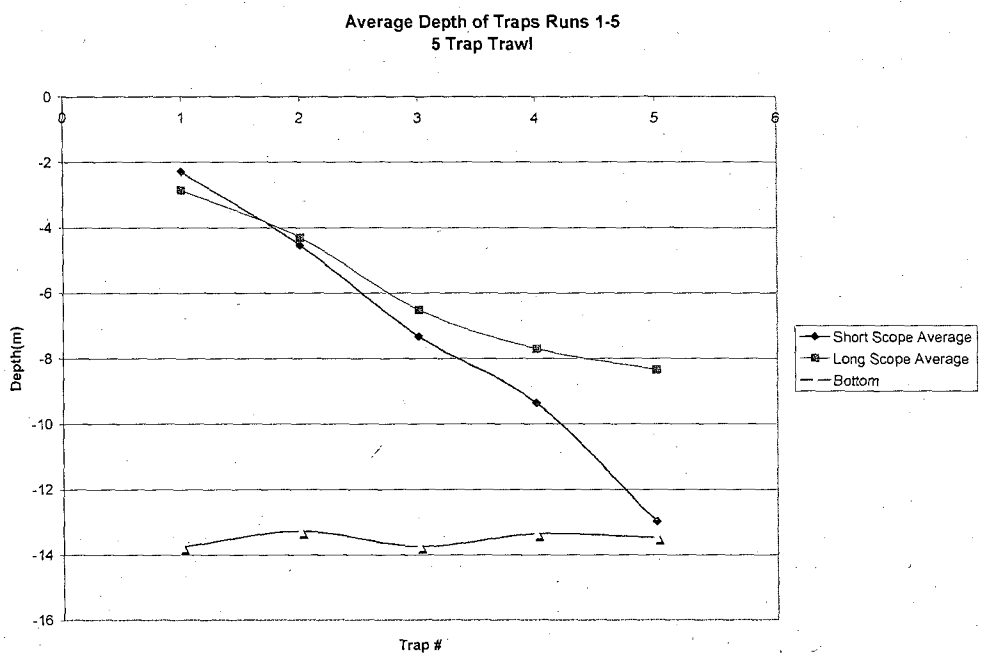
APPENDIX A: Trap movement daily composite and average results



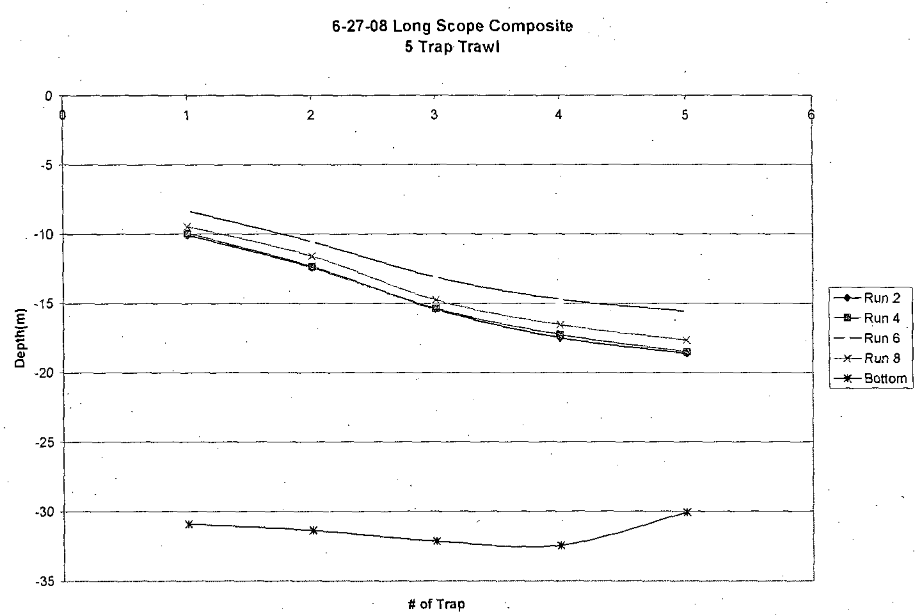
Appendix A.1 Composite plot of 5 runs using a long-scoped endline as the towing hawser on a 5 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.



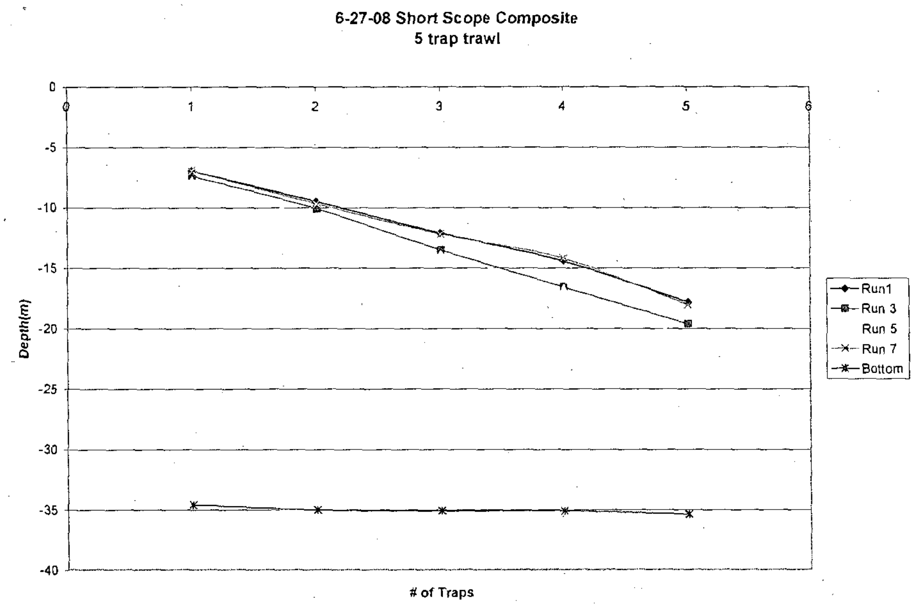
Appendix A.2 Composite plot of 5 runs using a short-scoped endline as the towing hawser on a 5 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.



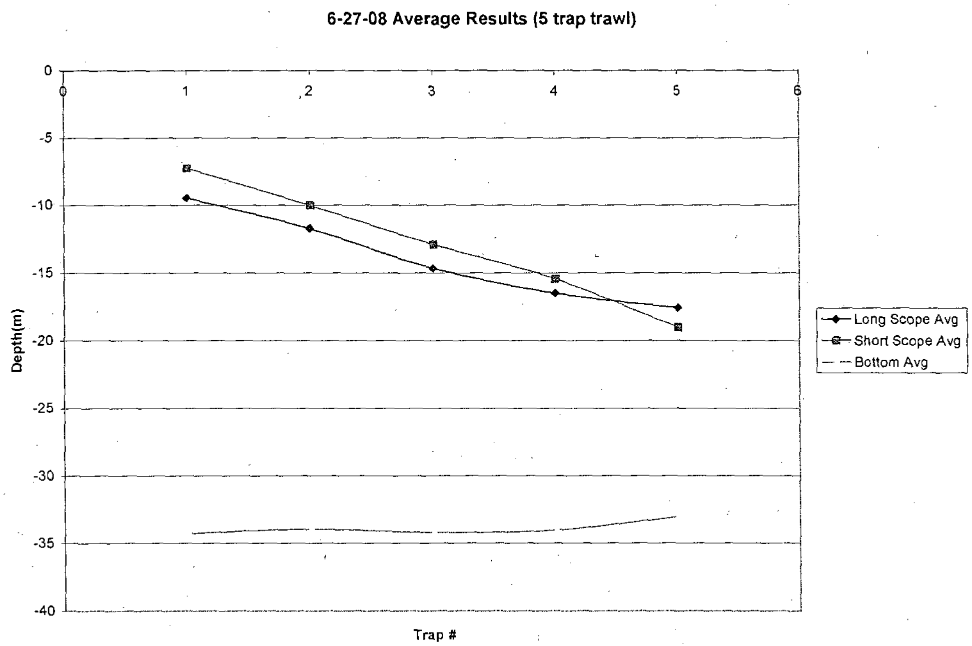
Appendix A.3 Plot of the average of the long, and short-scope runs for a 5 trap trawl of the 6-25-08 day of testing.



Appendix A.3 Composite plot of 5 runs using a long-scoped end line as the towing hawser on a 5 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.

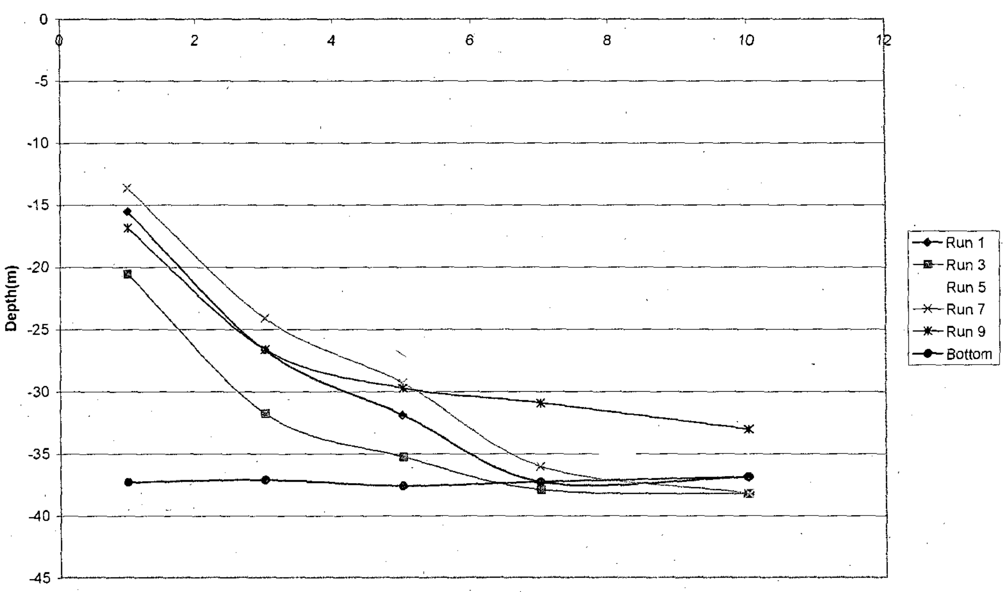


Appendix A.4 Composite plot of 5 runs using a short-scoped end line as the towing hawser on a 5 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.



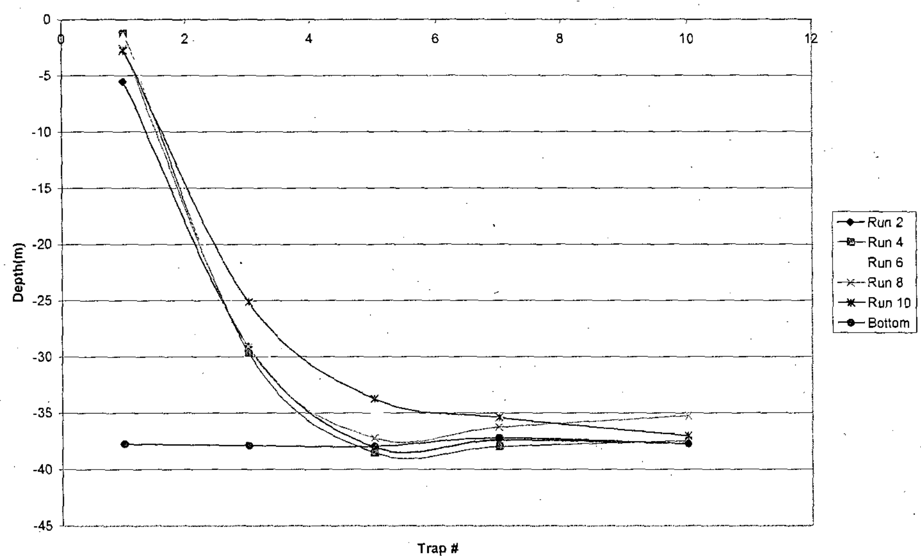
Appendix A.5 Plot of the average of the long, and short-scope runs for a 5 trap trawl of the 6-25-08 day of testing.

7-2-08 Short Scope Composite (10 trap trawl)

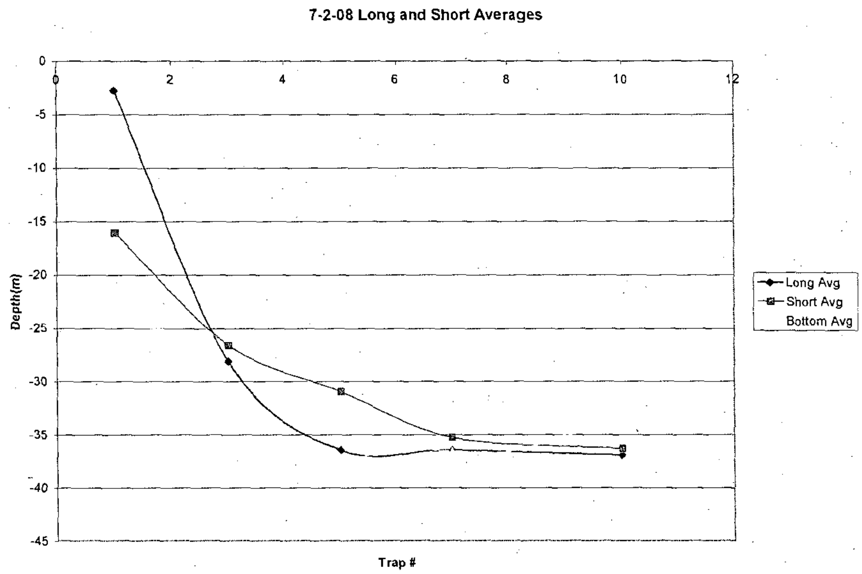


Appendix A.6 Composite plot of 5 runs using a short-scoped end line as the towing hawser on a 10 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.

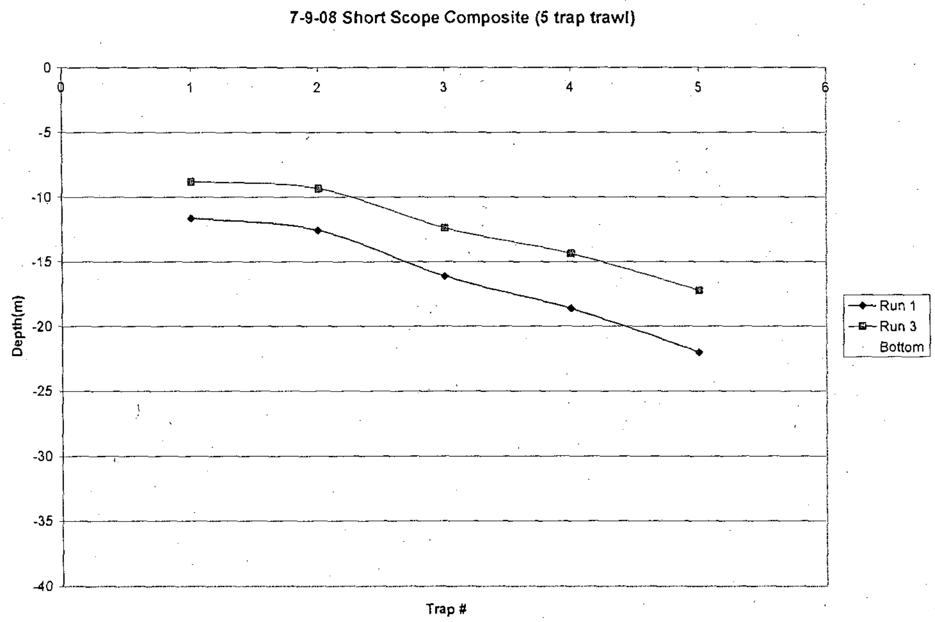
7-2-08 Long Scope Composite (10 trap trawl)



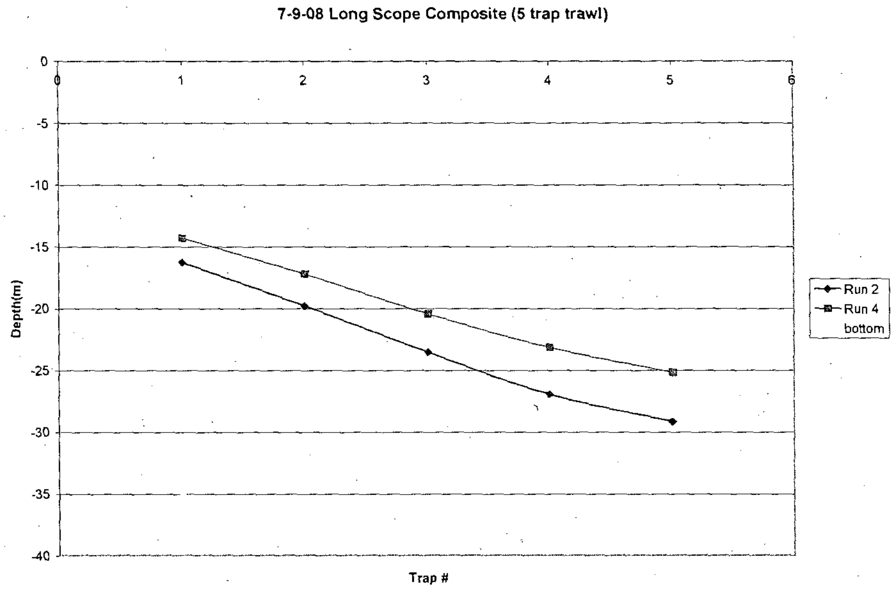
Appendix A.7 Composite plot of 5 runs using a long-scoped end line as the towing hawser on a 10 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.



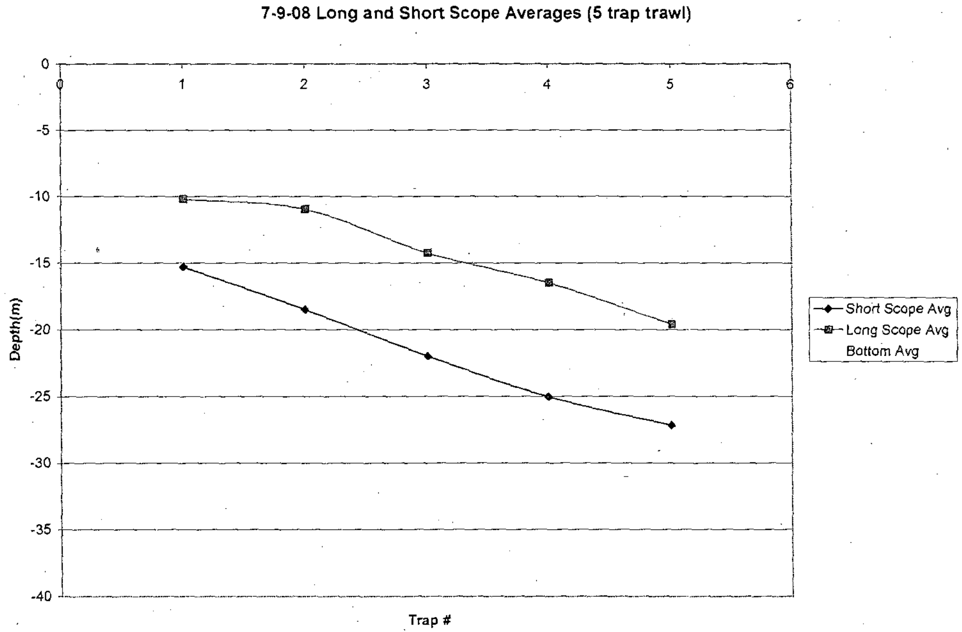
Appendix A.8 Plot of the average of the long, and short-scope runs for a 10 trap trawl of the 7-2-08 day of testing.



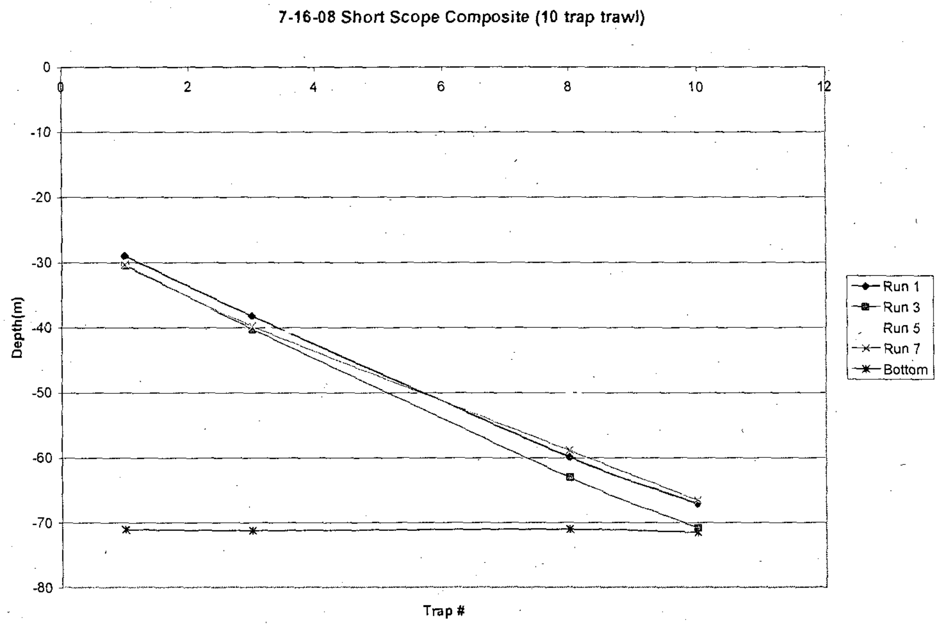
Appendix A.9 Composite plot of 2 runs using a short-scoped end line as the towing hawser on a 5 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.



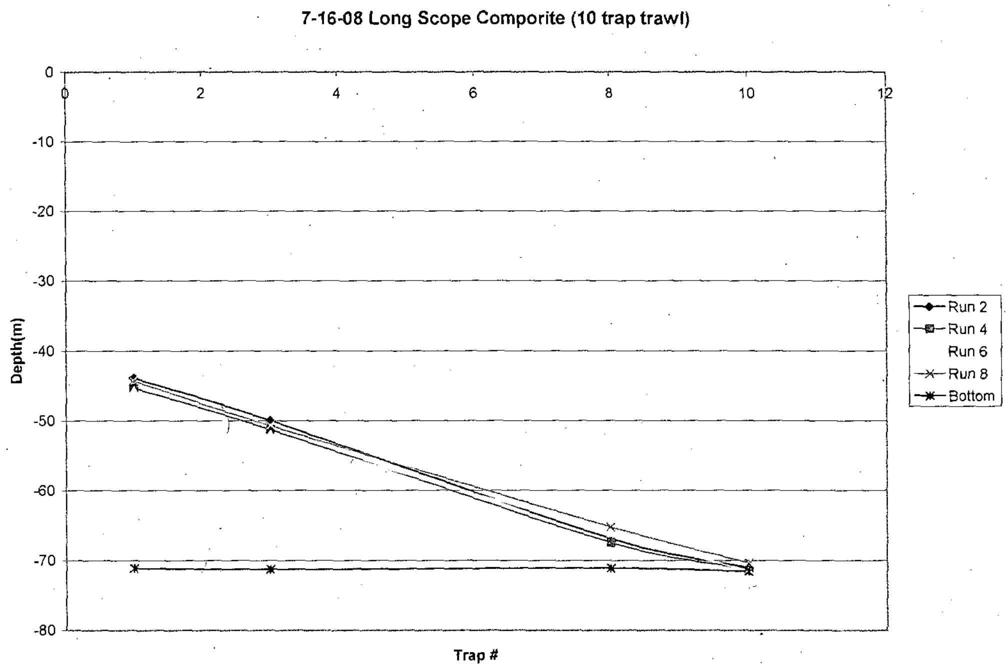
Appendix A.10 Composite plot of 2 runs using a long-scoped end line as the towing hawser on a 5 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.



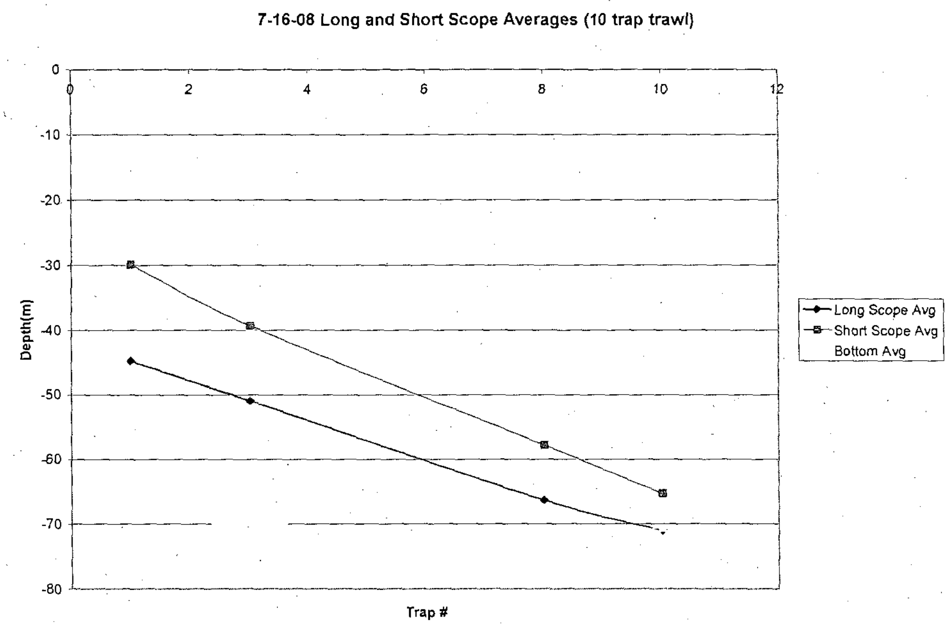
Appendix A.11 Plot of the average of the long, and short-scope runs for a 5 trap trawl of the 7-9-08 day of testing.



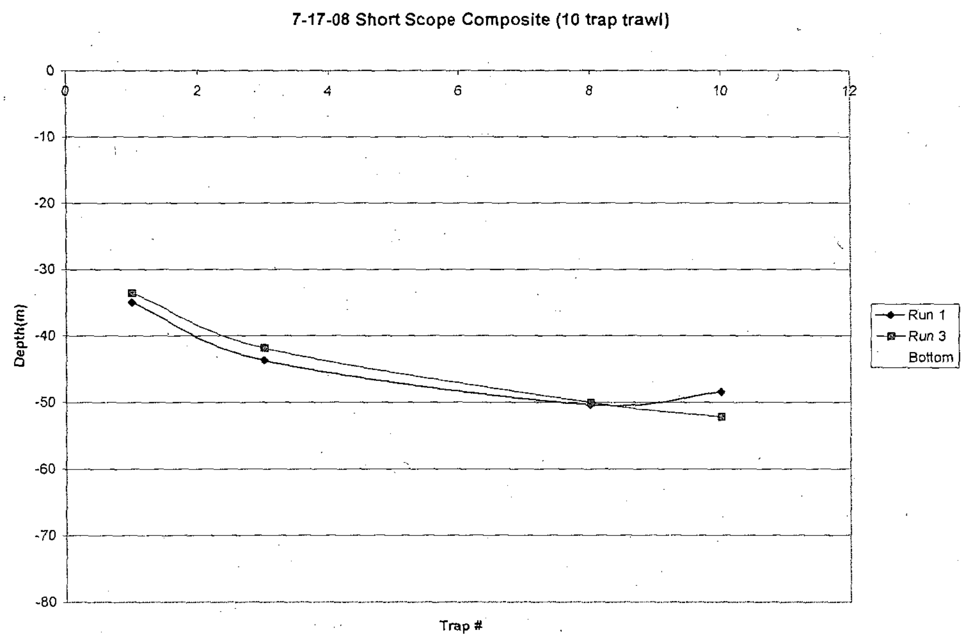
Appendix A.12 Composite plot of 4 runs using a short-scoped end line as the towing hawser on a 10 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.



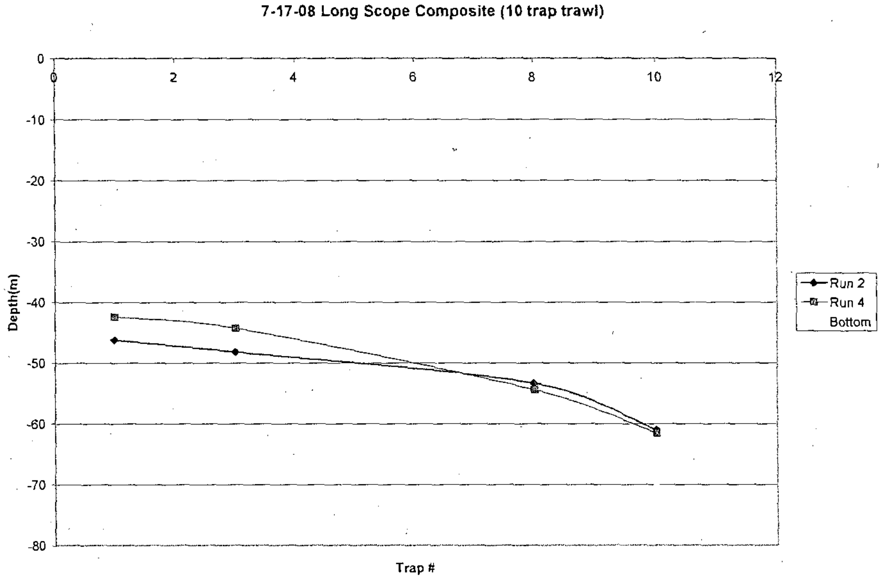
Appendix A.13 Composite plot of 4 runs using a long-scoped end line as the towing hawser on a 10 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.



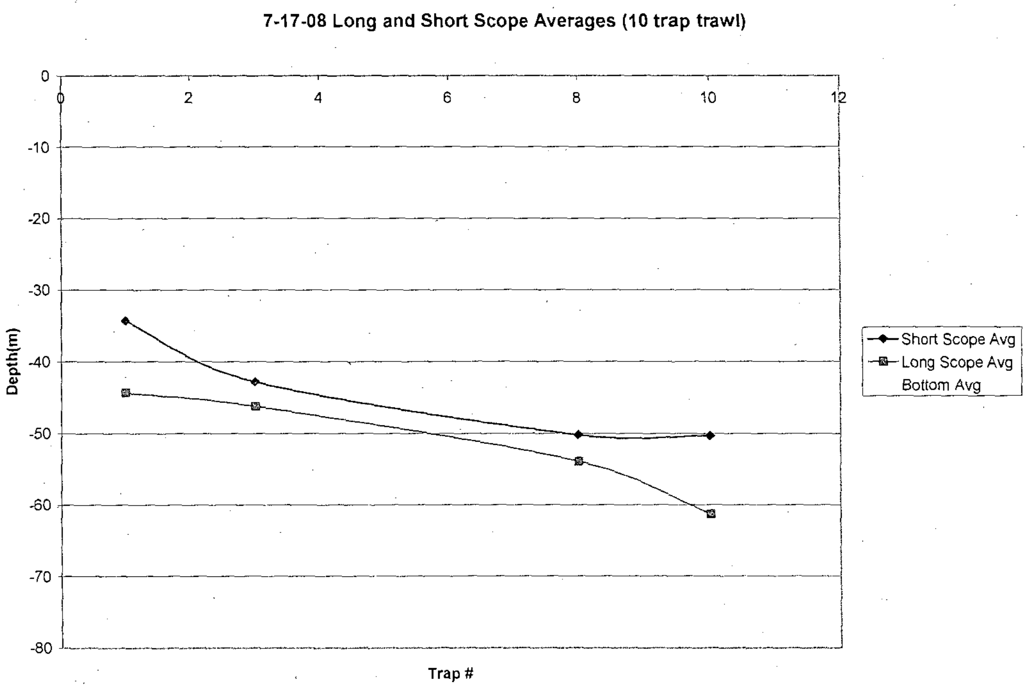
Appendix A.14 Plot of the average of the long, and short-scope runs for a 10 trap trawl of the 7-16-08 day of testing.



Appendix A.15 Composite plot of 2 runs using a short-scoped end line as the towing hawser on a 10 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.

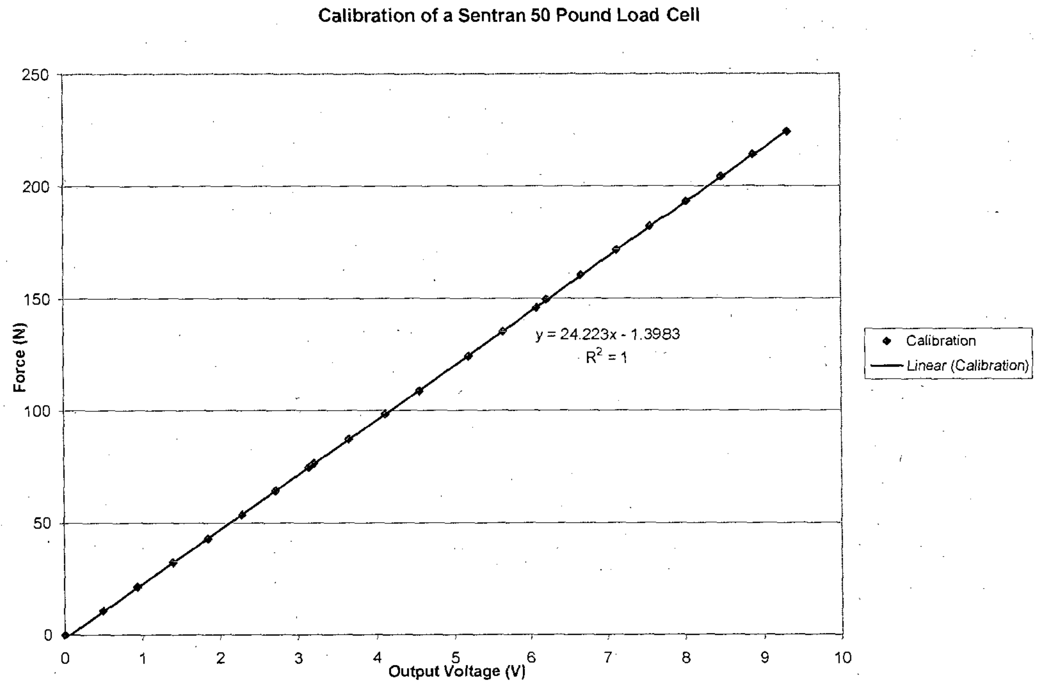


Appendix A.16 Composite plot of 2 runs using a long-scoped end line as the towing hawser on a 10 trap trawl. Each colored line represents one series of towing data, and the line at the bottom represents the average water depth throughout this series of tows.



Appendix A.17 Plot of the average of the long, and short-scope runs for a 10 trap trawl of the 7-17-08 day of testing.

APPENDIX B- Tow Carriage Load Cell Calibration Curve



APPENDIX C- Matlab Codes

C.1-DRAGFINDER.M

```
%DRAGFINDER.m
%finds line drag using equation from Fridman (1986)
%based on calculated geometry of individual trawls
space=12.8;
gang=1.828;
d=.01111;
boat_depth=0;
end_depth=0;
length=[182.8 25.6 51.2 25.6 100.54];
rho=1025;
V=2;
q=.5*rho*V^2;
totdrag=0;
dum=load( '10traplongdeep.txt');%name of file to
process angles
file_1=abs(dum);
for i=1:5
    distance=((length(i)*length(i))-
(file_1(i+1)*file_1(i+1)))^.5;
    m(i)=acos((file_1(i+1)-file_1(i))/length(i));
    m(i)=abs(90-m(i)*180/3.14159);
end
dum2=load( 'alpha.txt');
file_2=dum2;
for j=1:5
    for k=1:5
        for ii=1:8
    if m(k)>file_2(ii,1) && m(k)<file_2(ii+1,1)
        Cx(k)=file_2(ii,2)+(m(k)-
file_2(ii,1))*(file_2(ii+1,2)-
file_2(ii,2))/(file_2(ii+1,1)-file_2(ii,1));
    end
        end
    end
end
for jj=1:5
    dragforce(jj)=Cx(jj)*length(jj)*d*q;
end
for t=1:6
totdrag=totdrag+dragforce(t);
end
```

```
totdrag=0.224*totdrag;
```

C.2- strady_state_v3 (Courtesy of Andrew Drach)

```
% Written by smbd
% August 30, 2009 - Andrew Drach: Cleaned up a bit.
clear all
clc
for ii=8:9  %filenames indices
    clearvars -except ii av_m1;
dummy=ii-1;
    if ii<10 dumnm='0';
    else     dumnm='';
    end

    gname=['strain' dumnm num2str(dummy) '.LVM'];

    if ii<0
        file=load(gname);
        rawvoltage(:,1)=file(:,2);
    else
        [aa,bb,cc,dd,ee,ff]=textread(gname,'%c %f %c %f %c
%f','headerlines',21);
        %aa,cc,ee are just columns of commas
        %bb,dd and ff are the data columns 1,2,3
        rawvoltage=dd;
    end

     unzerovoltage=abs(rawvoltage);
    % calculate base offset
%     sum=0;
%     sum_den=0;
%     for i=1:50  %data points to average offset with
%         sum=sum+unzerovoltage(i);
%         sum_den=sum_den+1;
%     end
%     offset=sum/sum_den;

    % manual offset
    offset=0.5332;

    % debase data
    for i = 1:length(unzerovoltage)
```

```
    voltage(i) = unzerovoltage(i) - offset;
end

% find deviation and mean from the center values
volt_rm=voltage;
M = length(volt_rm);
for jj=1:M;
    if ( ~(jj>0.50*M && jj<0.75*M) )
        volt_rm(jj)=NaN;
    end
end
volt_rm = volt_rm(~isnan(volt_rm));

std_dev=std(volt_rm);
avg_vol=mean(volt_rm);
volt_rm=voltage;
M = length(volt_rm);
for jj=1:M;
    if ( abs(volt_rm(jj)-avg_vol)>std_dev )
        volt_rm(jj)=NaN;
    end
end
voltage = volt_rm(~isnan(volt_rm));

% trim data series
volt_rm=voltage;
M = length(volt_rm);
for jj=1:M;
    if ( ~(jj>0.15*M && jj<0.85*M) )
        volt_rm(jj)=NaN;
    end
end
voltage = volt_rm(~isnan(volt_rm));

Average_voltage_std=mean(voltage);

%Plot Original Values
subplot(2,1,1);
h = plot(-rawvoltage);
hold on,
set(h,{'Color'},{'r'})
hold on,
hold on,
grid on;
ylabel('Voltage (V)')
xlabel('Timesteps')
title('Original Voltage')
```

```
    %Plot Values
    subplot(2,1,2);
    h = plot(voltage);
    hold on,
    set(h,{'Color'},{'r'})
    hold on,
    hold on,
    grid on;
    ylabel('Voltage (V)')
    xlabel('Timesteps')
    title('Voltage')
    saveas(gcf,['strain' dumnm num2str(ii)],'png')
     close

    av_m1(ii+1)=Average_voltage_std;
end

fid=fopen('output.txt','wt');
for ii=1:length(av_m1)
  fprintf(fid,'%.6f\n',av_m1(ii));
end
fclose(fid);
```

C.3- loadplotter.m

```
%loadplotter.m
%Finds Maximum, average loads
%finds ttc
%plots results

clear
maxload(1)=0;
avgload(1)=0;
ttc(1)=0;
for ii=1:10

dum=load([ 'a00' num2str(ii) '.txt']);
file_1=dum;
a=size(file_1);

sumload=0;
count=2;
for i=1:a
    if (file_1(i,2)>200)
        count=count+1;
        m=file_1(i,2);
        sumload=sumload+m;
```

```
    end

    count_arr(1)=count;
ttc(ii)=(count/2)/60;

end
maxload(ii)=max(file_1(:,2));
avgload(ii)=sumload/count;
plot (file_1);
end
```

APPENDIX D- Pilot Study Log

TTLC Pilot Study Log

Vessel name: ____________ Vessel operator: ________________
Gear type: _____

TTLC/Trawl #	# traps	Date/ Haul #	Depth (fm)	Bottom type	TTLC Band	Note
1				M Sa Gr Rky	Gr Y R	
2				M Sa Gr Rky	Gr Y R	
3				M Sa Gr Rky	Gr Y R	
4				M Sa Gr Rky	Gr Y R	
5				M Sa Gr Rky	Gr Y R	
6				M Sa Gr Rky	Gr Y R	
7				M Sa Gr Rky	Gr Y R	
8				M Sa Gr Rky	Gr Y R	
9				M Sa Gr Rky	Gr Y R	
10				M Sa Gr Rky	Gr Y R	