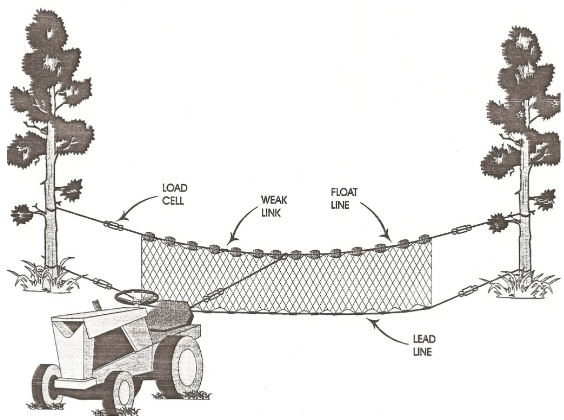
Land Testing of Gill Net Modifications



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Abstract

Three days of largely empirical land testing of gill net modifications were conducted to examine potential means to reduce whale entanglement. More than two dozen trials were conducted in which loads were recorded on each end of the float line and lead line as well as the simulated whale loading. Weak link devices tested included knotted line, light line, plastic links, and “Chinese fingers”. The breaking strength of 6.5 and 7.0 inch, 14 gage, monofilament webbing was also tested.

Introduction

The northern right whale (*Eubalanea glacialis*) is the most critically endangered large whale in the world, and is protected under the Endangered Species Act (ESA). The western North Atlantic population is estimated to be approximately 300 animals. In 1995, the re-authorized Marine Mammal Protection Act (MMPA) mandated that the kill of northern right whales from interaction with commercial fishing gear be reduced to zero. In September 1996, a Federal District Court in Massachusetts issued an injunction which ordered the Massachusetts Division of Marine Fisheries (MDMF) to develop a proposal to restrict, modify, or eliminate the use of fixed fishing gear in waters of Massachusetts considered right whale critical habitat, including most of Cape Cod Bay.

Some measures proposed to minimize the entanglement of right whales with fixed fishing gear include area/time closures and/or modification of the gear. Unfortunately, so little is known about the entanglement mechanism and behavior of the whales, that some of the protective measures under consideration could put fishermen out of business without solving the problem for the whales. It is imperative to find solutions which eliminate entanglement and keep fishermen in economically sound operations.

Surface buoys and buoy lines are used to mark the location of fixed gear including lobster traps and gill nets. Whales may become entangled in buoy lines and with nets and lines on the ocean bottom. It is surmised that when the animal encounters a line, it may move along that line until it comes up against something such as a buoy. The buoy can then be caught in the baleen, against a flipper or on some other body part. When the whale feels the resistance of the gear, it thrashes, which may cause it to become entangled. The vulnerability of whales to entanglement in gill nets may vary by species, local, and season. Many ideas have been proposed to solve the entanglement problem and there has been considerable discussion of the question by fishermen, biologists, and gear technologists.

This project is part of the gear research aimed at solving the entanglement problem. The specific projects were formulated by the NERO Large Whale Gear Advisory Group (LWGAG) in June, 1997. The group consisted of representatives of the fishing industry, federal and state governments and independent whale research organizations. One of the concerns expressed at the meeting was a lack of knowledge of loads on a gill net that are necessary for a whale to break loose from lines or webbing. Initial tests on a gill net, funded by the Massachusetts Environmental Trust at Coonamessett Farm, revealed some of the dynamics which will impact the choice of gill net design and rigging aimed at minimizing entanglement risk. The tests indicated that existing methods of hanging gill nets may negate the effectiveness of weak links in the bridles of the net. Continued testing of gill net modifications was recommended in order to overcome the problems with operation of the weak links.

The research described in this report focuses on rigging and land testing a gill net with weak links positioned in a manner that would potentially reduce the risk of entangling a whale encountering the gear. A 150 foot section of gill net was tested by simulating a whale encounter with the gear and recording the loads at each end of the net section. Several different designs for weak links were tested and the testing was video taped. Land testing of gill nets is a low cost first step in examining gear modifications.

Previous Research

In January, 1997 the International Wildlife Coalition (IWC) received a grant from the Massachusetts Environmental Trust to develop and test snag-free fishing gear for use in reducing right whale entanglement and mortality. The IWC research team consisted of members from the IWC (whale biologists), Coonamessett Farm (gear technologists), and the Massachusetts Lobstermen's and Massachusetts Bay Area Gill Netters Associations (fishermen). One aspect of the research program was the development of a means of surface buoy attachment that would break free without snagging a whale that came into contact with the buoy. After considerable research, a method was devised using hog rings to attach the buoy line to the buoy (Wiley et al, 1997). With a satisfactory working solution to this aspect of the entanglement problem, the research project began to focus on the gill net itself.

Bottom sink gill nets used in the new England groundfishery are 300 feet (91 m) in length, 8 feet (2.4 m) to 12 feet (3.7 m) in height, and are set end to end in strings of nets up to 6000 feet (1,828 m) in length (Figure 1). Each net consists of a float line and a lead line to which monofilament webbing is attached or "hung". The webbing in the groundfishery typically ranges from 6 to 8 inches in mesh size and is mostly 14 gage thickness. At the end of each net the float line attaches to the lead line forming bridles to which the next net in the string is attached. The end nets of the string are anchored and attached to the surface buoy line.

A land-based dry testing site for gill nets was established at Coonamessett Farm to observe and record the behavior of gill nets subjected to whale-simulated loads. Load cells were attached to points on the nets and the line towing the simulated whale model through the nets (Figure 2). The tests provided information on the forces acting on the nets and the breaking points of modifications. The following discussion highlights some of these observations from Wiley et al. (1997).

Float line resistance

One mechanism of entanglement is that a whale might hit the vertical "wall" of the gill net and become entangled in the net as the net wrapped around the whale's body. One proposed approach to minimize this risk is to lower the buoyancy of the float line and increase the anchoring/weight of the lead line and/or ground tackle (bottom holding capacity). The concept here is that the whale would be able to push over the net without getting entangled. In the land-based testing approach this situation was modeled by adjusting the tension in the float line while dragging a mesh bag of large plastic balls (maximum breadth 72 inches/1.8 meters) over the float line. The test demonstrated that when there was low tension in the float line, the bag of plastic balls was less likely to snag. However, when the tension was high there was a high probability that the bag would be hung up on the float line.

This test indicated that it may be a valid approach to lower float line buoyancy and/or raise bottom holding capacity. It further supported the hypothesis that if the float line broke early in an encounter there was a decreased chance of entanglement.

Catenary formation

The land testing identified another possible mechanism that may increase the likelihood of entanglement. When even low loads, several hundred pounds, are applied to the float line or webbing the net begins to form a large catenary. This bowing of the net around a striking whale may cause entanglement before enough force is generated to break free of the net. The factors that would affect this catenary forming process include the speed of the encounter, the length of the net string, the bottom holding capacity, and the ability of the lead line to move freely over the bottom without snagging. Bottom holding capacity is a function of the nets anchoring system and substrate. The ability of the net to move over the bottom freely is a function of bottom topography. The speed of encounter is an important variable because the resistance of the net, and thus the forces generated in the float line, is exponentially related to the movement of the dragged gear through the water.

Weak link location at bridles

One proposed solution to make nets less likely to snag whales has been to place weak links between each net at the location of the bridles. Tying the nets together with a weak link inserted at the top bridle connection would not damage the integrity of each net on the string. Testing demonstrated that this approach did not work because when the link failed the load was transferred to the section of vertical float line that connects to the lead line at each net end. The end result was that the float line still remained taught under the simulated whale load.

Weak link design

These initial land tests were not designed to test a variety of weak link designs. Plastic swivels (270 lb breaking strength) and flat plastic plates with reduced cross-section areas (250 and 450 breaking strengths) were utilized at the bridle location. One important observation made was that as load was applied there was some twisting of the bridle creating torque loads on the flat weak links. As a consequence, these links failed below there designed breaking strength.

The results of the weak link tests at the bridle location lead to the belief that it may be a better approach to insert the weak links into the float line within the net itself. A disadvantage of this approach is that if the link accidentally fails the webbing will tear requiring replacement of the net. Another consideration with this approach is that the link has to be designed so that it will not snag on the webbing creating problems in setting the gear.

The testing did not evaluate the idea of placing a weak link in the lead line in addition to the float line. Having a weakened lead line would create problems for the fisherman trying to retrieve his gear. More importantly, it is not certain that a weakened lead line would improve the situation for an encountering whale. Instead of pushing over or breaking through the gear, a weakened lead line might allow the whale to carry the gear away.

Webbing strength

The strength of the webbing itself was tested by pulling the bag of plastic balls through the mesh. The irregular shape of the bag provided for uneven distribution of loading on the twine. To compensate for uneven loading, the tests were also conducted with a 48 inch (1.2 m) diameter disk for uniform stress distribution and replication. In either case relatively low loads, on the order of 250-300 pounds, were needed to break through the twine. Even at these low loads, a significant catenary was formed.

Instrumentation requirements

Instrumentation proved to be one of the biggest difficulties in conducting these tests. The digital output of the load cells had to go through an interface and into the data logger. There was no real-time display of the loads due to equipment problems and lack of software. These trials indicated a need for real-time viewing of the loads coming from each sensor.

Methods

The project followed similar procedures to that in the previous land-based testing discussed above. The focus was on inserting different weak link devices into the float line of the hanging gill net section and to record the loads and gear behavior. The maximum loads that we could safely record on the load cells had to stay below 1000 lbs. We decided to target breaking strengths of approximately 500 lbs for weak link design to stay within our equipment's working range. The load was applied by using a tractor that was directly tied to the float line via a load cell.

Instrumentation

The load cells were the same ones used in the previous testing; Model SM-1000 Super-Mini Load Cells with rod-end bearings from Interface, Inc. (Scottsdale, AZ). These load cells were chosen because of their low cost, highly linear output, and suitability for non-submersible applications. The load cells were connected to the data logger with dual shielded twisted-pair instrumentation cable (Belden # 8723).

The data logging instrumentation differed significantly from the first test series. The data logger used was a prototype version designed for evaluating bridge deck parameters. We leased this unit to record the testing and also to aid in evaluating future data logger design for this type of fishing gear work. The unit consisted of a 16 channel differential multiplexor, a programmable pre-offset gain amplifier stage (for gains of 1x, 10x, 100x, and 1000x), a programmable offset circuit (producing voltages from -4 to+4 volts in 2 millivolt increments), and a programmable post-offset gain amplifier stage (for gains of 1x, 2x, 4x, and 8x).

The DC offset produced by the first amplifier stage is nulled out by the offset cancellation circuitry. The post-offset gain stage allows further gain as required. The output of the second stage amplifier is fed to the 12 bit A/D converter of the Model 8 Tattletale (Onset Computer, Inc.). The Model 8 Tattletale performs the functions of selecting the channel, selecting the appropriate gain and offset value for the selected channel, converting the signal into digital format, communicating with the laptop PC, and saving the data to the Persistor (Peripheral Issue, Inc).

The Persistor is a 2 Mbyte flash PCMCIA card that stores the data. It also provides a simplified DOS environment. This provides a very easy avenue for data storage and system setup. Data files are simply stored as comma delimited files. Configuration files were stored in ASCII text file format.

Three layers of software were involved in this project. The first layer included that needed for channel selection, offset cancellation, gain selection, A/D conversion, data storage, and transmission functions. These were embedded in the Model 8 program which is written in C. The second layer covered the operational mode, real-time display, and operator interface program. This was written in Visual Basic running under Windows 95. Thirdly, the data processing software requirements which were met by using Excel.

The real-time viewing of the data was essential in order to help determine/verify proper sensor gains and offset. An automatic offset program was written to simplify the set-up. Other features of the developed software include the ability to view one or all of the real-time sensors, ability to change the vertical scale of each sensor, the ability to change the horizontal time scale for each sensor group, the ability to inject a user event mark for annotation, and the ability to change the sample rate and number of channels per experiment.

Results

On October 21 through 23, 1997 gill net test were conducted at Coonamessett Farm. Present were research team members Ronald Smolowitz (Coonamessett Farm), Dave Wiley and Heather Rockwell (International Wildlife Coalition), John Kenney (NMFS), John Our (Cape Cod Gill Netters Association), Arnie Carr and Henry Milliken (Massachusetts Division Marine Fisheries), and Bruce Ambuter (Electronics/Data consultant).

The tests began using a new gill net section hung between a barn corner post and a tree located more than 150 feet away. Initially the measured lengths (eye to eye on load cells) were: float line = 145’10” and lead line = 147'2". After two pulls the measures were: float line 147’6” and lead line = 147'2". On 10/22/97 the net was rehung between two trees resulting in overall float line and lead line lengths of 189 feet each. The gill net for the first series of tests consisted of 6.5" mesh constructed of 14 gage twine; the float line was 5/16" polypropylene. The lead line was #65 Nova leaded line. In reviewing these results the reader must keep in mind that all four corners of the net section were rigidly fixed. Catenary measurements indicate the horizontal displacement of the float line from its original position to the position it obtained at maximum applied loading.

The following is a test by test summary of the results. All tests that have file numbers beginning with 1021 and 1022 (actual month/day group) start out with the load cells zeroed under an unknown pretension. In most cases this tension was under 100 lbs in the float line and near zero in the lead line. Files beginning with 1023 start out with the load cells reading the actual pretension. Negative numbers indicate slack line.

The data recording system apparently saturated at loads exceeding 734 lbs. This fact was not discovered until after the tests were completed and the data under went final processing. For the purposes of the following discussion, where saturation was reached (734 lbs) the data was extrapolated by assuming approximately linear expansion.

File # 10211204:

In this test the tractor was tied to the float line 25% down from the north end and a straight 90 degree pull was applied until the tractor load cell read 476 lbs. The maximum depth of the catenary formed at this load was 22.5 feet. The load of 476 pounds on the tractor line (TL) resulted in loads of approximately 900 pounds on the North float line (NFL) sensor and 800 pounds on the South float line (SFL) sensor. The corresponding lead line loads were 202 lbs (NLL) and 187 lbs (SLL). This test demonstrated that the load in an anchored net can greatly exceed an applied load at low force angles. A portion of the applied load was transmitted to the lead line by the net webbing. This load was distributed throughout the net section thus did not result in any meshes tearing.

File # 10220845

In this test a weak link made of 1/4" natural fiber manila line was spliced into the float rope at the center of the net section. The tractor was attached to the float line six feet north of the weak link position and the load applied at 0.8 mph. The manila weak link parted when the (TL) attained 600 lbs. The corresponding loads at this point were 388 lbs (NFL), 688 lbs (SFL), 248 lbs (NLL), and 193 lbs (SLL). The monofilament webbing tore at the point of failure after the float line parted.

File # 10220906:

This test was a replicate of the previous test, however, it must be kept in mind that some of the gill net webbing was now torn at the start of the test. The manila weak link parted when the (TL) attained 458 lbs. The corresponding loads at this point were 437 lbs (NFL), 550 lbs (SFL), 213 lbs (NLL), and 154 lbs (SLL).

File#10220926

This test was a replicate of the two previous tests but the load was applied at a higher speed; 8.2 vs 0.8 mph. The manila weak link parted when the (TL) attained 313 lbs. The corresponding loads at this point were 365 lbs (NFL), 355 lbs (SFL), 147 lbs (NLL), and 105 lbs (SLL). There was a 406 lb reading on the (SFL) just before breaking. The applied load was maintained after the float line failed and was taken up by the lead line. With a (TL) of 140 lbs, resulting in lead line loads just above 200 lbs, the monofilament mesh began to rip rapidly.

File #10220947

This test was similar to the previous slow speed tests except that the lead line was tied down near the point on the float line where the load was applied. This was to simulate the lead line being snagged on rocky bottom. The weak link (1/4" manila) did not break before the monofilament mesh began to rip. The webbing began to part when the (TL) attained 677 lbs. The corresponding loads at this point were 552 lbs (NFL), 635 lbs (SFL), 223 lbs (NLL), and 217 lbs (SLL). This would indicate that if the lead line is not free to move, i.e., snagged on the bottom, the webbing could be torn apart without the float line failing. The weak point in the float line would probably fail when all the webbing in that net section parted up to the bridles.

File #10221018

By this point in our testing the net webbing was badly torn. We used mending twine to connect the float line to the lead line at approximately six foot spacings in the vicinity of the applied load. We then repeated the first test; a weak link of 1/4" manila and a tractor speed of 0.8 mph. The manila weak link parted when the (TL) attained 638 lbs. The corresponding loads at this point were 596 lbs (NFL), 667 lbs (SFL), 298 lbs (NLL), and 292 lbs (SLL). It seems that with a stronger connection between the float line and the lead line the lead line was able to take up more of the loading before the float line failed. This would imply that stronger mesh twine, or nets with up and down lines, would be able to take higher applied loads before the float line failed.

File # 10221040

This test was a replicate of the previous test. The 1/4" manila weak link used in these tests consisted of 8” of splice on each end and 26” of free line between splices. In this test the link failed when 2 strands of the line broke at the splice point and the third strand pulled free. The manila weak link parted when the (TL) attained approximately 750 lbs. The corresponding loads at this point were 601 lbs (NFL), 734 lbs (SFL), 356 lbs (NLL), and 358 lbs (SLL). This agrees with the hypothesis made from the results of the previous test.

File #10221115

The high observed loads in the previous test raised the question of the breaking strength of the manila line splices being used as weak links. To address this question we spliced the manila line into a section of float line and applied a straight tractor pull with load cells on each end. The line failed at 710 lbs with the break occurring in the free section of the link (not at splice). During this test the cables to the computer tangled and pulled out and tests were terminated for the day because of equipment failure.

Date: October 23, 1997
Location: Coonamessett Farm
Team members: Ron Smolowitz, Dave Wiley, John Our, Henry Milliken, Bruce Ambuter

File # 10230927

In this test we tested the webbing breaking strength by pulling a 48" diameter concave plastic disk through a section of webbing. This test was conducted on a net section about 15 feet away from the (NFL) and (NLL) load cells at very slow speed. The disk tore through the webbing when the (TL) attained 140 lbs. The corresponding loads at this point were 215 lbs (NFL), 81 lbs (SFL), 93 lbs (NLL), and 134 lbs (SLL).

File #10230938

In this test the load was applied at the center of the float line without a weak link and the angle of pull adjusted to observe changes in load at the four corners of the net section. We wanted to determine what would fail in the net system without a weak link present. The test terminated when the line pulled loose from the tractor load cell at a load probably in excess of 900 lbs (actual load unknown since we exceeded saturation).

File # 10230958

We attempted a repeat of the previous test but again the line failed at the attachment point to a load cell; this time the (NFL) at a load probably in excess of 900 lbs. These failures occur at knots in the 7/16" line used to connect the net to the load cells. These tests were conducted with vertical lines connecting the float line to the lead line.

File # 10231006

This repeat attempt resulted in a failure of the knot attachment to both the load cells in the south end of the net. The load probably exceeded 1000 lbs. The catenary at the time of failure was about 37 feet. We concluded we did not have the safe means to test an unmodified net to destruction. The whiplash occurring with each failure was having its toll on equipment.

File # 10231032

This was a test of a 1/4" manila link located seven feet from the (NFL) sensor. A load was applied at the net section center approximately 60 feet from the weak link at slow speed. As in the previous tests, the float line and lead line were attached by up and down lines every six feet near the applied load. The manila weak link parted when the (TL) attained approximately 900 lbs. The corresponding loads at this point were 733 lbs (NFL), 262 lbs (SFL), 570 lbs (NLL), and 688 lbs (SLL). The catenary at failure was 36 feet.

File #10231046

In this test one strand was cut on the float line near the net center. The load was applied at the center of the net section. The line parted at the bridle knot (attachment point to the NFL load cell) when the (TL) attained approximately 830 lbs. The corresponding loads at this point were approximately 800 lbs (NFL), 280 lbs (SFL), 478 lbs (NLL), and 611 lbs (SLL). The line did not fail at the cut strand.

File # 10231056

This was a replicate of the previous test with basically the same results; the line failing at the (NFL) load cell knot. The link (cut point) did not fail. The catenary at failure was 33’6”. The failure occurred when the (TL) attained approximately 800 lbs. The corresponding loads at this point were approximately 900 lbs (NFL), 313 lbs (SFL), 524 lbs (NLL), and 674 lbs (SLL). The net section by this time was completely torn apart.

File # 10231136

A replacement net was hung consisting of new webbing 7.5” mesh X 14 gage and a used float line approximately 2 years old. A 1/4" manila link was placed in the float line 50’ north from a load applied to the center of the float line. The link failed when the (TL) attained 740 lbs. The corresponding loads at this point were approximately 446 lbs (NFL), 255 lbs (SFL), 392 lbs (NLL), and 480 lbs (SLL). In this test net more load seems to be distributed to the lead line when compared to similar tests on the previous net. The fact that the lead line (SLL) showed higher loading than the float line, where the load was being applied, is interesting (as in test 10231228). This may be due to the way the net was tied off or torn. This may indicate that a gill net can be hung in such a way as to transmit more load to the lead line, for example, by using different hanging ratios for the float line and lead line.

File # 10231228

This was a repeat of the previous test conditions but with a piece of 1/4" poly as the weak link. The link failed when the (TL) attained approximately 850 lbs. The corresponding loads at this point were approximately 458 lbs (NFL), 218 lbs (SFL), 414 lbs (NLL), and 719 lbs (SLL).

File # 10231302

In this test a fisherman's knot was tied in the float line in the net center 15 feet north of the applied load. The knot failed when the (TL) attained 411 lbs. The corresponding loads at this point were 366 lbs (NFL), 263 lbs (SFL), 78 lbs (NLL), and 116 lbs (SLL). The results of this test indicate that the used float line may be a lot weaker than new line of the same material.

File # 10231308

This was a repeat of the previous test. The knot failed when the (TL) attained 553 lbs. The corresponding loads at this point were 410 lbs (NFL), 322 lbs (SFL), 108 lbs (NLL), and 172 lbs (SLL). Similar to the previous test, the float line failed at the knot at lower than expected loads for that size line.

File # 10231333

A "Chinese finger" type connection was made on the float line in the same location the previous fisherman's knots were placed. This connection consisted of a piece of braided line, with core removed, placed over the ends of the float line and seized in place by two bands of light twine on each side. During this test the (TL) load cell malfunctioned and that load was not recorded. The recorded loads at failure were 383 lbs (NFL), 326 lbs (SFL), 186 lbs (NLL), and 159 lbs (SLL). The "Chinese finger" failed by the float line slipping from the braided line covering.

File # 10231403

In this test we spliced into the float line a flat plastic "Anderson" link, designed to fail at 250 lbs, into the float line 15 feet north of the applied load. The (TL) load cell was still inoperative so we used the (SLL) load cell in its place. The recorded loads at failure were 243 lbs (NFL), 97 lbs (SFL), 91 lbs (NLL), and 139 lbs (TL).

File # 10231411

In this test we tested the webbing breaking strength by pulling a 48" diameter concave plastic disk through a section of webbing as in test 10230927. The recorded loads when the disk broke through the mesh were 273 lbs (NFL), 129 lbs (SFL), 242 lbs (NLL), and 181 lbs (TL).

File # 10231415

In this test we spliced into the float line a flat plastic "Anderson" link, designed to fail at 450 lbs, into the float line 15 feet north of the applied load. The recorded loads at failure were 448 lbs (NFL), 165 lbs (SFL), 217 lbs (NLL), and 362 lbs (TL).

File # 10231421

This was a replicate of the fisherman's knot test. The recorded loads at failure were 404 lbs (NFL), 176 lbs (SFL), 398 lbs (NLL), and 490 lbs (TL).

File # 10231433

By this time in the testing the net was all torn apart and distorted. Three of the six load cells were malfunctioning due to banging around each time the net failed. This last test consisted of applying a load to the center of the float line at 8.2 mph. The recorded loads at failure were 438 lbs (NFL), 184 lbs (SFL), 405 lbs (NLL), and 488 lbs (TL). This test damaged two load cells beyond field repair putting an end to the experiment.

Discussion

In spite of the long history of using gill nets, little is known on what happens when a large object encounters a net string. The large objects that most commonly encounter bottom sink gill nets in the New England groundfishery include otter trawl doors, scallop dredges, and whales. Whales may encounter gill nets frequently but may not make physical contact. Whale encounters with gill nets that are known to result in entanglements have not been observed to our knowledge and are extremely rare events when compared to mobile gear striking gill nets. The interaction of mobile gear and gill nets may shed some light on what transpires when a whale encounter occurs.

From experience, fishermen know that when a trawl door encounters a gill net string it commonly drags the string, sometimes for long distances, balling the gear up and/or breaking it apart. The gill net gear is commonly destroyed. On the other hand, when a scallop dredge encounters a gill net string the dredge commonly cuts right through the gear; float line, webbing, and lead line. After scallop dredge encounters the gill net fisherman can usually retrieve both remaining pieces of his gear as it is not often moved very far from where set. We can only speculate on the difference between these two types of encounters. A trawl door might snag the float line and webbing while a dredge might catch the lead line. Regarding whales, one can surmise that most encounters with the gill net gear do not result in an entanglement as whales are often observed swimming around gear without entanglement occurring. What portion of the encounters actually result in the whale striking the gear is unknown.

Since we know little about whale encounters with gear, and can not replicate these encounters using whales, we have to simulate to the best extent possible a situation where a large object comes into contact with a gill net. If the net can be modified in some manner to reduce the possibility of large objects snagging the gear, one can then postulate that whale entanglement risk would be reduced as well. In these tests the large object was designed to represent a whale calf.

Land testing of a gill net section is a poor substitute for at-sea testing of actual gill net strings. However, land testing is a very inexpensive means to get a preliminary understanding of what may occur with a particular net modification. While we did measure loads during the tests this again is not a substitute for laboratory testing of material breaking strengths. To accurately understand the forces working on the gill net section and weak links would require additional load cells and the measurement of angles to get complete force vectors. Experimental collection of these data would be extremely difficult because as load is applied the net changes shape in three dimensions. In addition, after each test the net is altered by stretching and tearing, so replication is not simple to accomplish. Trying to measure the speed of the impacting object, and the corresponding acceleration and torque, is beyond the scope of these low budget tests. All this being said, this discussion will need to be kept in general terms with specific numbers only being used to show direction and tendencies.

In light of the above discussion, one of the first questions to arise in viewing the results is how valid are the loads observed at the point of failure of a weak link. Two tests (10231403 and 10231415) used calibrated links of 250 and 450 lbs breaking strength. These links, when placed in the float line between the applied load (TL) and the (NFL) load cell, failed when the (NFL) load cell indicated 243 and 448 lbs respectively. It would seem that in tests without up and down lines the float line load cell nearest the link gives a good indication of breaking strength.

Many of the tests were conducted using pieces of 1/4" manila line as the weak link. This size line should have a breaking strength around 600 lbs when new. Failures occurred at 688 lbs (10220845), 550 lbs (10220906), 667 lbs (10221018), 734 lbs (10221040), and 733 lbs (10231032) averaging 674 lbs for the five tests. In a straight pull (10221115) the 1/4" link failed at 710 lbs. In a high speed pull (10220926) the link failed at 406 lbs. In another test (10231136) the link failed when the nearby float line load cell read 446 lbs but the lead line in this test showed high loads as well. In all cases failures occurred close to the calculated breaking strength of this material.

The age and history of use of the line is an important consideration. Fishermen estimate that more than 80% of the gill nets in use may be older re-hung nets, that is, nets with new webbing but that reuse the old float and lead lines. Fishermen may be working with gear that is a lot weaker than they suspect. Fishermen use float lines, ranging in size from 5/16" to possibly as large as 7/16", made of polyolefins which should provide breaking strengths of 1,350 to 3,500 lbs. Since most of the nets in use are rehung and have been in operation for several years their breaking strengths might be considerably less. There is a need to take float line samples from the fishing fleet, test them to breaking, to get an understanding of what actual working strength is needed to safely haul gill nets.

The use of lower strength float lines in lieu of weak links is an option. Deterioration in strength due to the elements would likely require these lines to be replaced more frequently then larger diameter lines of the same material. On the other hand, gear with weaker float lines might be less likely carried away by draggers in gear conflict situations thus saving the gear and catch. Making the entire float line weak and biodegradable, for example, using manila would be a maintenance nightmare to a fisherman. Manila also becomes negatively buoyant as it soaks up water over time. However, this is an idea that may have some value.

The advantage of using a calibrated weak link in the float line is that its failure, if properly designed, would not be a function of float line strength/weakening over time. A properly designed link maintains its breaking strength while line deteriorates in strength with age and use. Weak links would also be very obvious to enforcement. The weak links need to be designed so that they can resist torque loading, and they should not snag the webbing during setting. They should also be streamlined to offer no snagging opportunities to the whale.

It may be best to place the links within each gill net section as opposed to the bridle location. If two links were placed in each net, 75 feet in from each bridle, that would provide one link for every 150 feet of net string. An encountering whale would never be more than 75 feet from a link. Links at the bridle, instead of within the net, would double this distance. If links are to be placed at the upper bridles then the float line connection to the lead line would also have to be weakened.

These tests confirmed the previous test results that the webbing is not a very strong component of the gill net gear (10220947 and 10221018). A whale would probably go right through the mesh if the whale does not snag the float or lead line (10230927 and 10231411). It has also been demonstrated that the float line would break when a load is applied, before the webbing starts to tear, except in the situation where the lead line is holding fast to the bottom. This scenario would likely occur in rocky and boulder strewn substrates. With the float line parted, gill net webbing will tear apart with loads exceeding 140 lbs. However, the use of up and down lines can possibly add to the risk of entanglement by the added strength they provide to the gill net structure. In common practice, up and down lines are used to bag the webbing near the bottom to catch flatfish. This in effect lowers the profile of the gear in the water column which should reduce the risk of whales encountering the gear. However, once a whale physically makes contact with the gear, up and down lines could defeat the purposes of placing a weak link in the float line which would increase the risk of whale entanglement.

Any treatment that increase the bottom holding capacity of the gill net, or prevents the float line from moving (stretching in the direction of the applied force), would expedite a whale breaking through the float line and webbing and minimize catenary formation. Minimizing the displacement of the float line (low angles of displacement) increases the loading (reaction forces) in the float line relative to the applied load (force). Less elastic float lines might expedite a whale or trawl door breaking through the gear. Similarly, setting the gear under strain would help the gear resist displacement. The strain in the gear is a function of setting relative to the tidal current. In some areas fishermen deliberately set their gear without much strain or fish the gear in other than a straight set. Curved sets may increase the chance of whale entanglement from the standpoint of how a whale may behave to gear that, for example, partially surrounds the whales position (a horseshoe like set).

Knots are known to weaken a line. The line does not fail inside the knot but usually just before where the knot begins. In all likelihood this is due to the fact that the fibers in the line can not function as designed; the fibers are prevented from moving freely and thus sharing the applied loading. The load cells were attached to the gill nets using lengths of 7/16" poly, looped and knotted. These knots failed at loads around 1000 lbs (10230938,10230958, 10231006). We decided to test cutting and knotting the float line using a fishermen's knot; probably one of the strongest known methods of joining fine lines using a knot. These knots failed at 411 lbs (TL) and 366 lbs (NFL)(10231302); 553 lbs (TL) and 410 lbs (NFL)(10231308); and 490 lbs (TL) and 404 lbs (NFL)(10231421). The average of the float line loads at failure of the fishermen's knots was 393 lbs. The problem with using the float line itself as the weak link, either by knotting or cutting a strand, is that the breaking strength will be a function of the age and condition of the line.

Instrumentation

The use of the prototype data logger suggested a number of improvements. Ideally it would be best to fabricate a printed board version of the logger. This would eliminate the reliability issues and hazards of using a hand-wired prototype. Several changes to the prototype that would improve flexibility include the ability to support multiple sensor excitation voltages, the ability to turn off the sensor excitation to reduce power consumption (allows for smaller batteries), the ability to save the sensor gain and configuration settings, the ability to support user axis labeling with an input section to support displays in actual sensor values, and the ability to easily change and resize the number of graphs on the screen. This latter ability might be attained by running multiple versions of the program with 1-4 screens.

The end result of the above suggested improvements to the prototype would be an integrated logger and software package where virtually all post data processing steps would be eliminated. The user would have more flexibility in reviewing the results in real time thus avoiding problems such as the load saturation we encountered. The software would support either both screen capture (which it does now) and direct integration into

Excel or equivalent spreadsheet format. It is estimated that an integrated logger and software as described would cost about $6,000 for the first unit (includes development cost of designing printed circuit and software) and $3,000 for each additional unit.

Conclusion

Previous tests by our group had established that if the float line of a bottom set gill net lost tension or the ability to transmit force (breaks), the line offers little resistance and consequently is less likely to snag and hold a moving object. This can be accomplished by reducing the floatation (buoyant force) and/or strength of the float line (for example, inserting a weak link).

The land testing performed in this project demonstrated that weak links placed in the float line will fail, when a force is applied, and will release tension on the float line. The link will only fail if the gear offers enough resistance to allow the breaking strength of the weak link to be exceeded. The resistance must come from the bottom holding characteristics of the lead line and anchors and the drag resistance of the webbing and float line in the water column. The lower the breaking strength of the weak link, the more likely the float line will part when hit by a large object. This would result in less risk of snagging the offending object and less damage to the gill net string.

One of the biggest unknowns in this whole problem is the question of the momentum of a whale and the resulting impulse related forces. If a whale hits a gill net, and the net offers resistance, the whale should generate enough force to break an appropriately designed weak link. However, if a whale just brushes up alongside a gill net, or a substantial catenary is formed prior to weak link failure, a weak link may not break before an entanglement occurs.

Recommendations

1. Accurately survey the type of gill net gear in use including mesh size, twine size, float and lead line size, material, and age. Take known age samples of float line and test the breaking strength of these samples.

2. Test different net hauling procedures to develop ways to haul the gill nets with minimum loading on the float line.

3. Conduct in water tests, similar to the land testing of gill nets, but using longer strings. Develop photographic techniques for measuring net displacement.

4. Have fishermen fish nets with float line weak links to determine operational problems. We suggest low breaking strengths on the order of 500 lbs for starters.