2009 Project Report

Update on Gulf of Mexico Pelagic Longline Bluefin Tuna Mitigation Research

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Executive Summary

Research was conducted in 2008 and 2009 by the Engineering and Harvesting Branch of NOAA Fisheries, Southeast Fisheries Science Center, Mississippi Laboratories to evaluate the efficacy of a new 16/0 "weak" circle hook design in reducing the bycatch of bluefin tuna in the Gulf of Mexico yellowfin tuna fishery. Five commercial vessels completed 197 pelagic longline sets. Experimental hooks and standard 16/0 circle hooks were alternated on the longline during 197 sets, with a total of 123,872 hooks set. A total of 20 bluefin were caught during the experiment, of which four were caught on the experimental hook (75% reduction). The difference in bluefin catch was statistically significant. Vessels landed a total of 1,573 yellowfin tuna. The difference in the yellowfin catch rate for standard and experimental hooks was not significant.

Background

Atlantic bluefin tuna (*Thunnus thynnus*) are widely distributed across the Atlantic Ocean and Mediterranean Sea. The presence of two distinct spawning areas, the Gulf of Mexico (GOM) and the Mediterranean, has led the International Commission for the Conservation of Atlantic Tunas (ICCAT) to divide the Atlantic bluefin into east and west management units.

The GOM, which is the spawning area for the western Atlantic bluefin tuna stock, has become an area of concern due to the bycatch mortality of spawning bluefin tuna associated with yellowfin tuna (*Thunnus albacares*) pelagic longline fishery. Starting in 2007, the NOAA Fisheries, Engineering and Harvesting Branch of the Southeast Fisheries Science Center (SEFSC), Mississippi Laboratories conducted scientific research in consultation and cooperation with the domestic pelagic longline fleet in the GOM. Research efforts focus on utilizing the difference in the relative size of spawning bluefin as compared to the target species, yellowfin tuna.

NOAA researchers worked with hook manufacturers to develop a hook design that has less tensile strength than standard hook designs. Research conducted in 2008 evaluated the efficacy of a weaker 16/0 circle hook in reducing the bycatch of bluefin tuna by comparing it to a standard 16/0 circle hook used in the pelagic longline fishery. Results from the fishery dependent research conducted in 2008 were encouraging (Appendix 1). In order to improve the statistical precision and confidence of the results, additional research was conducted in 2009.

Figure 1: Control and experimental hooks used in 2008 and 2009 bluefin tuna mitigation research

Materials and methods

2009 Experimental Design

Five commercial pelagic longline vessels were used to evaluate the new hook design in reducing the incidental bluefin tuna catch rate associated with pelagic longline gear in the GOM. The control treatment was an industry standard Mustad 16/0 circle hook (model 39960D) with 0° of offset, constructed of 4.0 mm steel wire with Duratin coating. The experimental treatment was a custom made Mustad 16/0 circle hook (model 39988D) with 0° of offset, constructed from 3.65 mm steel wire with Duratin coating. Control and experimental hooks were alternated on the longline for a minimum of 500 total hooks. Five hooks were deployed between each float. Hook spacing was consistent within a trip. Buoy lines, leader lengths and size, mainline, and leader color were consistent within a trip. Spanish sardine (75-125 g) was the primary bait used. A few sets incorporated squid bait. However, bait type was consistent within each section of gear. Other than the experimental design requirements, captains were allowed to fish normally and chose the location of fishing, length of trips, total number of hooks fished, etc.

Data Collection

All vessels participating in the experiment carried NOAA trained observers. Both the observers and the captains were well versed in the experimental design. Each observer was trained in safety; fish, marine mammal, and seabird identifications; data collection; and the operation of a pelagic longline fishing vessel. Observers collected fishery data as described by the SEFSC Pelagic Longline Observer Program (Beerkircher et al. 2002), with minor modifications to accommodate the experiment. The time and location of each section of gear was recorded as it was deployed and retrieved, as was the sea surface temperature. These data were obtained from the vessel's existing wheelhouse equipment. The section number, treatment (hook model), time on deck, and species were recorded for each animal captured. The lengths of animals caught were measured in centimeters. Length was estimated for animals which were not boated. A carcass tag applied to each fish kept was used to match the dressed weight (carcass with head and fins removed and animal eviscerated) of the fish during unloading at the dock to the particular data collected on that animal at sea.

Hooks that had been straightened with no catch were recorded as species "unknown" and the hook condition was documented. Control and experimental hooks that caught yellowfin tuna, bluefin tuna and swordfish were tagged and retained. These hooks were compared to an unused hook in order to evaluate the effects that result from the physical forces that these fish exert on the experimental hook design.

Statistical methods

The relationship between the catch rate (or catch probability) and the explanatory variables (hook type, mean sea surface temperature, vessel and year) was investigated using generalized linear models. In particular, logistic regression analysis (with maximum likelihood estimation procedure) for binary response (bluefin tuna, yellowfin tuna, yellowfin tuna kept, swordfish , wahoo, and straightened hooks) count data and traditional regression analysis (with least squares estimation procedure) for continuous response weight data was used. Sea surface temperatures were averaged for each set.

The modeling results presented used set as the experimental unit. All analyses utilized the original units of measurements (e.g., sea surface temperature). Since the probability of a species catch (per hook) for the hook types being compared is fairly small, the catch probability ratio for the two hook types was approximated from the odds ratio (corresponding to hook types) estimated from the fitted logistic regression models. Thus, subtracting the odds ratio (and 95% confidence limits (CIs)) from 1 provides an estimate of reduction rate (and related confidence limits) due to experimental hook.

Approximation of relative risk for other factors also utilized odds ratio owing to low magnitude of catch probability. Statistical significance was assessed at $\alpha < 0.05$ level.

Size-frequency distributions of yellowfin tuna were plotted and compared by two-sample Kolmogorov-Smirnov (KS) tests.

Results

2009 Experimental Effort

As a continuation of the bluefin mitigation research conducted in 2008, five commercial pelagic longline vessels made 125 research sets in the northern GOM during the period of April 2, 2009 to June 25, 2009. A total of 87,106 hooks (43,553 of each hook type) were deployed. Vessels fished an average of 697 hooks per set. Sea surface temperature ranged from 27.7 to 30.6 °C, with an average of 26.6 °C and standard deviation of 2.03 °C.

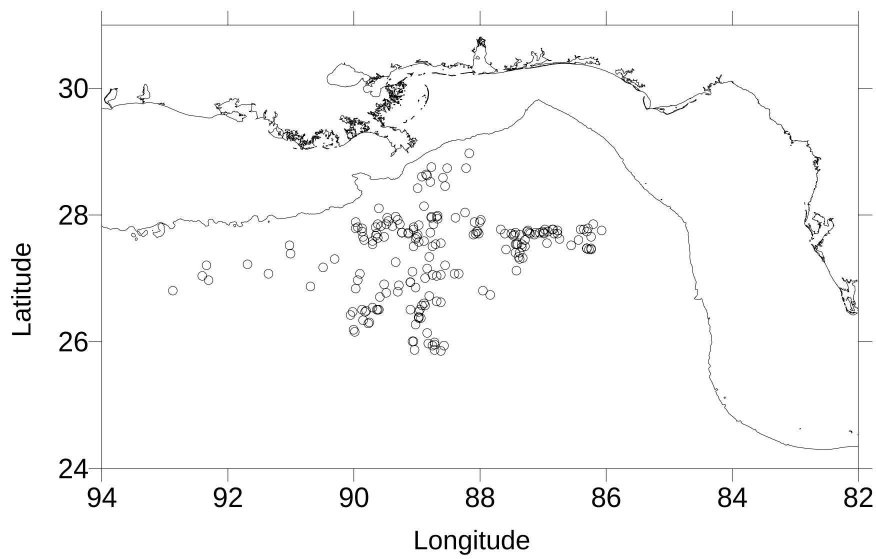

Figure 2: Geographical distribution of sets made in 2008 and 2009.

2008 - 2009 Cumulative Results

In 2008 and 2009, five vessels have made 20 trips. One hundred and ninety-seven (197) sets have been conducted with a total of 123,872 hooks set (61936 of each hook type)(Figure 2). Vessels fished an average of 629 hooks per set. Sea surface temperature averaged 27.3 °C, with a range from 22.7 to 30.6 °C and a standard deviation of 2.0 °C. A total of 4,600 animals were caught, representing 42 taxa (Table 1). During the course of the experiment, six leatherback turtles and one pantropic spotted dolphin were captured and released alive.

Bluefin tuna

A total of 20 bluefin were caught during the experiment, of which four were caught on the experimental hook. The mean dressed weight for the three bluefin retained for sale was 237 kg (range 198-265 kg). Of the 20 bluefin caught, 12 were landed alive. The 75% reduction in bluefin observed with the experimental hook was statistically significant (CI = 25%-92%, $p = 0.0131$)(Table 2). The effects of sea surface temperature, vessel and year were not significant ($p > 0.25$).

Yellowfin tuna

Yellowfin tuna, which is the primary target species in the GOM pelagic longline fishery, comprised 34% of the total catch. Vessels landed a total of 1573 yellowfin tuna, of which 1204 were retained for sale. The mean weight of fish retained was 40.3 kg (range 11.4–83.2 kg). The total yellowfin CPUE (per 1000 hooks) for the control and experimental hooks (13.06 and 12.34 respectively) was not significantly different (p = 0.2525). The difference in the catch of fish retained for sale (10.22 control and 9.22 experimental) was marginally significant (9.9%, $p = 0.0724$). The difference in CPUE by weight (413 kg control and 371 kg experimental) was not significant ($p = 0.1488$).

Sea surface temperature effect for yellowfin tuna was highly significant ($p < 0.0001$). The odds of catching yellowfin tuna increased by a multiplicative factor of 1.075 per one degree Fahrenheit (0.56^{o}C) increase in sea surface temperature.

The yellowfin models for count and weight detected a significant vessel effect on yellowfin CPUE ($p <= 0.0008$). The experimental hook results for individual vessels were highly variable; ranging from a 38% decrease to a 7% increase in the catch of yellowfin tuna retained for sale (Figure 3). Two vessels observed an increase in catch with the experimental hook while three vessels had a reduction. Vessel #4 exhibited the highest rate of reduction (38%) which was over twice the reduction rate of next highest reduction observed among the vessels in the experiment. An analysis of the catch rates of yellowfin retained for sale with vessel #4 data removed shows a 5.45% reduction in catch rate with the experimental hook ($p = 0.3561$).

A two-sample Kolmogorov-Smirnov test comparing the length distributions of yellowfin tuna caught on control and experimental hooks failed to detect a significant difference (Figure 4). The maximum difference between the cumulative distributions, D, is: 0.0273 with a corresponding P of: 0.932.

Table 1: Fish, sharks, sea turtles and marine mammals caught during the 2008 - 2009 GOM bluefin tuna pelagic longline experiment.

Scientific Name	Common Name	Control	Experimental
Thunnus albacares	YELLOWFIN TUNA	809	764
Alepisauridae	LANCETFISH SPP	513	406
Coryphaena	DOLPHIN SPP	327	305
Euthynnus pelamis	SKIPJACK TUNA	132	133
Lepidocybium flavobrunneum	ESCOLAR	99	111
Thunnus atlanticus	BLACKFIN TUNA	102	101
Xiphias gladius	SWORDFISH	93	92
Acanthocybium solandri	WAHOO	77	62
Sarda sarda	BONITO	36	30
Makaira nigricans	MARLIN BLUE	29	32
Istiophorus platypterus	SAILFISH ATLANTIC	23	21
Bramidae	POMFRET SPP	25	15
Sphyraenidae	BARRACUDA	19	13
Tetrapturus albidus	MARLIN WHITE	10	22
Chondrichthyes	SHARK	17	11
Carcharhinus plumbeus	SANDBAR	14	13
Carcharhinus falciformis	SILKY	13	8
Thunnus thynnus	BLUEFIN TUNA	16	4
Galeocerdo cuvier	TIGER	9	8
Strongylura marina	BILLFISH	9	7
Isurus oxyrinchus	MAKO SHORTFIN	3	5
Thunnus	TUNA	7	1
Carcharhinus obscurus	DUSKY	4	2
Dermochelys coriacea	LEATHERBACK	3	3
Alopias superciliosus	THRESHER BIGEYE	4	2
Ruvettus pretiosus	OILFISH	3	2
Isurus paucus	MAKO LONGFIN	4	
Thunnus obesus	BIGEYE	2	1
Isurus	MAKO SPP	1	2
Lampris guttatus	OPAH	2	1
Tetraodontidae	PUFFER SPP	3	
Alopias	THRESHER	3	
Carcharhinus longimanus	WHITETIP OCEANIC	2	
Thunnus alalunga	ALBACORE	1	1
Mola mola	SUNFISH OCEAN	2	
Prionace glauca	BLUE		1
Sphyrna lewini	HAMMERHEAD SCALLOPED		1
Stenella attenuata	DOLPHIN PANTROPIC SPOTTED		1
Gempylus serpens	MAKERAL SNAKE		1
Centrarchidae	SUNFISH SPP	1	
Alopias vulpinus	THRESHER COMMON	1	

Table 2: Odds ratio estimates from the model for yellowfin tuna, bluefin tuna, swordfish and wahoo.

Effect	Odds Ratio	95% Wald confidence limits		*p*
Bluefin tuna (count)				
Hook type	0.250	0.084	0.748	0.0131
Mean surface temp.	0.891	0.732	1.086	0.2526
Vessel				0.7262
Year	1.499	0.457	4.921	0.5043
Total yellowfin tuna (count)				
Hook type	0.943	0.854	1.042	0.2525
Mean surface temp.	1.131	1.105	1.158	<0.0001
Vessel				<0.0001
Year	1.001	0.884	1.133	0.9904
Yellowfin tuna retained for sale (count)				
Hook type	0.901	0.804	1.010	0.0724
Mean surface temp.	1.075	1.047	1.103	<0.0001
Vessel				<0.0001
Year	1.095	0.952	1.260	0.2038
Swordfish (count)				
Hook type	0.989	0.741	1.320	0.9413
Mean surface temp.	0.951	0.895	1.010	0.1028
Vessel				0.2818
Year	0.752	0.488	1.157	0.1947
Wahoo (count)				
Hook type	0.792	0.566	1.108	0.1738
Mean surface temp.	1.123	1.040	1.213	0.0032
Vessel				0.0927
Year	0.514	0.334	0.791	0.0025

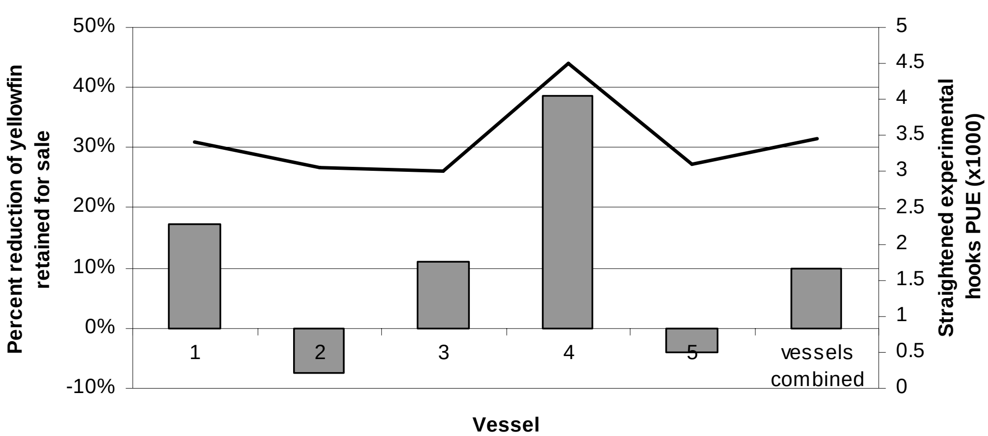

Figure 3: Reduction rate of marketable yellowfin tuna by vessel and vessels combined (left axis); and straightened experiment hooks per 1000 experimental hooks set by vessel and vessels combined (right axis). A negative value denotes an increase.

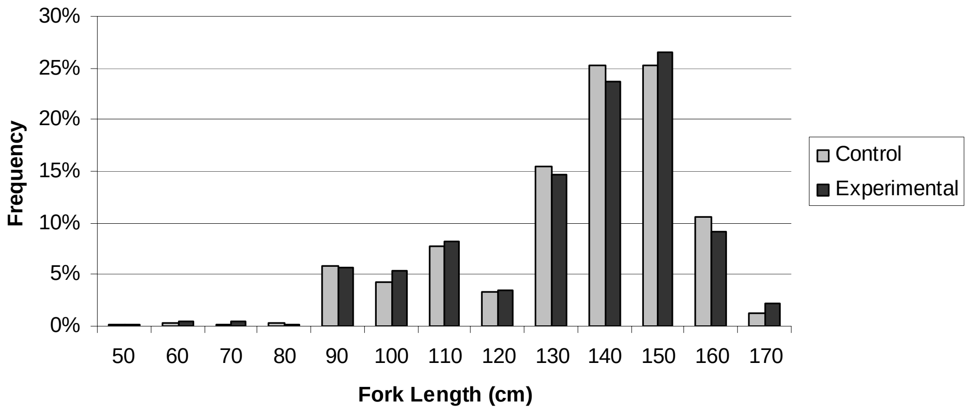

Figure 4: Yellowfin tuna length distribution for the control and experimental hooks.

Other Marketable Catch

Two other species that are commonly retained for sale and have the potential to straighten the experimental hook are swordfish (*Xiphias gladius*) and wahoo (*Acanthocybium solandri*). One hundred and eighty-five (185) swordfish were caught during the experiment, and 38 were retained for sale. One hundred and thirty-eight (138) wahoo were caught, with 124 retained for sale. The CPUEs for the control and experimental hooks for swordfish (1.50 and 1.49 respectively) and wahoo (1.24 and 0.98 respectively) were not significantly different ($p > 0.17$).

Hook Condition

During the experiment, observers recorded 53 control hooks and 215 experimental hooks that had been straightened to the degree for which the animal escaped. The difference in the rate of fish escapement between hook designs was highly significant ($p < 0.0001$) (Table 3). The model failed to detect a significant vessel effect ($p = 0.5467$). However, the vessels with the two highest reductions in catch rates of yellowfin tuna also had the highest occurrences of straightened experimental hooks (Figure 3).

Table 3: Odds ratio estimates from the model for straightened hooks.

Effect	Odds Ratio	95% Wald confidence limits		*p*
Straightened hooks (animal escaped)				
Hook type	4.068	3.011	5.495	<0.0001
Mean surface temp.	0.957	0.910	1.007	0.0891
Vessel				0.5467
Year	0.629	0.434	0.913	0.0147

In 2008, experimental hooks that caught yellowfin tuna, bluefin tuna and swordfish were retained for evaluation from three trips. In 2009, both control and experimental hooks were retained from 10 trips. An evaluation of 206 control hooks and 324 experimental hooks that successfully landed yellowfin tuna indicated that approximately 35.8% of the experimental hooks that landed yellowfin had some degree of deformation evident compared to 9.7% of the control hooks.

Bent hooks that landed fish were classified by the degree of deformation evident. Hooks with points opened less than 20^o from the original angle were classified as minor deformation with greater than 20^o classified as major deformation (Figure 5). The proportion of experimental and control hooks that exhibited major deformation was 10.2% and 1.4% respectively (Figure 6). An evaluation of hooks that resulted in fish escapement indicates escapement generally occurs with hooks that have been opened to angles greater than 25^o.

Hook Deformation

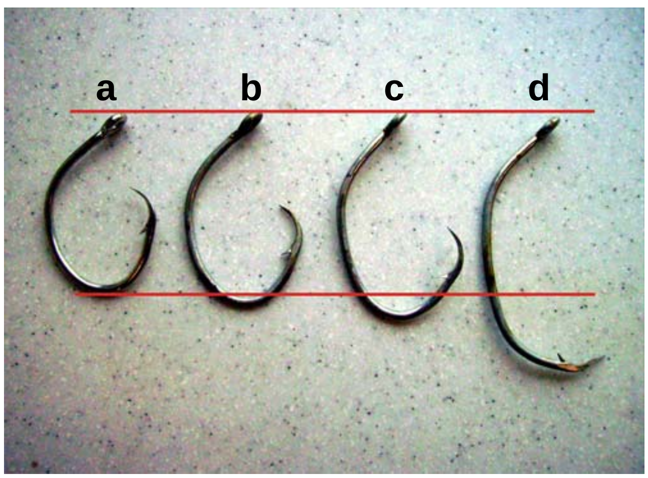

Figure 5: Examples of experimental hooks with varying degrees of deformation, (a) hook that landed a yellowfin with no bending evident; (b) yellowfin caught with minor deformation, point opened by 15^o; (c) yellowfin caught with major deformation (25^o); (d) hook straightened, animal escaped.

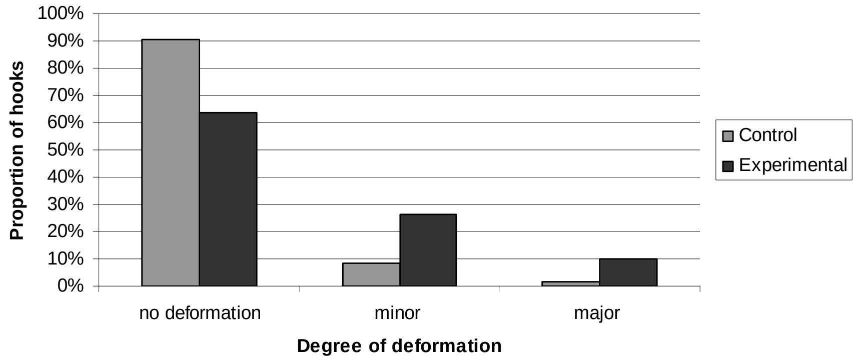

Figure 6: Proportion and degree of deformation with control and experimental hooks that caught yellowfin tuna. The "minor" classification is for hooks with points that have opened at angles less than 20°. The "major" classification is for hooks with angles greater than 20°.

The relationship between the probability of a yellowfin tuna catch resulting in a bent hooks and the explanatory variables of hook type and dressed weight was investigated using a logistic regression model. The dressed weight term and hook type are both significant in the model (each p-value <0.0001) implying higher odds for hook bending with increasing weight of yellowfin tuna and also with experimental hooks compared to the control hooks (Figure 7).

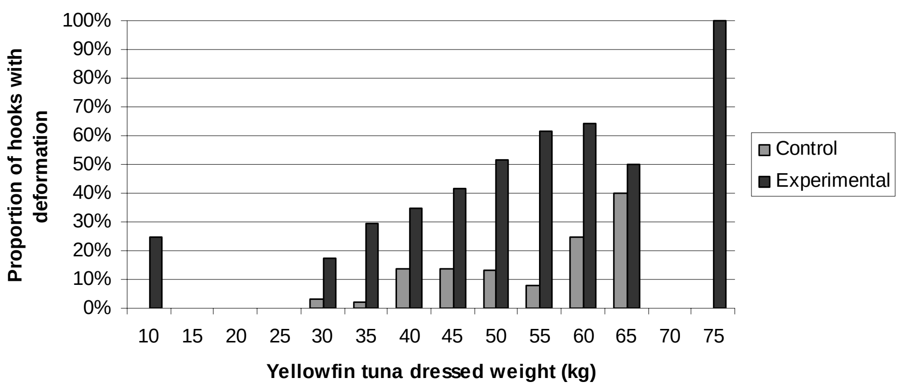

Figure 7: Proportion of control and experimental hooks with some degree of deformation by dressed yellowfin tuna weight.

A total of seven hooks that caught bluefin tuna, four control and three experimental hooks were evaluated (Figure 8). Three of the four control hooks had some degree of deformation with two hooks showing major deformation. All three of the experimental hooks exhibited major deformation. One of the experimental hooks became completely straightened while the tuna was along side of the vessel, resulting in the release of the fish

A total of 25 hooks that caught swordfish were retained for evaluation. None of the 15 control hooks were bent. Two of the 10 experimental hooks showed some deformation, with one showing major deformation. Both of the experimental hooks that were bent came from vessel #4.

Hooks with Bluefin

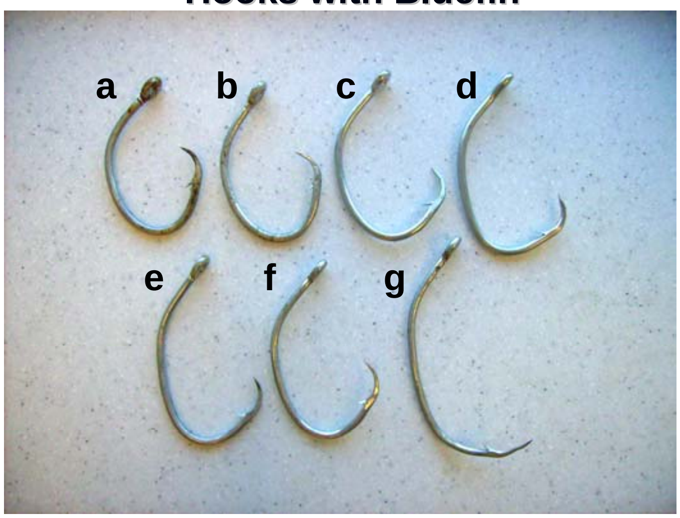

Figure 8: Sample of control hooks (a-d), and experimental hooks (e-g) that caught bluefin tuna.

Discussion

The estimated takes of spawning size bluefin tuna by the GOM pelagic longline fishery have raised concerns that this fishery may be impacting efforts to recover the western Atlantic bluefin tuna stocks. Data presented suggest a weaker circle hook design have the potential to mitigate this issue while maintaining a high retention rate for the target catch of yellowfin tuna.

A total of 20 bluefin tuna were caught during the experiment. The 75% reduction rate observed was constant for each year of the experiment and is consistent with expectations of the new hook design. The evaluation of the condition of hooks that caught bluefin shows that bluefin interaction with control hooks (the industry standard) commonly results in deformation of the hook. These observations suggest some portion of the 53 straightened control hooks that resulted in fish escapement were likely due to bluefin interactions. In 2004, federal regulation mandated the use the use of circle hooks in pelagic longline fisheries of the U.S. as a means of reducing sea turtle mortality. This rule requires the use of circle hooks in the GOM fishery (50 CFR Parts 223 and 635, Federal Register). Prior to the rule, the primary hook style used in the fishery were "J" hooks of sizes that have a higher tensile strength than the circle hooks used today. Therefore, it is possible that the 2004 regulations, implemented to address the sea turtle mortality associated with pelagic longlines, may have had some level of bluefin tuna mitigation benefit.

It would be difficult to assess the all of factors contributing to the level of force exerted on hooks during the interactions with animals. This research has shown that yellowfin tuna weight is a contributing factor. It is reasonable to suspect the same is true for bluefin. Other factors which may influence the level of force exerted on a hook by an animal during interaction include: water temperature, currents, fishing depth, hooks between floats, distance to the nearest float, interaction with other animals on the longline, and vessel hauling practices.

The retention rate of yellowfin tuna with the experimental hook was highly variable among the vessels participating in the experiment. The two vessels with the highest reduction of yellowfin also had the highest rate of fish escapement due to straightened experimental hooks. We attempted to standardize the gear configurations as much as possible during this fishery dependant research. Therefore, it is probable that variability in yellowfin retention rates were a result of the variability in hauling practices. We suspect that this variability in the performance of the new hook design will be reduced over time. As with any new conservation technology, minor adjustments in fishing practices are often needed in order to optimize the gear performance.

The directed fishing of large bluefin tuna by commercial fleets in the GOM has been prohibited since the early 1980s. As a result, fishers tend to avoid concentrations of bluefin tuna due to the loss of gear, time and target catch associate with large catches of bluefins. This study has not addressed the potential economic benefit that may result from reducing the interactions with bluefin on pelagic longlines. However, the majority of the vessels involved with the study continue to use the new hook design. Additional vessels, not involved in the study, have purchased the experimental hook for use.

It is our plan to continue this study in order to improve the statistical precision and confidence of the results. Due to the fact that vessels are likely to use the new hook design on a year round basis, we hope to extend the experiment to later in the season in order to evaluate the temporal effect the weak hook may have on the target catch.

References

Beerkircher, L.R., Brown, C.J., and Lee, D.W. 2002. SEFSC pelagic observer program data summary for 1992–2000. NOAA Tech. Memo. NMFS-SEFSC-486: 1–23. Available from http://www.sefsc.noaa.gov/observerresearch.jsp [accessed July 2004; updated April 2005].

APPENDIX I

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Bluefin Tuna Mitigation Research

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Executive Summary

Research was conducted in 2008 by the Engineering and Harvesting Branch of NOAA Fisheries, Southeast Fisheries Science Center, Mississippi Laboratories to evaluate the efficacy of a new 16/0 “weak” circle hook design in reducing the bycatch of bluefin tuna in the Gulf of Mexico yellowfin tuna fishery. From 5/09/08 to 7/02/08, two commercial vessels completed 72 pelagic longline sets. Experimental hooks and standard 16/0 circle hooks were alternated on the longline with a total of 36,766 hooks set. A total of five bluefin tuna were caught during the experiment. Four were caught on the control hook with one coming from the experimental gear (75% reduction). A total of 652 yellowfin tuna were caught, with the experimental hook having a 6% higher catch rate than the standard hook. The differences in the standard and experimental hooks for bluefin and yellowfin catch rates were not significantly different. However, the failure to detect a significant difference in bluefin catch was likely due to the small sample size. Additional trials are needed to fully evaluate the potential of the new hook design to reduce the incidental take of bluefin tuna on pelagic longlines in the Gulf of Mexico yellowfin tuna fishery.

Background

Atlantic bluefin tuna (*Thunnus thynnus*) are widely distributed across the Atlantic Ocean and Mediterranean Sea. The presence of two distinct spawning areas, the Gulf of Mexico (GOM) and the Mediterranean, has led the International Commission for the Conservation of Atlantic Tunas (ICCAT) to divide the Atlantic bluefin into east and west management units.

The GOM, which is the spawning area for the western Atlantic bluefin tuna stock, has become an area of concern due to the bycatch mortality of spawning bluefin tuna associated with pelagic longline fisheries. The U.S. National Marine Fisheries Service (NOAA Fisheries) is evaluating time/area closures in the GOM to mitigate the bycatch mortality of spawning bluefin tuna. Modifying fishing gear and/or fishing practices to reduce the mortality of bluefin tuna, while maintaining catches of yellowfin tuna (*Thunnus albacares*) in the GOM directed yellowfin tuna fishery is being considered as an alternative to additional time/area closures.

Starting in 2007, the NOAA Fisheries, Engineering and Harvesting Branch of the Southeast Fisheries Science Center (SEFSC), Mississippi Laboratories conducted scientific research in consultation and cooperation with the domestic pelagic longline fleet in the GOM. The objective of the research is to develop and assess the efficacy of new technologies and changes in fishing practices in reducing the bycatch mortality of bluefin tuna in the directed yellowfin tuna fishery.

During the first year of the research, experiments were conducted aboard the NOAA research vessel *R/V Gandy* to collect data on the relative force exerted by bluefin and yellowfin tuna when captured on pelagic longline gear (NOAA SEFSC Project Report October, 2007). Treatments of three different breaking strengths of monofilament leader (64, 91, and 113 kg) were tested to determine which leader strength would effectively release bluefin tuna yet retain yellowfin. Results indicate that 64 kg and 91 kg monofilament leader were capable of releasing bluefin tuna of the sizes of fish captured.

With this information, NOAA researchers began working with hook manufacturers to develop a hook design that has less tensile strength than standard hook designs. Research conducted in 2008 evaluated the efficacy of a weaker 16/0 circle hook in reducing the bycatch of bluefin tuna by comparing it to a standard 16/0 circle hook used in the pelagic longline fishery.

Materials and methods

Hook Development

Experiments were conducted at the Lindgren Pitman tackle company to evaluate the relative strengths of hooks currently being used by the pelagic longline industry in the GOM. During the test, monofilament line was attached on one end to the eye of the hook and the other to an electronic scale. A loop of monofilament was placed over the bend of the hook. The monofilament loop was pulled at 9 kg (20 lb) increments. After being subjected to each weight increment, the tension was relaxed and the relative spread in the hook gape (deformation) was measured. This process was repeated in a stepwise progression until the gape of the hook was spread to the degree that the monofilament loop contacted the hook barb (considered straightened). Based on the results of the hook bend test with standard hooks, a weaker hook design was developed. The new hook design was then subjected to the hook bend test to ensure that the experimental hook strength was near the target strength.

Hook Evaluation: Experimental design

Two commercial pelagic longline vessels were used to evaluate the new hook design in reducing the incidental bluefin tuna catch rate associated with pelagic longline gear in the GOM. The control treatment was an industry standard Mustad 16/0 circle hook (model 39960D) with 0° of offset, constructed of 4.0 mm steel wire with Duratin coating. The experimental treatment was a custom made Mustad 16/0 circle hook with 0° of offset, constructed from 3.65 mm steel wire with Duratin coating. Control and experimental hooks were alternated on the longline for a minimum of 450 total hooks. After the experimental portion of the gear was set, vessels were allowed to complete the set using only control hooks. Only animals caught on the experimental portion of the set were used in the analysis. The number of hooks deployed between floats differed between vessels, with one vessel deploying three hooks between floats and the other, five hooks. The number of hooks set between floats was consistent within a set. Hook spacing was consistent within a trip. Buoy lines, leader lengths and size, mainline, and leader color were consistent within a trip. Spanish sardine (75-125 g) was the primary bait used. A few sets incorporated squid bait. However, bait type was consistent within each section of gear. Other than the experimental design requirements, captains were allowed to fish normally and chose the location of fishing, length of trips, total number of hooks fished, etc.

Data Collection

All vessels participating in the experiment carried NOAA trained observers. Both the observers and the captains were well versed in the experimental design. Each observer was trained in safety; fish, marine mammal, and seabird identifications; data collection; and the operation of a pelagic longline fishing vessel. Observers collected fishery data as described by the SEFSC Pelagic Longline Observer Program (Beerkircher et al. 2002), with minor modifications to accommodate the experiment. The time and location of each section of gear was recorded as it was deployed and retrieved, as was the sea surface temperature. These data were obtained from the vessel's existing wheelhouse equipment. The section number, treatment (hook model), time on deck, and species were recorded for each animal captured. The lengths of animals caught were measured in centimeters. Length was estimated for animals which were not boated. A carcass tag applied to each fish kept was used to match the dressed weight (carcass with head and fins removed and animal eviscerated) of the fish during unloading at the dock to the particular data collected on that animal at sea.

Hooks that had been straightened with no catch were recorded as species "unknown" and the hook condition was documented. Experimental hooks that caught yellowfin tuna were tagged and retained. These hooks were compared to an unused experimental hook in order to evaluate the effects that result from the physical forces that yellowfin exert on the experimental hook design.

Statistical methods

The relationship between the catch rate (or catch probability) and the explanatory variables (hook type, mean sea surface temperature, and vessel) was investigated using generalized linear models. In particular, logistic regression analysis (with maximum likelihood estimation procedure) for binary response (bluefin tuna, yellowfin tuna, yellowfin tuna kept, swordfish , wahoo, and failed (straightened) hooks) count data was used. Some animals were caught on the portion of the gear that was not part of the experiment (i.e., not set in an alternating hook design). These data were excluded from the analysis. Sea surface temperatures were averaged for each set.

The modeling results presented used set as the experimental unit. All analyses utilized the original units of measurements (e.g., sea surface temperature). Since the probability of a species catch (per hook) for the hook types being compared is fairly small, the catch probability ratio for the two hook types was approximated from the odds ratio (corresponding to hook types) estimated from the fitted logistic regression models. Thus, subtracting the odds ratio (and confidence limits) from 1 provides an estimate of reduction rate (and related confidence limits) due to experimental hook. Approximation of relative risk for other factors also utilized odds ratio owing to low magnitude of catch probability.

Size-frequency distributions of yellowfin tuna were plotted and compared by two-sample Kolmogorov-Smirnov (KS) tests.

Results

Hook Development

The results of the experiments conducted at the Lindgren Pitman tackle company to evaluate the relative strengths of circle hooks are presented in Figure 1. Two of the hook designs and sizes that are currently being used in the GOM are the 16/0 Mustad 39960 (4.0 mm wire diameter) and the 16/0 Eagle Claw L 2048 (4.1 mm wire diameter). The tests show that these two hook designs exhibit plastic deformation (change in shape that takes a permanent set when the stresses that caused it are removed) at between 70 and 90 kg of pull. The hooks became straightened (deformed to a degree in which fish escapement is likely) at between 110 and 125 kg of pull. To evaluate the potential utility of a smaller wire diameter, a Mustad 15/0 circle hook (3.65 mm wire diameter) was tested. The test results of the 3.65 mm wire in the 15/0 hook gave indication that the strength of 16/0 hooks can be reduced by using smaller wire size. Based on these results, a Mustad 16/0 hook was constructed using 3.65 mm wire. Due to the increased leverage given by the larger hook gape of the 16/0 hook as compared to the 15/0 hook, the new design was found to have a lower strength than its 15/0 counterpart. The new hook design begins to show signs of plastic deformation at between 35 and 45 kg of pull and straightens at around 72 kg. Based on the results, 5,000 of the new 16/0 design hooks were manufactured for evaluation in the experiment.

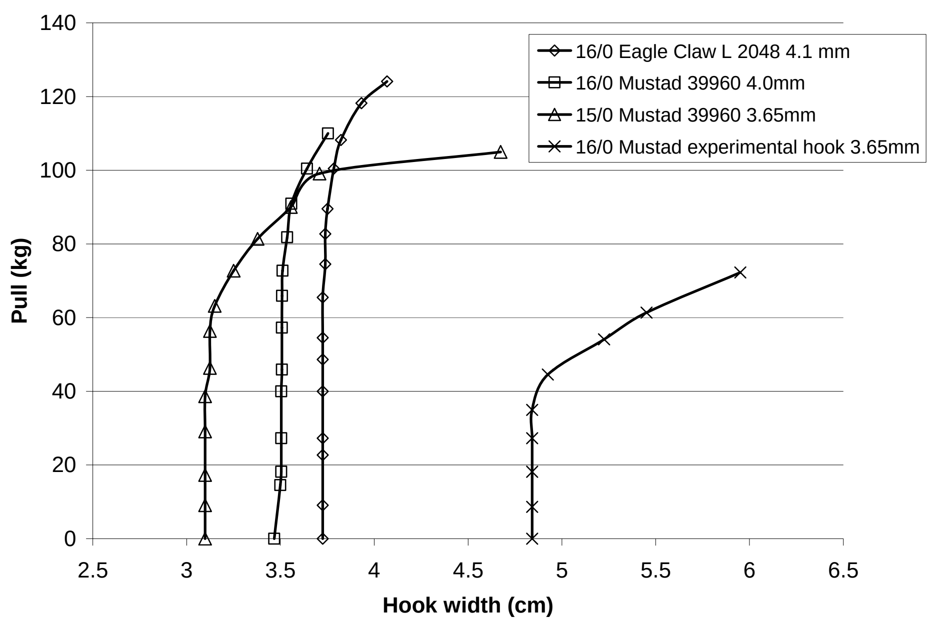

Figure 1: The result of hook strength tests conducted on three commercially available circle hooks as well as the experimental hook developed for this study. Increase in hook width corresponds to the relative bending of hooks when subjected to the corresponding force.

Hook Evaluation Results

During June-July 2008, two commercial pelagic longline vessels made 72 research sets in the northeastern GOM, fishing a total of 42,762 hooks (Figure 2). Of the hooks fished, 36,766 were involved in the experiment (18,383 of each hook type). Vessels fished an average of 594 hooks per set; the minimum number of hooks fished in a set was 450 hooks, and the maximum was 765 hooks. Surface temperature ranged from 25.4 to 30.9 °C, with an average of 28.3 °C and standard deviation of 2.5 °C. The vessels caught 36 taxa of fish, sharks and sea turtles on the experimental portion of the gear (Table 1). During the course of the experiment, four leatherback turtles were captured and released alive.

Table 1: Fish, sharks and sea turtles caught during the 2008 GOM bluefin tuna pelagic longline experiment.

Scientific Name	Common Name	Discarded	Kept
Thunnus albacares	YELLOWFIN TUNA	182	474
Alepisauridae	LANCETFISH SPP	551	1
Coryphaena	MAHI MAHI	51	420
Euthynnus pelamis	SKIPJACK	145	
Thunnus atlanticus	BLACKFIN TUNA	107	
Acanthocybium solandri	WAHOO	8	76
Lepidocybium flavobrunneum	ESCOLAR	19	64
Auxis rochei rochei	MACKEREL, FRIGATE	62	
Sarda sarda	BONITO	62	
Xiphias gladius	SWORDFISH	48	8
Carcharhinus falciformis	SILKY	31	
Makaira nigricans	MARLIN, BLUE	29	
Carcharhinus plumbeus	SANDBAR	25	
Sphyraenidae	BARRACUDA	23	
Tetrapturus albidus	MARLIN, WHITE	22	
Bramidae	POMFRET SPP	14	
Istiophorus platypterus	SAILFISH, ATLANTIC	12	
Galeocerdo cuvier	TIGER	12	
Chondrichthyes	SHARK	8	
Carcharhinus obscurus	DUSKY	6	
Thunnus thynnus	BLUEFIN	4	1
Isurus paucus	MAKO LONGFIN	4	
Rajiformes	RAY, PELAGIC	4	
Isurus oxyrinchus	MAKO SHORTFIN	2	2
Dermochelys coriacea	LEATHERBACK	4	
Thunnus obesus	BIGEYE TUNA		2
Strongylura marina	BILLFISH	2	
Prionace glauca	BLUE	2	
Ruvettus pretiosus	OILFISH	2	
Myliobatidae	RAY, MANTA	1	
Mola mola	SUNFISH, OCEAN	1	
Carcharhinus longimanus	WHITETIP OCEANIC	1	
Lampris guttatus	OPAH		1
Alopias vulpinus	THRESHER COMMON	1	
Tetraodontidae	PUFFER SPP	1	
Sphyrna lewini	HAMMERHEAD SCALLOPED	1	

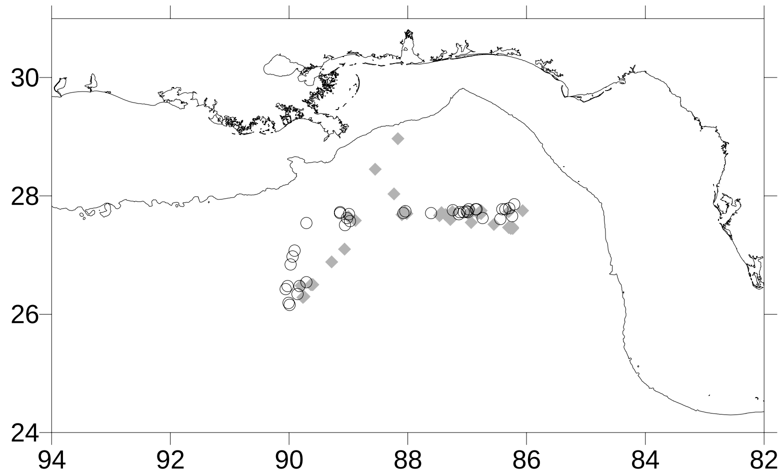

Figure 2: Geographical effort distribution for vessel 1 (diamonds) and vessel 2 (circles).

Yellowfin tuna is the primary target species in the GOM fishery. The vessels landed a total of 656 yellowfin tuna of which 474 were retained for market. Yellowfin tuna caught during the experiment averaged 63 cm in length (range 50–172 cm). The mean weight of yellowfin retained was 38.2 kg (range 11.4–73.2 kg). The experimental hook caught more yellowfin tuna than the control hook (6.5% increase), as well as a higher number of yellowfin tuna that were retained for sale (1.3% increase) (Figure 3). The effect of the experimental hook on both classifications of yellowfin was not significant ($p > 0.4$) (Table 2). The effect of the experimental hook for individual vessels ranged from a 10% decrease to a 25% increase in total yellowfin tuna catch. However, yellowfin models failed to detect a significant vessel effect ($p > 0.58$).

Sea surface temperature effect for yellowfin tuna was highly significant ($p < 0.0001$). The odds of catching yellowfin tuna increased by a multiplicative factor of 1.19 per one degree Fahrenheit (0.56^{o}C) increase in sea surface temperature (Table 2). Extrapolations of the effects of sea surface temperatures outside of the range observed were not appropriate.

A two-sample Kolmogorov-Smirnov test comparing the length distribution of yellowfin tuna caught failed to detect a significant difference between the tuna caught on control and experimental hooks (Figure 4). The maximum difference between the cumulative distributions, *D*, is 0.0249 with a corresponding *p* of 1.000.

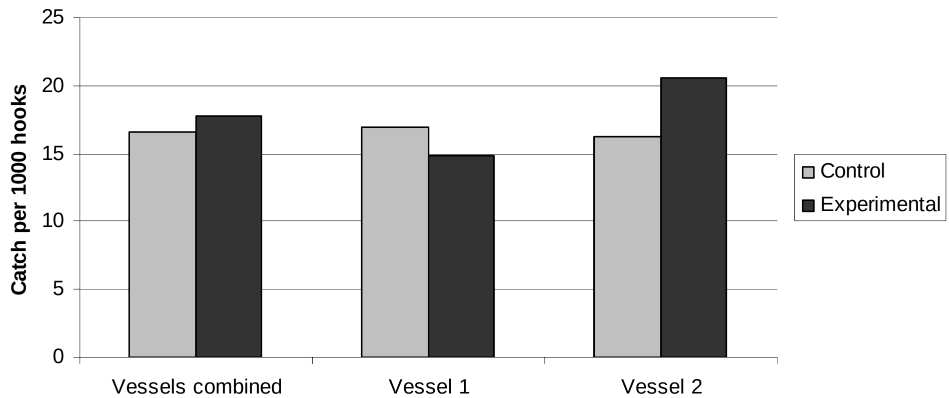

Figure 3: Total yellowfin tuna CPUE for the control and experimental hooks.

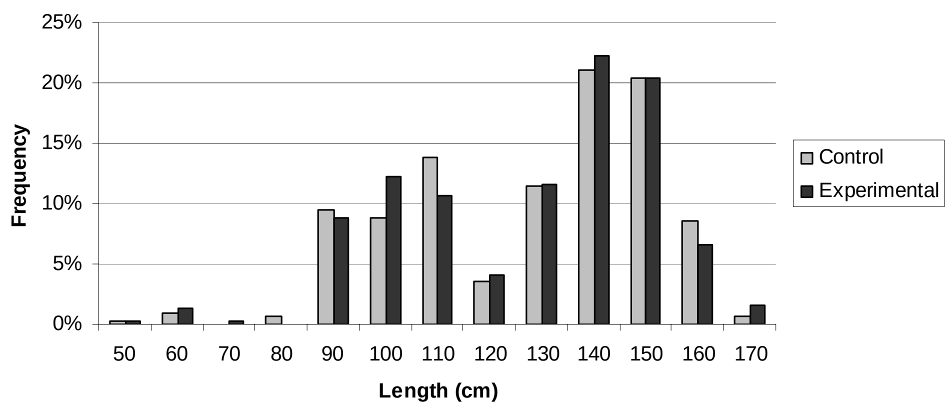

Figure 4: Yellowfin tuna length distribution for the control and experimental hooks.

Only one of the vessels involved with the experiment caught bluefin tuna. A total of five bluefin were caught, of which one was caught on an experimental hook. The observer noted that the one bluefin caught on the experimental hook had straightened the hook almost to the point of releasing the fish. The average estimated length of all bluefin caught was 239 cm (range 200–264 cm). One fish was retained for sale which weighed 249 kg (dressed weight). Of the five bluefin landed, four were alive with the one mortality occurring on a control hook. The 75% reduction in bluefin observed with the experimental hook was not statistically significant ($p = 0.2149$). The sea surface temperature effect was marginally significant ($p = 0.0992$).

Two other species that are commonly retained for sale and have the potential to straighten the experimental hook are swordfish (*Xiphias gladius*) and wahoo (*Acanthocybium solandri*). Fifty six (56) swordfish were caught during the experiment, and eight were retained for sale. Eighty-four (84) wahoo were caught, with 76 retained for sale. The point estimates for the effect of the experimental hook are an increase of 7.4% in swordfish and a 23.5% decrease in wahoo. The statistical analysis failed to detect an experimental hook effect for either species ($p > 0.22$).

Table 2: Odds ratio estimates from the model for yellowfin tuna, bluefin tuna, swordfish, and wahoo.

Effect	Odds Ratio	95% Wald confidence limits		*p*
Total yellowfin tuna (count)				
Hook type	1.065	0.912	1.243	0.4289
Mean surface temp.	1.188	1.144	1.234	<.0001
Vessel	0.987	0.842	1.158	0.8737
Yellowfin tuna retained for sale (count)				
Hook type	1.013	0.844	1.216	0.8888
Mean surface temp.	1.112	1.067	1.159	<.0001
Vessel	1.054	0.874	1.270	0.5822
Bluefin tuna (count)				
Hook type	0.250	0.028	2.236	0.2149
Mean surface temp.	0.737	0.513	1.059	0.0992
Vessel*	-	-	-	-
Swordfish (count)				
Hook type	1.074	0.636	1.815	0.7891
Mean surface temp.	0.810	0.726	0.904	0.0002
Vessel	1.347	0.796	2.279	0.2664
Wahoo (count)				
Hook type	0.765	0.496	1.182	0.2281
Mean surface temp.	1.164	1.050	1.289	0.0038
Vessel	1.041	0.669	1.621	0.8578

*Analysis of vessel effect not appropriate. Only one vessel had a bluefin tuna catch.

During the experiment, observers recorded nine control hooks and 76 experimental hooks that had been straightened to the degree for which the animal escaped. The rate at which this occurred between hook designs was highly significant ($p < 0.0001$) (Table 3). One vessel accounted for the majority of the straightened hooks of both types (8 control, 49 experimental) and a significant vessel effect was detected ($p = 0.0118$). Observations of 150 experimental hooks that successfully landed yellowfin tuna indicate approximately 27% of the experimental hooks that landed yellowfin had some degree of deformation evident. The degree of distortion ranged from barely detectable to hooks that had been straightened almost to the point of releasing the fish (Figure 5). The weight distribution of retained yellowfin tuna caught on experimental hooks that were unaffected and deformed (to some degree) is presented in Figure 6. A Kolmogorov-Smirnov test comparing the size-frequency distributions shows a marginally significant difference in the weight compositions between yellowfin tuna that did not deform the experimental hooks and ones that did ($p = 0.067$).

Table 3: Odds ratio estimates from the model for straightened hooks.

Effect	Odds Ratio	95% Wald confidence limits		*p*
Straightened hooks (animal escaped)				
Hook type	8.474	4.246	16.915	<.0001
Mean surface temp.	0.977	0.891	1.071	0.6161
Vessel	0.555	0.351	0.878	0.0118

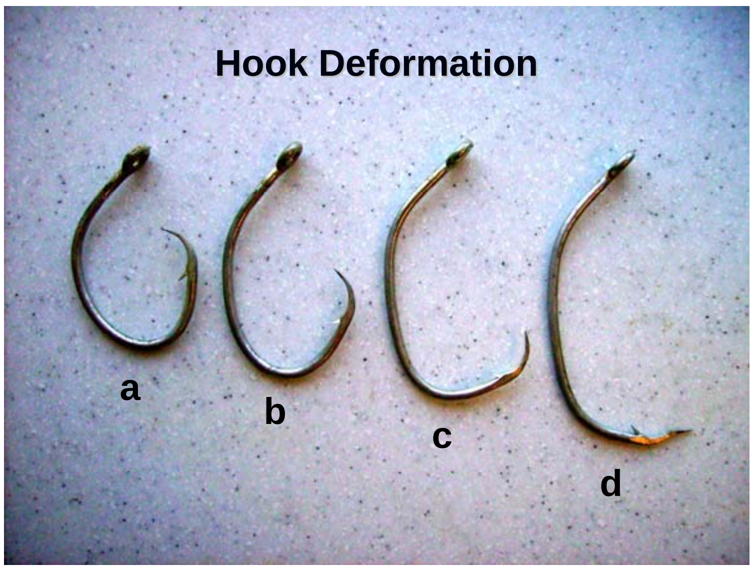

Figure 5: Examples of experimental hooks with varying degrees of deformation, (a) hook that landed a yellowfin with no bending evident, (b) yellowfin caught with minor deformation, (c) yellowfin caught with major deformation, (d) hook straightened, animal escaped.

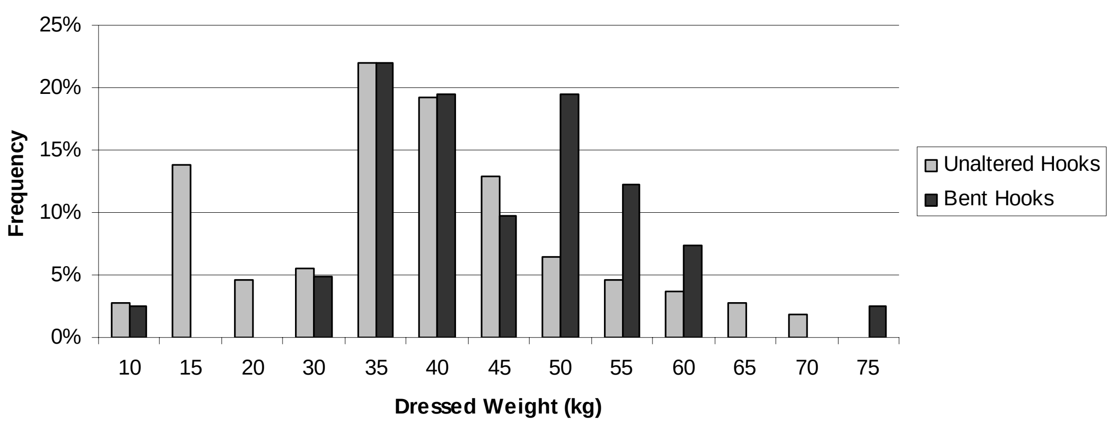

Figure 6: Yellowfin frequency distribution by weight class for unaltered (not deformed) and deformed hooks.

Discussion

The estimated takes of spawning size bluefin tuna by the GOM pelagic longline fishery have raised concerns that this fishery may be impacting efforts to recover the western Atlantic bluefin tuna stocks. Data presented suggest a weaker circle hook design may have the potential to mitigate this issue while maintaining the target catch of yellowfin tuna.

A total of five bluefin tuna were caught during the experiment. Although the sample size was not sufficient to demonstrate a significant difference between the control and experimental hooks, the 75% reduction rate is consistent with expectations of the new hook design. All five bluefin tuna caught came from one vessel, even though the two vessels participating in the experiment fished in close proximity of one another. A possible indication as to why one of the vessels caught no bluefin is the fact that eight of the nine control hooks that had been straightened during the experiment occurred on this vessel. Additionally, the same vessel had a significantly higher proportion of straightened experimental hooks. The higher rate of straightened hooks (both designs) give indication that fishing practices (e.g., gear configuration, hauling practices) may have an effect on escapement rate. However, we have thus far been unable to draw firm conclusions about the effect which fishing practice has on the results of this experiment.

We found no significant difference in the catch rate of yellowfin tuna for the experimental hooks as compared to the experimental design. On the other hand, some yellowfin tuna (27%) demonstrated the ability to apply enough force to deform the experimental hooks to varying degrees, suggesting the likelihood that a small portion of yellowfin may be capable of escaping from the new hook design. The deformation of experimental hooks was disproportionately higher among large yellowfin tuna (> 40 kg dressed weight), which supports the belief that tuna escapement with the experimental hooks is a function of size and strength.

It is our plan to continue this study in order to obtain a sufficient sample size to evaluate the potential of this conservation gear in reducing the incidental take of bluefin tuna in the GOM longline fishery. Additionally, we hope to increase the number of vessels and geographical range of the effort in order to assess the effect that varying fishing practices have on the effectiveness of the experimental hook design.

References

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