4-25-2019

A Comparison of Circle and J Hook Performance within the Grenadian Pelagic Longline Fishery

Anthony G. Burns
Nova Southeastern University, ab2629@mynsu.nova.edu

NSUWorks Citation

Anthony G. Burns. 2019. *A Comparison of Circle and J Hook Performance within the Grenadian Pelagic Longline Fishery.* Master's thesis. Nova Southeastern University. Retrieved from NSUWorks, . (510)
https://nsuworks.nova.edu/occ_stuetd/510.

Thesis of
Anthony G. Burns

Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Science

M.S. Marine Biology

Nova Southeastern University
Halmos College of Natural Sciences and Oceanography

April 2019

Approved:
Thesis Committee

Major Professor: David Kerstetter

Committee Member: Amy C. Hirons, Ph.D.

Committee Member: Paul T. Arena, Ph.D.

HALMOS COLLEGE OF NATURAL SCIENCES
AND OCEANOGRAPHY

A COMPARISON OF CIRCLE AND J HOOK PERFORMANCE WITHIN THE GRENADIAN PELAGIC LONGLINE FISHERY

By:

Anthony G. Burns

Submitted to the Faculty of
Halmos College of Natural Sciences and Oceanography
in partial fulfillment of the requirements for
the degree of Master of Science with a specialty in:

Marine Biology

Nova Southeastern University

May 2019

Thesis of
Anthony G. Burns

Submitted in Partial Fulfillment of the Requirements for the Degree of

Masters of Science:
Marine Biology

Nova Southeastern University
Halmos College of Natural Sciences and Oceanography

May 2019

Approved:

Thesis Committee

Major Professor: ______________________________

David W. Kerstetter, Ph.D.

Committee Member: ____________________________

Amy C. Hirons, Ph.D.

Committee Member: ____________________________

Paul T. Arena, Ph.D.

Table of Contents

Acknowledgements

Support for the trials was provided by The Caribbean Billfish Project component of the GEF-funded, World Bank-implemented, Ocean Partnership for Sustainable Fisheries and Biodiversity Conservation Models for Innovation and Reform. Trial support was facilitated through the Fisheries Division, Ministry of Agriculture and Lands of the Government of Grenada.

I would like to thank Dr. David Kerstetter for allowing me to work on this project and for the mentorship he has provided me. I want to extend my thanks to my committee members, Dr. Amy Hirons and Dr. Paul Arena, for their guidance throughout the project. Special thanks to Grenada Fisheries Division chief fisheries officer Crafton Isaac and senior fisheries officer Moran Mitchell for their efforts facilitating the project. I would also like to acknowledge Luis Acosta for his work as the fisheries at-sea observer, and the captains and the crew of the F/Vs *Rayhannah* and *Lady Cynthy II* for their work conducting the trials.

Abstract

The development and adaptation of gear technologies to local fisheries has been a management-oriented research strategy commonly used to mitigate the ecological effects of pelagic longline (PLL) gear on bycatch species. Grenada's PLL fishery primarily targets yellowfin tuna, however while minimal, their bycatch of blue marlin and white marlin exceeds the Total Allowable Catch (TAC) allowed by the International Commission for the Conservation of Atlantic Tunas (ICCAT). A switch to circle hooks may benefit these nontargeted, bycatch species by reducing catch rates and haulback mortality, as well as increasing post-release survival. To determine differences in performance, assessments of 16/0 circle hooks and 9/0 J hooks were alternated over 26 sets between January and June 2018. Catch, mortality, hook location, length and grade of fish were compared between hook types. No differences in haulback mortality rate for all species, or yellowfin tuna grade were found between hook types. However, significantly fewer billfish collectively (t= 2.36, p= 0.028), and sailfish specifically (t= 3.04, p=0.005), were caught on circle hooks. Additionally, tuna caught with circle hooks had a 69% greater chance of external hooking compared to J hooks ($X^2 = 4.38$ p=0.036). All other species analyzed had statistically similar catch rates regardless of hook type ($p < 0.05$), including, yellowfin tuna. The results of this study indicate the Grenadian PLL can reduce its impact on billfish bycatch by using 16/0 circle hooks without incurring negative effects on their tuna catch rate or grade. This research provides further evidence that circle hooks should be the recommended gear type when using a bycatch mitigation approach to manage PLL fisheries.

Keywords: Bycatch mitigation; circle hooks; pelagic longline

Introduction

Fishing activities targeting swordfish *Xiphias gladius* and tunas with pelagic longline gear is conducted throughout the world's oceans. The pelagic longline gear type was initially developed in Japanese fisheries to target Pacific bluefin tuna *Thunnus orientalis*, and it was expanded to global use in the mid-20th century (Watson and Kerstetter 2006). Modern pelagic longline gear consists of a monofilament mainline suspended by floats to which weighted leaders or gangions ending in baited hooks are attached (Figure 1). The gear uses a standardized construction method with monofilament mainline and metal "clip" connectors between leaders and buoy float lines, allowing for various configurations and therefore adjustments to the selectivity of target species. For example, increasing the effective fishing depth via longer float lines and leaders is often done for nighttime sets targeting swordfish during new moon periods, when they tend to be deeper in the water column (Lerner 2013). Beyond gear configuration, the selectivity of pelagic longline gear is also influenced by factors including operational characteristics, bait, leader material, and hook types and sizes (Løkkeborg and Bjordal 1992).

Interactions of regulated or non-marketable animals (bycatch) with pelagic longline gear also occurs, presumably due to similar feeding ecology among pelagic animals. Bycatch species interact with longline gear via hooking or entanglement, often resulting in the animal being discarded dead or released alive with varying degrees of injury or mortality. The resulting impact of pelagic longline gear on bycatch species has gained attention, with focus on vulnerable species including sharks, sea turtles, billfishes, marine mammals, and seabirds (Clarke et al. 2014).

One common strategy to reduce bycatch in pelagic longline fisheries is changing the hook, the location of most interactions with the gear. Experimental fishing trials in which hook types are alternated are a highly effective means for evaluating differences in performance while minimizing confounding variables (Watson and Kerstetter 2006). Additionally, the feasibility and relatively low cost involved with changing hooks in comparison to other gear modifications has prompted several hook modification experiments to efficiently test for possible bycatch reduction.

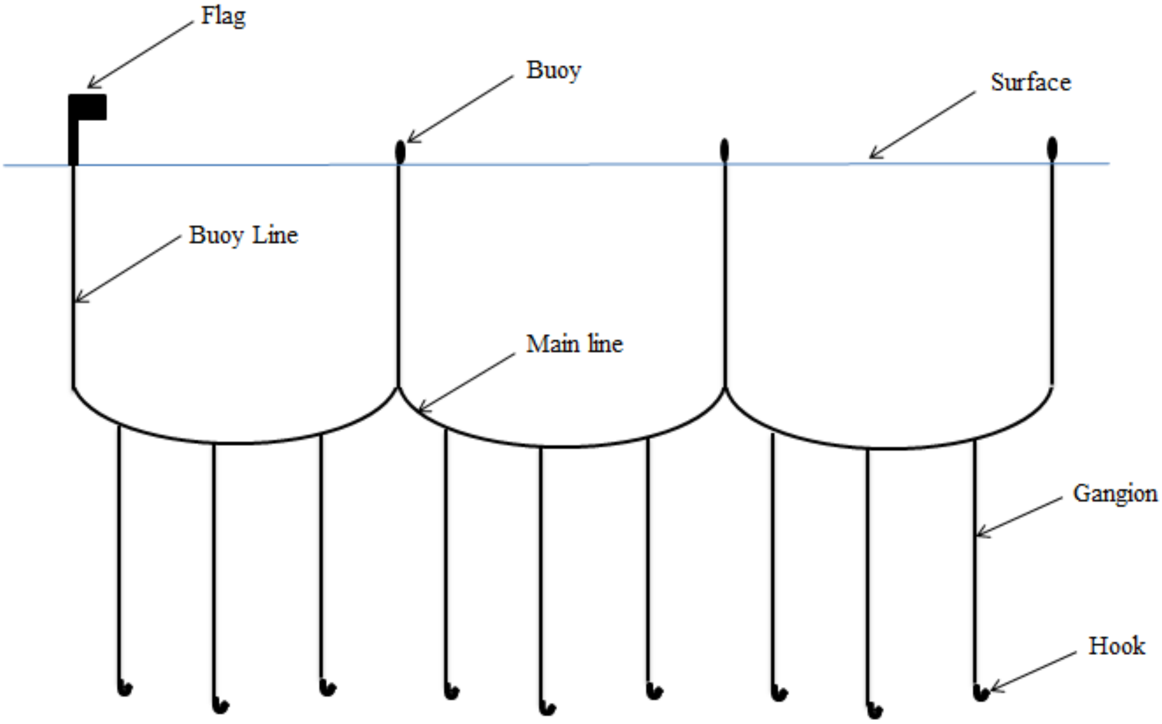


Figure 1. Diagram of pelagic longline gear commonly used in the Grenada fishery. The number of leaders between floats were either three (shown) or four for all 26 of the experimental sets conducted. Image components are not shown to scale.

Three hooks types are predominantly used in Atlantic pelagic longline fisheries: J-style hooks, circle hooks, and so called "tuna hooks" (Figure 2). Each of these hook types vary in morphological features, but they can be described by the same general components; eye, shank, bend, point, and offset (Figure 3). Conventionally, the difference between circle hooks and J-style hooks or tuna hooks has focused on the orientation of the point in relation to the shank and the shape of the hook. The general defining characteristics of a circle hook are its circular shape and a point that is perpendicular in relation to the shank (Cooke and Suski 2004).

A variety of hooks marketed as circle hooks meet this general standard, yet they vary significantly in dimensions; this may affect the efficacy of circle hooks' impact on selectivity and mortality To address this market confusion, a comprehensive definition of circle hooks was developed during the 2012 *International Symposium on Circle Hooks in Research, Management, and Conservation* to further delineate the characteristics of a so-called "true circle hook." A true circle hook was subsequently defined as having three key components: the angle of the point to the shank must be a minimum of 90°, the angle of the front length of the hook must bend minimum of 20° toward the shank, and the front length of the hook should be 70-80% of the hook's total length (Serafy et al. 2012)

The design of the circle hook allows it to engage primarily in the jaw as the eye of the hook exits the mouth, thereby avoiding deep-hooking associated injury to internal viscera or at-vessel mortality often seen in J-style hooks (Cooke and Suski 2004; Read et al, 2007; Serafy et al. 2009; Godin et al. 2012; Graves et al 2012; Serafy et al. 2012). Specifically, circle hooks have been reported to reduce the rate of deep hooking events in tuna, shark, billfishes, and sea turtle species in several pelagic longline fisheries (e.g., Falterman and Graves 2002; Kerstetter and Graves 2006a; Rice et al. 2012). Consequently, circle hooks have been proposed as a conservation measure to reduce mortality for vulnerable bycatch species that have high rates of interaction with pelagic longline gear.

Increased catch rates for highly valued tuna species with circle hooks have also been reported in fisheries suggesting ecological and economic benefits (e.g., Falterman and Graves 2002; Kerstetter and Graves 2006a; Ward et al. 2009; Sales et al. 2010; Domingo et al. 2012; Pacheco et al. 2012; Huang et al. 2016). The voluntary adoption of circle hooks has been observed in some fisheries due to the possibility of increased catch of target species. For

Figure 2. The three types of hooks used in global pelagic longline fisheries (left to right): J-style hook, tuna hook, circle hook.

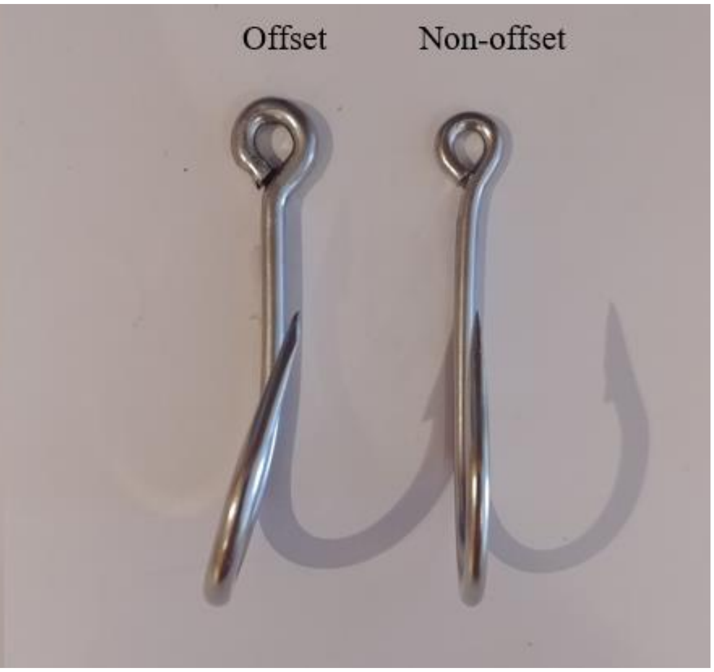


Figure 3a (Left): The components of a circle hook. **Figure 3b (Right)**: Offset and non-offset J-style hooks.

example, the domestic Venezuelan live-bait, pelagic longline fishery which targeted yellowfin tuna employed circle hooks after improved catch and condition of target species was reported by fishers participating in an early hook comparison field trial (Falterman and Graves, 2002).

Regional fisheries management organizations (RFMOs) have recognized the benefits of circle hooks to conservation, however their suggestions have not been uniformly implemented among fisheries to date. The International Commission for the Conservation of Atlantic Tunas (ICCAT) Standing Committee on Research and Statistics (SCRS) has acknowledged circle hooks as a conservation tool to reduce bycatch mortality of sea turtles and some billfish species, but the commission has yet to enact circle hook requirements for participating members. Currently, four ICCAT contracting parties (Brazil, Canada, Mexico, and the United States) either mandate or encourage circle hook use in their domestic pelagic longline fisheries (ICCAT, 2018). For example, the U.S. domestic Atlantic pelagic longline and Pacific shallow-set pelagic longline fisheries are both currently required to use circle hooks. This regulatory requirement was primarily in response to a U.S. government-funded study which found that large (size 18/0) circle hooks used in combination with finfish bait significantly reduced interactions with sea turtles (Watson et al. 2005).

Pelagic longline practices began in Grenada in the 1980s as a government initiative, with the assistance of the government of Cuba, through the donation of vessels and training (Grant and St Louis 2007). Modern commercial pelagic longline operations began in the early 1990s, targeting yellowfin tuna *Thunnus albacares* for the fresh export market to the United States. Yellowfin tuna are graded on a scale of 1 to 3 with 1 being of highest quality. Generally, all Grade 1 and 2 fish are exported, and the remainder are sold for local consumption. Incidentally caught species with high food-value including blackfin tuna *Thunnus atlanticus*, common dolphinfish *Coryphaena hippurus*, and sailfish *Istiophorus albicans* are also commonly landed and sold for local consumption. Rare-event or seasonal pelagic species such as white marlin *Kajikia albida*, blue marlin *Makaira nigricans*, swordfish, and wahoo *Acanthocybium solandri* are also present in the fishery and locally consumed.

A variety of fishing vessels are used in Grenada to target large pelagic fishes with pelagic longline gear that can be categorized into three types based on operational capacity and length (Figure 4) (Gentner et al. 2018). The smallest category of vessels (Type I) are <7 m length overall (LOA) and deploy 50-100 hooks using a hand reel and spool to manipulate the gear. The vessels are manned by one or two crew, with fishers typically staying in territorial coastal waters and returning daily. The middle category (Type II) is for vessels 7-9 m LOA that fish between 100-300 hooks. The vessels are manned by two or three crew and may stay at sea overnight, but generally return within 24 hours. Finally, the third category (Type III) includes the largest vessels >9 m LOA that are diesel inboard powered, decked vessels, that operate for 2-5 days per trip and deploy 400-1000+ hooks per set. The larger vessels usually fish within the territorial exclusive economic zone (EEZ) with three to five crew members. The bait used in the Grenadian pelagic longline varies, but primarily consists of locally caught four-winged flying fish (*Hirundicthys affinis)* and bigeye scad (*Selar crumenophthalmus*). Bigeye scad are purchased from local beach seine fishers, while four-winged flying fish are primarily caught at sea prior using gill nets.

Grenada's fisheries are governed by the Fisheries Division (Fisheries Management Unit), a division of the Ministry of Agriculture, Lands, Forestry, Fisheries, Energy and Public Utilities. No current governmental restrictions exist on landings or fishing effort for pelagic fish species. Regionally, the major pelagic species caught in Grenada (yellowfin tuna, blue marlin, white marlin, sailfish, and blackfin tuna) are ultimately under the management purview of ICCAT. Grenada became a contracting party of ICCAT in October 2017 and will eventually be allocated quotas for pelagic species under total allowable catch (TAC) based management plans. While Grenada's commercial catch of blue marlin and white marlin are relatively low, both are considered overfished, with overfishing occurring (ICCAT, 2018). One way to reduce the impact of pelagic longline gear in Grenada on overfished marlin stocks may be to implement circle hooks as a conservation tool to reduce bycatch mortality of billfish species.

Prior to this study, circle hooks had not been regularly used by Grenadian domestic commercial pelagic longline vessels. The aim of this study was to evaluate the performance of circle hooks in comparison to traditional J-style hooks within the coastal Grenadian pelagic longline fishery. Catch rates, size, grade, hooking location, and mortality at haulback (gear retrieval) of species encountered were analyzed. The results of this study may be used to best inform government fisheries managers regarding the possible ecological and economic impacts of circle hook implementation in Grenada.

Figure 4. Vessel types I (top), II (middle), and III (bottom) used in the Grenadian pelagic longline fishery. Type III vessels were used for this research due to their operational capacity (number of hooks per set and ability to accommodate fisheries observer).

Materials and Methods

The relative performance of 16/0 circle hooks and 9/0 J-style hooks was tested during 26 pelagic longline sets (15,800 hooks deployed in total) between January and June 2018. The two vessels used (F/V *Rayhanna* and F/V *Lady Cynthy II*) conducted sets between 12.17° and 13.01° N latitude and 62.1° and 62.52° W longitude (Figure 5). Other than hook type, experimental sets were not chartered, with fishing operations at the discretion of the captain. On average, gear deployment ("set") start time was 3:53 pm and average start of gear retrieval ("haulback") time was 5:51 am, resulting in an average soak time of 10 hours and 41 minutes.

Two types of size 16/0, 0º offset, circle hooks (Mustad model #39960 or #39880, and Lindgren-Pitman design) were tested against size 9/0, 0º offset J hooks (model 7691-SS). Hooks were alternated during the gear deployment with the use of two separate hook boxes. The alternating hook methodology was used to minimize the confounding effects of environmental factors and operational factors when testing for differences in catch rates in the pelagic longline fishery (Falterman and Graves 2002; Watson et al. 2005; Kerstetter and Graves 2006a). Size 16/0 circle hooks were chosen due to the similarity in size with the traditional hooks used in the fishery and comparability to other studies investigating the performance of circle hooks in Atlantic PLL fisheries (Watson et al. 2005, Kerstetter and Graves 2006a). Bait used throughout the study was four-winged flying fish or bigeye scad. The estimated average total length of bait used during the trial was 17 cm for flying fish (*Hirundicthys affinis*) and 10 cm for bigeye scad (*Selar crumenophthalmus*).

Vessels participating in the experiment carried one observer that collected fishery data on custom, waterproof data log sheets (Appendix I). The observer recorded operational characteristics such as the starting time, ending time, and location of each gear deployment and haul. Gear configuration factors were also recorded for each set including: the total number of hooks, hooks per float, mainline, length, float line length, gangion length, and bait type. For each animal caught, corresponding species, hook type, hook location, damage, status, action, and length (TL) was recorded. Hook location was assessed as external, internal or foul as per Kerstetter and Graves (2006a). If the hook was lodged in the edge of the jaw, the corner of the

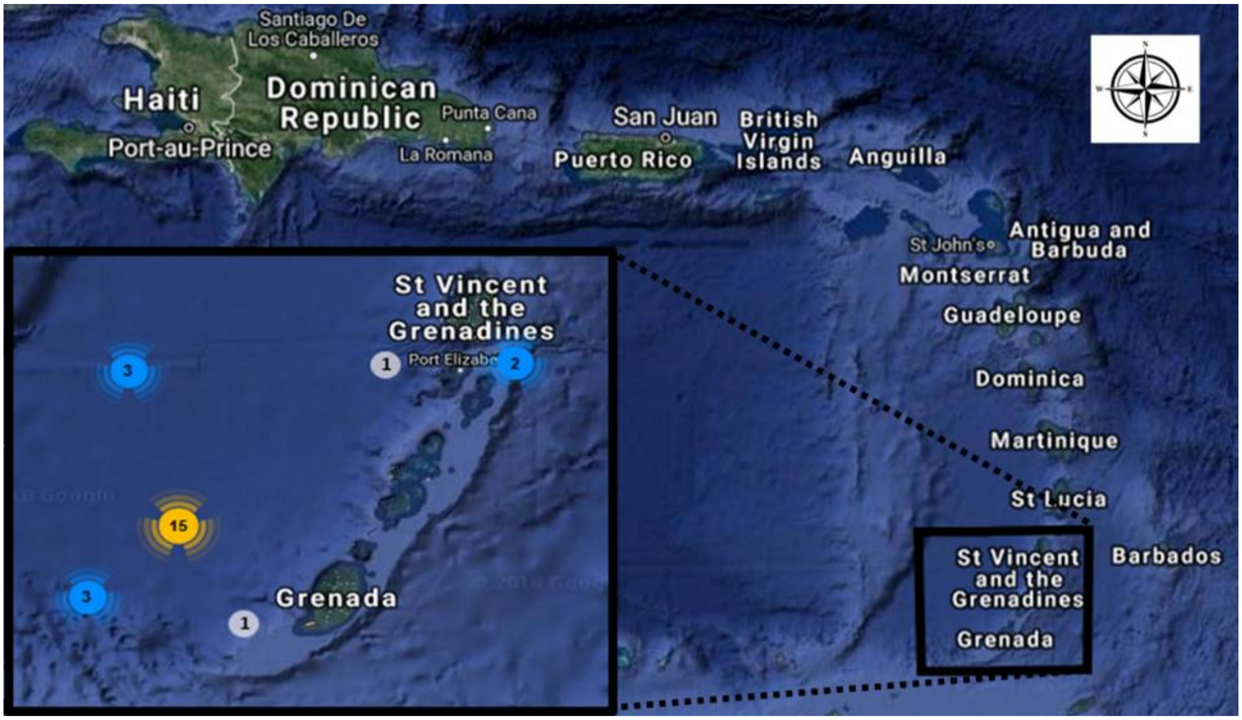


Figure 5. General location and corresponding number of sets conducted for 26 trial sets comparing circle and J-style hooks in the pelagic longline fishery in Grenada.

mouth, or the bill area, it was considered "external." If the hook was distal to the esophageal sphincter or lodged in the roof of mouth or throat, it was assessed as "internal." If the hook was lodged anywhere excluding the previous two locations, it was assessed as "foul." The presence of damage due to depredation, entanglement, or the gear retrieval process, was recorded. Action was assessed as kept, discarded dead, released alive, or lost. Fish that did not move while hooked or on deck were considered dead as per Falterman and Graves (2002). The length of each fish was determined on board for retained and discarded fish or estimated for fish released alive in the water. Lengths were recorded as total length (TL) for all species excluding billfishes, which were measured as lower jaw fork length (LJFL).

Yellowfin tuna and bigeye tuna were marked at sea at the time of dressing (removal of viscera and head) using serialized tags attached with zip-ties to the caudal peduncle. At the point of sale, dressed weights (headed-and-gutted) and market grade were recorded for yellowfin tuna and bigeye tuna. The observer then matched the weight and grade to the catch data using the serialized tag number. Upon completion of each trip, data sheets were subject to quality assurance and quality control (QA/QC) by the Grenadian Fisheries Division chief fisheries officer. The approved data sheets were then scanned, emailed, and entered into a Microsoft Excel spreadsheet, upon which a final round of (QA/QC) was performed.

Catches were analyzed for individual species with >20 individuals and the composite groups: "BILLFISH" (all istiophorid billfish), "TUNA" (all thunnid species and skipjack tuna *Katsuwonus pelamis*, but excluding bonito *Sarda* due to its small size), "SHARK" (all elasmobranch species, including pelagic stingray *Pteroplatytrigon violacea*), "OTHER" (e.g., wahoo, common dolphinfish, king mackerel *Scomberomorus cavalla*, great barracuda *Sphyraena barracuda*), and "ALL FISHES" (all teleost and elasmobranch species combined). Catch rates were expressed as catch-per-unit-effort (CPUE), standardized as the number of individuals caught per 1000 hooks. Mean CPUE per trip was calculated for species and composite groups by hook type and tested for normality (Shapiro test) and homoscedasticity (Bartlett's test). If normality and homoscedasticity assumptions were met, differences in CPUE between circle hooks and J-style hooks for all sets combined were tested using a t-test after performing the $X = \log(X + 1)$ transformation on each set to conform to the assumption of normality per Kerstetter and Graves (2006). Differences in length frequency were also analyzed for species with >20 individuals using paired t-tests to assess potential size-selectivity for each hook type.

The effect of hook type on species mortality rate and external hooking rate was analyzed using chi-squared tests. Mortality rate was calculated as a ratio of the individuals dead at haulback divided by the total (alive + dead). External hooking rate was similarly calculated as the ratio of individuals externally hooked at haul divided by the total (internal + external). Additionally, the relative change of mortality or hooking location outcome probabilities, based on hook type, was assessed using odds ratios. Differences in grade for yellowfin tuna between hook types were also analyzed using chi-squared tests. All statistical analyses were performed using R (v 3.2.2; R Project for Statistical Computing 2018) with significance assessed at $\alpha = 0.05$.

Results

During the trials, 31 bent circle hooks were observed. The bend force rating for these hooks is approximately 400 lbs or 181.44 kgs (C. Bergman, NOAA Fisheries, unpubl. data) suggesting a large animal was hooked, then straightened the hook enough to free itself. Large pelagic species such as blue marlin, swordfish, yellowfin tuna, and bigeye tuna, as well as several marine mammal species, are present in waters used by the fishery (Romero et al. 2002; ICCAT 2018), and individual animals can generate enough force to straighten the hook. However, all but yellowfin tuna catches are considered rare event species in the fishery based on in-person discussions with the fisherman and a review of reported landings (A. Burns and L. Acosta, pers. comms.; ICCAT 2018).

To determine the possible impact of the yellowfin tuna loss on bent circle hooks, analyses of catch rate and catch composition were conducted with and without an additional 31 circle hooks. No statistical difference was determined for catch rate or catch composition regardless of inclusion or exclusion of the straightened hooks. The catch results presented include an additional 31 yellowfin tuna attributed to straightened circle hooks.

A total of 318 animals were caught comprising 26 species. Of these animals, 150 were caught on circle hooks and 168 on J-style hooks. Catches are summarized in Figure 6 and Table 1. Collectively, yellowfin tuna, common dolphinfish, and sailfish comprised the majority of total catches, consisting of 227 individuals and 71.38% of total catch combined. Yellowfin tuna was the most abundantly caught species during the trials, accounting for 120 individuals and 37.74% of the total catch.

Significantly different CPUEs between hook types were observed for sailfish (*t*-value = 3.04, $p = 0.005$) and the composite group BILLFISH (*t*-value = 2.31, $p = 0.029$) of all the species and composite groups analyzed, (Figure 8). Sailfish CPUE was significantly lower for circle hooks (1.27) compared to for J-style hooks (2.40). No significant difference in yellowfin tuna CPUE (*t*-value = 1.36, $p = 0.185$) or common dolphinfish CPUE (*t*-value = 0.89, $p = 0.385$) was found. However, observed CPUEs of circle hooks compared to J-style hooks were higher for yellowfin tuna (8.99 vs. 6.02), but lower for dolphinfish (3.29 vs. 6.58).

Lengths of all species measured or estimated were compared between hook types. Hook type did not have a significant effect on the length frequency for any species tested (Figure 9). Although non-significant, larger mean sizes for all species analyzed were caught on circle hooks compared to J-style hooks. Yellowfin tuna ranged from 114 to 171 cm TL with an average of 146 cm for circle hooks and 144 cm for J-style hooks. Common dolphinfish ranged from 30 to165 cm TL with an average of 69 cm for circle hooks and 61 cm for J-style hooks. Sailfish ranged from 40 to 91 cm LJFL with an average of 80 cm for circle hooks and 77 cm for J-style hooks.

Dressed weights were recorded for yellowfin tuna, bigeye tuna, and swordfish at the fish house upon offload by the fishing vessel. However, only yellowfin tuna (n = 89) were graded regularly for export (unlike bigeye tuna, with only n = 3 graded). The overall grade of yellowfin tuna landed consisted of 45.7% “Grade 1”, 31.5% “Grade 2”, and 22.8% “NS” (“non-sellable” for export). No significant difference in assigned grade ($\chi^2 = 0.03$, $p = 0.988$) was found between tunas caught on circle hooks and J-style hooks (Table 3). Nonsignificant differences in grade by hook type included an observed lower percentage of “Grade 1” yellowfin tuna caught on circle hooks (45%) compared to J-style hooks (49%), but higher percentage of exportable (“Grade 1 + “Grade 2”) tunas caught on circle hooks than J-style hooks (85.2% versus 75.5%).

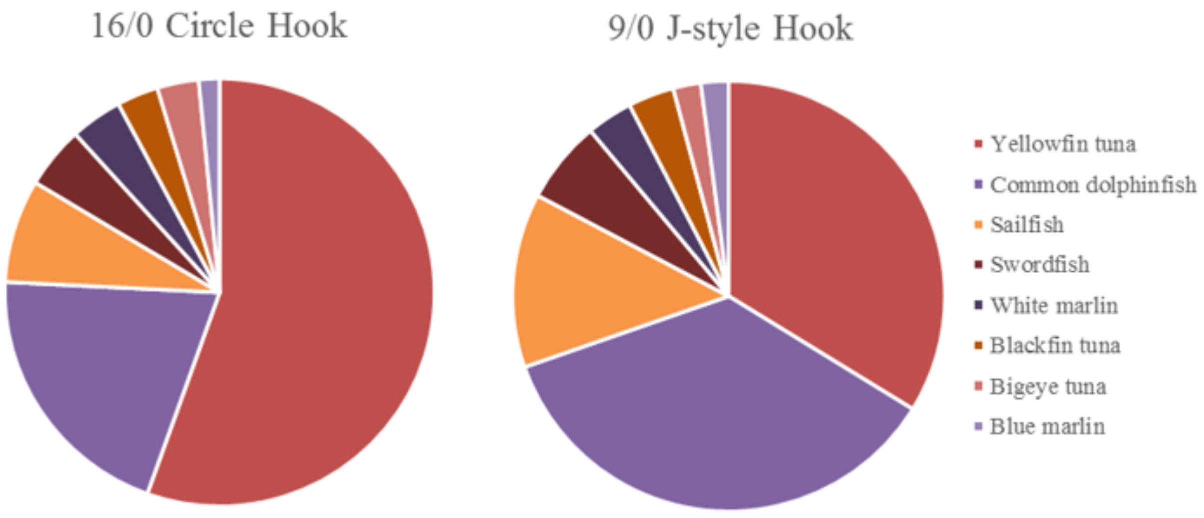


Figure 6. Catch species composition by hook type for 26 trial sets comparing circle and J-style hooks in the pelagic longline fishery in Grenada.

Table 1. Catch composition by hook type for 26 trial sets comparing circle and J-style hooks in the pelagic longline fishery in Grenada.

Species	Overall	Circle Hook	J-style Hook
***Thunnus albacares* (Yellowfin tuna)**	**120 (37.74%)**	**71 (60.17%)**	**49 (36.57%)**
Thunnus atlanticus (Blackfin tuna)	9 (2.83%)	4 (2.67%)	5 (2.99%)
Thunnus obesus (Bigeye tuna)	7 (2.20%)	4 (2.67%)	3 (1.80%)
Thunnus alalunga (Albacore tuna)	4 (1.26%)	1 (0.67%)	3 (1.80%)
*Katsuwonus pelamis (*Skipjack tuna)	4 (1.26%)	3 (2.00%)	1 (0.60%)
Tunas combined	**144 (45.28%)**	**83 (55.33%)**	**61 (36.31%)**
***Xiphias gladius* (Swordfish)**	**15 (4.72%)**	**6 (5.08%)**	**9 (6.72%)**
***Istiophorus platypterus* (Sailfish)**	**29 (9.12%)**	**10 (8.47%)**	**19 (14.18%)**
Kajikia albida (White marlin)	10 (3.14%)	5 (4.23%)	5 (3.73%)
Makaira nigricans (Blue marlin)	5 (1.57%)	2 (1.33%)	3 (1.80%)
Tetrapturus sp. (Unidentified spearfish)	3 (0.94%)	2 (1.33%)	1 (0.60%)
Billfishes combined	**47 (14.78%)**	**19 (12.67%)**	**28 (16.67%)**
***Coryphaena hippurus* (Common dolphinfish)**	**78 (24.53%)**	**26 (22.03%)**	**52 (38.80%)**
Acanthocybium solandri (Wahoo)	3 (0.94%)	2 (1.33%)	1 (0.60%)
Alepisaursus sp. (Unidentified lancetfish)	3 (0.94%)	0 (0%)	3 (1.80%)
Sphyraena barracuda (Great barracuda)	3 (0.94%)	2 (1.33%)	1 (0.60%)
Sarda (Bonito)	3 (0.94%)	2 (1.33%)	1 (0.60%)
Scomberomorus cavalla (King mackerel)	2 (0.63%)	1 (0.67%)	1 (0.60%)
Revettus pretiosus (Oilfish)	2 (0.63%)	0 (0%)	2 (1.20%)
Lobotes surinamensis (Tripletail)	1 (0.31%)	1 (0.67%)	0 (0%)
Other teleosts combined	**95 (29.87%)**	**34 (22.67%)**	**61 (36.31%)**
Pteroplatytrogon violacia (Pelagic stingray)	5 (1.57%)	1 (0.67%)	3 (1.80%)
Galeocerdo cuvier (Tiger shark)	3 (0.94%)	3 (2.00%)	0 (0%)
Isurus sp. (Unidentified mako shark)	2 (0.63%)	1(0.67%)	1 (0.60%)
Unidentified Shark	2 (0.63%)	1 (0.67%)	1 (0.60%)
Prionace glauca (Blue shark)	2 (0.63%)	1(0.67%)	1 (0.60%)
Carcharhinus limbatus (Blacktip shark)	1 (0.31%)	0 (0%)	1 (0.60%)
Alopias superciliosus (Bigeye thresher)	1 (0.31%)	1 (0.67%)	0 (0%)
All sharks Combined	**16 (5.03%)**	**8 (5.33%)**	**8 (4.76%)**
***Delphinus delphis* (Common dolphin)**	**1 (0.31%)**	**0 (0%)**	**1 (0.60%)**

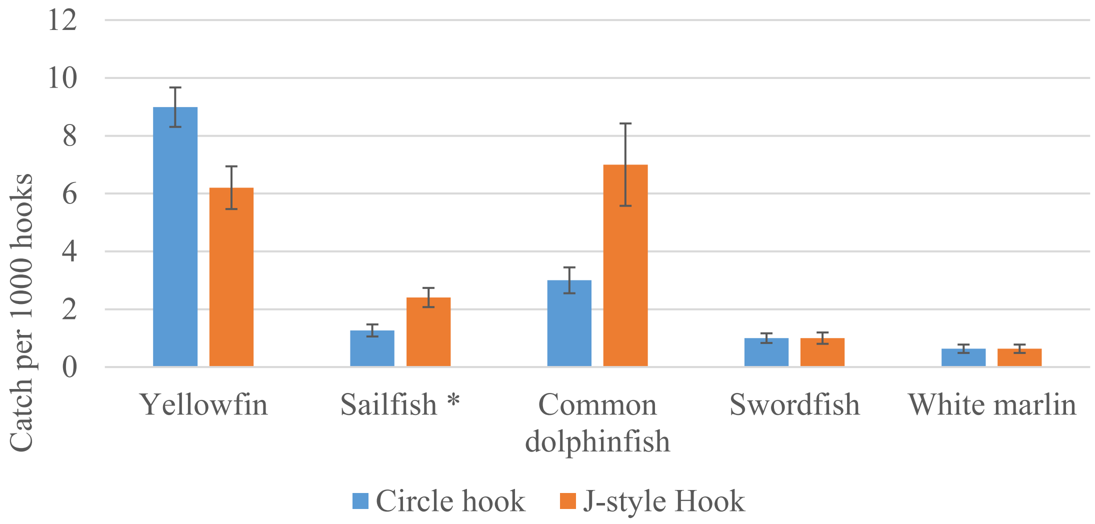


Figure 8. Mean CPUE for all sets by hook type for 26 trial sets comparing circle and J-style hooks in the pelagic longline fishery in Grenada. Error bars indicate ± 1 standard error. An asterisk (*) indicates significant difference between hook type.

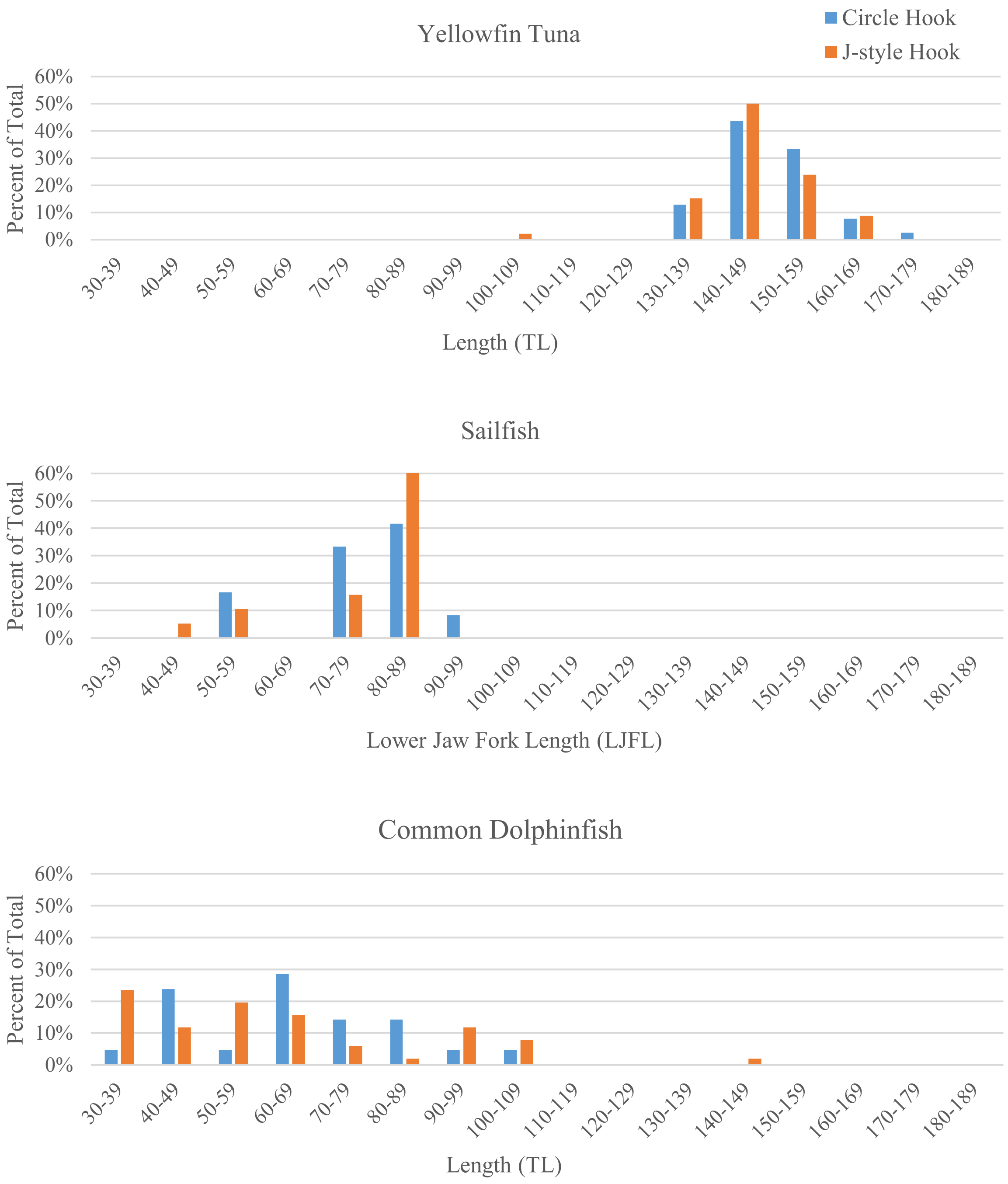


Figure 9. Length frequency distributions for yellowfin tuna *Thunnus albacares* (top), sailfish *Istiophorus platypterus* (middle), and common dolphinfish *Coryphaena hippurus* (bottom), from 26 trial sets comparing circle and J-style hooks in the pelagic longline fishery in Grenada. No significant difference in length frequencies was found between hook types.

Table 3. Grade of yellowfin tuna by hook type for 26 trial sets comparing circle and J-style hooks in the pelagic longline fishery in Grenada. "NS" = non-sellable for export.

Grade	Circle	J-style	χ^2	p-value
1 (n = 42)	45% (18)	49% (24)	0.02	0.988
2 (n = 28)	37.5% (15)	26.5% (13)		
NS (n = 19)	17.5% (7)	24.5% (12)		

The external hooking rate varied between species, with the overall rate of 78.75% for all species combined (Table 4). Of the fishes caught by circle hooks, 84.96% were externally hooked, while 74.38% of fishes caught by J-style hooks were externally hooked. Hook type significantly affected the hooking location of tuna ($\chi^2 = 4.38$, $p = 0.036$), with a 69% decrease in the odds of external hooking if caught on J-style hook. A non-significant increased external hooking rate was observed for all remaining species tested except for common dolphinfish, which had a slight decrease (Figure 12). At haul mortality rates varied between species and composite groups, although no significant difference between hook types was established (Figure 13 and Table 5). Observed mortality rates for circle hooks were lower for yellowfin tuna (23% vs. 31%), but higher for sailfish (70% vs. 53%), compared to J-style hooks. However, these finding were not statistically significant.

Discussion

A growing number of studies have investigated the influence of circle hooks on catch rates and at-haul mortality rates of target and bycatch species to determine their potential as a management tool. The findings of these studies are understandably heterogeneous as the complexity of each fishery lends to a variety of possible confounding variables. Aspects of the gear and operational characteristics largely influence selectivity, but the relative roles of each parameter remain uncertain. Important gear covariates to consider include hook shape, hook size, bait type (e.g., squid versus finfish), degree of hook offset, and gear depth. This study adds to the growing body of literature on how circle hook implementation may affect a range of species

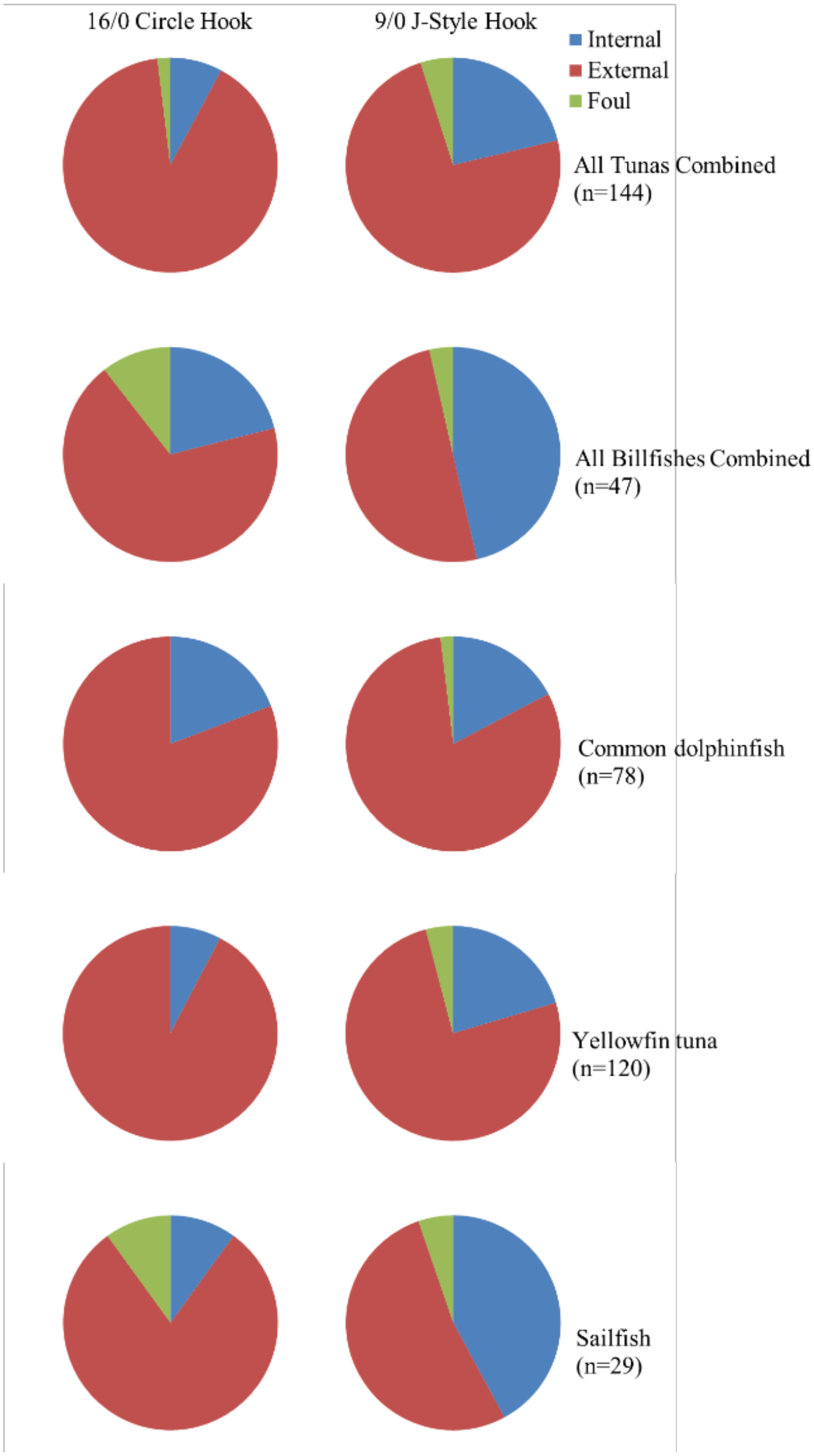


Figure 12. Hook location by hook type for 26 trial sets comparing circle and J-style hooks in the Grenadian pelagic longline fishery.

Table 4. External hooking rate by hook type for 26 trial sets comparing circle and J-style hooks in the pelagic longline fishery in Grenada. "-" indicates no input, "na" = not analyzed.

Species	Overall	Circle Hook	J-style Hook	χ^2	p-value	Odds Ratio
Thunnus albacares **(Yellowfin tuna)**	84.68%	92.31%	77.97%	3.07	0.08	1.00:0.32
Thunnus atlanticus (Blackfin tuna)	100%	100%	100%	na	na	na
Thunnus obesus (Bigeye tuna)	71.43%	75%	66.67%	0	0.809	na
Thunnus alalunga (Albacore tuna)	50%	100%	33.33%	1.3	0.248	na
*Katsuwonus pelamis (*Skipjack tuna)	100%	100%	-	na	na	na
Tunas combined	84.26%	92%	77.59%	4.2	0.043	1.00:0.32
Xiphias Gladius (Swordfish)	53.85%	75%	44.44%	1	0.308	1.00:0.31
Istiophorus platypterus **(Sailfish)**	62.07%	88.89%	55.56%	3	0.083	1.00:0.18
Kajikia albida (White marlin)	44.44%	75%	20%	2.7	0.099	1.00:0.12
Makaira nigricans (Blue marlin)	100%	100%	100%	na	na	na
Tetrapturus sp. (Unidentified spearfish)	0%	0%	0%	na	na	na
Billfishes combined	61.36%	76.47%	51.85%	2.67	0.103	1.00:0.35
Coryphaena hippurus **(Common dolphinfish)**	81.82%	80.77%	82.35%	0	0.865	1.00:1.12
Acanthocybium solandri (Wahoo)	100%	100%	100%	na	na	na
Alepisaursus sp. (Unidentified lancetfish)	66.67%	-	66.67%	na	na	na
Sphyraena barracuda (Great barracuda)	100%	100%	100%	na	na	na
Sarda (Bonito)	100%	100%	100%	na	na	na
Scomberomorus cavalla (King mackerel)	100%	100%	-	na	na	na
Revettus pretiosus (Oilfish)	100%	-	100%	na	na	na
Lobotes surinamensis (Tripletail)	100%	100%	-	na	na	na
Other teleosts combined	84.04%	85.29%	83.33%	0	0.803	1.00:0.80
Pteroplatytrogon violacia **(Pelagic Stingray)**	100%	100%	100%	na	na	na
Galeocerdo cuvier (Tiger shark)	66.67%	66.67%	-	na	na	na
Isurus sp. (Unidentified mako shark)	100%	100%	100%	na	na	na
Unidentified Shark	100%	100%	100%	2	0.157	na
Prionace glauca (Blue shark)	100%	100%	100%	na	na	na
Carcharhinus limbatus (Blacktip shark)	100%	-	100%	na	na	na
Alopias superciliosus (Bigeye thresher)	0%	0%	-	na	na	na
Sharks combined	81.25%	62.50%	100%	3.7	0.054	na
Delphinus delphis **(Common dolphin)**	0%	-	0%	na	na	na

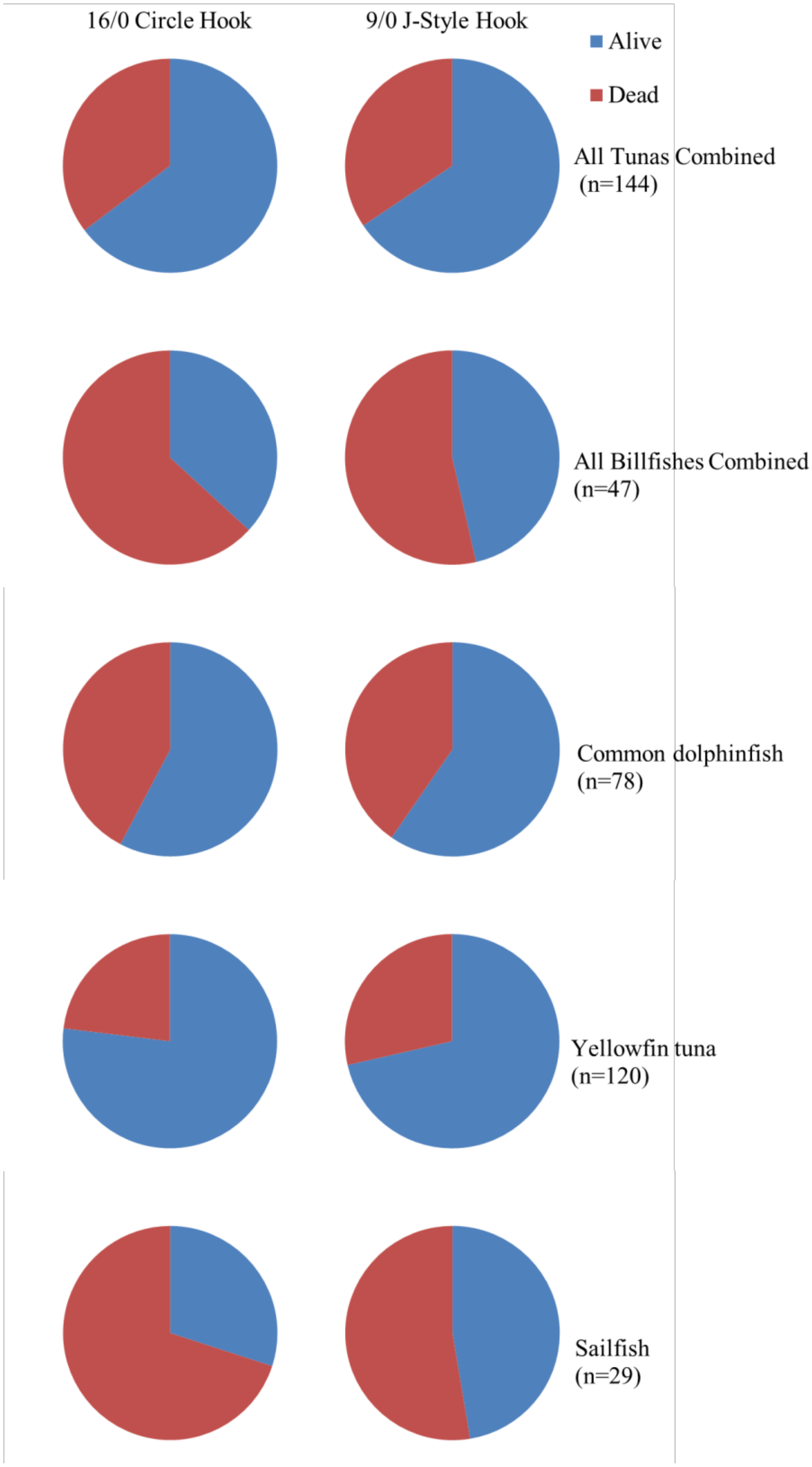


Figure 12. Mortality by hook type for 26 trial sets comparing circle and J-style hooks in the Grenadian pelagic longline fishery.

Table 5. Mortality rate by hook type for 26 trial sets comparing circle and J-style hooks in the pelagic longline fishery in Grenada. “-” indicates no input, “na” = not analyzed.

Species	Overall	Circle Hook	J-style Hook	χ^2	p-value	Odds Ratio
***Thunnus albacares* (Yellowfin tuna)**	**26.14%**	**23.08%**	**28.57%**	**0.6**	**0.43**	**1.00:1.46**
Thunnus atlanticus (Blackfin tuna)	77.78%	75%	80%	0	0.858	1.00:1.29
Thunnus obesus (Bigeye tuna)	42.86%	50%	33.33%	0.2	0.659	1.00:0.70
Thunnus alalunga (Albacore tuna)	50%	100%	33.33%	1.3	0.248	na
*Katsuwonus pelamis (*Skipjack tuna)	100%	100%	100%	na	na	na
Tunas combined	**34.82%**	**35.29%**	**34.43%**	**0**	**0.9235**	**1.00:0.96**
***Xiphias gladius* (Swordfish)**	**46.67%**	**66.67%**	**33.33%**	**1.6**	**0.205**	**1.00:0.28**
***Istiophorus platypterus* (Sailfish)**	**58.62%**	**70.00%**	**52.63%**	**0.8**	**0.367**	**1.00:0.50**
Xiphias gladius (Swordfish)	46.67%	66.67%	33.33%	1.6	0.205	1.00:1.
Kajikia albida (White marlin)	50%	60%	40%	0.4	0.527	1.00:0.49
Makaira nigricans (Blue marlin)	40%	0%	66.67%	2.2	0.136	na
Tetrapturus sp. (Unidentified spearfish)	58.62%	100%	100%	na	na	na
Billfishes combined	**57.45%**	**63.16%**	**53.57%**	**0.43**	**0.514**	**1.00:0.54**
***Coryphaena hippurus* (Common dolphinfish)**	**41.03%**	**42.31%**	**40.38%**	**0**	**0.871**	**1.00:0.92**
Acanthocybium solandri (Wahoo)	100%	100%	100%	na	na	na
Alepisaursus sp. (Unidentified lancetfish)	0%	0%	0%	na	na	na
Sphyraena barracuda (Great barracuda)	33%	0%	100%	3	0.083	na
Sarda (Bonito)	100%	100%	100%	na	na	na
Scomberomorus cavalla (King mackerel)	50%	100%	0%	2	0.157	na
*Revettus pretiosus (*Oilfish)	0%	0%	0%	na	na	na
Lobotes surinamensis (Tripletail)	0%	0%	0%	na	na	na
Other teleosts combined	**42.11%**	**47.06%**	**39.34%**	**0.5**	**0.465**	**1.00:0.72**
***Pteroplatytrogon violacia* (Pelagic stingray)**	0%	0%	0%	na	na	na
Galeocerdo cuvier (Tiger shark)	0%	0%	0%	na	na	na
Isurus sp. (Unidentified mako shark)	0%	0%	0%	2.2	0.136	na
Unidentified Shark	50%	100%	0%	2	0.157	na
Prionace glauca (Blue shark)	0%	0%	0%	na	na	na
Carcharhinus limbatus (Blacktip shark)	100%	100%	0%	na	na	na
Alopias superciliosus (Bigeye thresher)	100%	0%	-	na	na	na
Sharks combined	**18.75%**	**25%**	**12.5%**	**0.4**	**0.522**	**1.00:0.88**
***Delphinus delphis* (Common dolphin)**	0%	0%	0%	na	na	na

catch and mortality rates with applicability for small scale surface pelagic longline fisheries. Additionally, the catch composition and mortality rates presented are essential to improve the accuracy of stock assessment models and mitigation measures aimed to protect threatened and endangered species.

The results of the present study indicate that size 16/0 circle hooks type would ecologically benefit billfishes without significantly affecting the catch rate of the primary target species, yellowfin tuna. Although typically artisanal or otherwise small-scale, fisheries exist in many parts of the world where billfishes are targeted, retained as incidental catch, or discarded as bycatch. Growing concerns of the impact of pelagic longline-induced mortality on billfishes have led numerous researchers to assess circle hook performance and conservation benefits (see reviews by Serafy et al. 2009 and Serafy et al. 2012). The present study here found significantly lower numbers of both billfishes as a whole, and specifically, sailfish caught on circle hooks, indicating an ecological benefit to these species by avoiding gear interaction. This finding has been similarly reported by a previous study conducted in the tropical western Atlantic Ocean that evaluated the performance of 18/0 circle hooks in the Brazilian pelagic longline fishery targeting bigeye tuna (Pacheco et al. 2011).

An increased catch rate of targeted yellowfin tuna on circle hooks were found, although this finding was not significant. This result agrees with other studies conducted in western Atlantic Ocean (Sales et al. 2010; Pacheco et al. 2011; Domingo et al. 2012) which found non-significant increases in yellowfin tuna when comparing 18/0 circle hooks to 9/0 J-style hooks. However, significantly higher catch rates on circle hooks have been reported in western and equatorial Atlantic pelagic longline fisheries (Falterman and Graves 2002; Kerstetter and Graves 2006a; Huang et al. 2016).

Common dolphinfish exhibited higher catch rates on J-style hooks than circle hooks, although these too were not statistically significant. Evidence of significantly lower common dolphinfish catches on circle hooks have been reported in two studies conducted in the Ecuadorian longline fishery where common dolphinfish were the target species. Larchaga et al. (2005) and Adraka et al. (2013) both found significantly lower catch rates of common dolphinfish in the Ecuadorian fishery when using 15/0 and 14/0 circle hooks. A possible reason for this may be the greater external hook width associated with circle hooks than the J-style hooks being compared, especially for individual dolphinfish smaller sizes (Adraka et al. 2013).

Circle hooks have been promoted to increase the external hooking of animals, thus lowering the risk of internal damage and ultimately post-release mortality. The effect of hook type on hooking location and haulback mortality has not been universal with species-specific outcomes (Cooke and Suski 2004; Serafy et al. 2012). The present study found significantly higher external hooking rates for tuna caught with circle hooks. Additionally, all species except common dolphinfish had an observed increase in external hooking with circle hooks. However, this did not correlate to lower haulback mortality rates, which were species specific and independent of hook style. Coelho et al. (2012) and Huang et al. (2016) also found that most species had an equal probability of being alive on circle compared to J-style and tuna hooks, respectively. Conversely, increased haulback survival was two to four times greater for targeted yellowfin tuna and swordfish caught on circle hooks in the northwest Atlantic tuna and swordfish fishery (Carruthers et al. 2009). Significantly increased haulback survival of blue and white marlin when caught on circle hooks compared to J-style hooks have also been reported from the U.S. pelagic longline fleet in the Gulf of Mexico (Diaz 2008).

It is worth noting the mortality information presented represents only immediate mortality. Some level of additional, post-capture mortality is expected after living animals are released. The ultimate mortality rate is likely influenced by several factors in addition to hook type such as animal size, handling practices by the vessel crew, and water temperature. Studies estimating the post-release survival of common pelagic longline bycatch species including billfishes (Kerstetter et al. 2003; Kerstetter and Graves, 2006b, 2008; Diaz 2008), sharks (Moyes et al. 2006; Campana et al. 2009; Musyl et al. 2011, Afonso and Hazin 2014), and sea turtles (Swimmer et al. 2012; Swimmer et al. 2014) suggest that these species have a low probability of post-release mortality given proper handling and release methods. Outreach efforts to the fishery regarding best practices for handling and release of bycatch species (e.g., not gaffing the fish prior to release) may result in additional conservation benefits greater than hook type alone.

There were no size selectivity differences between hook types for most target species; these results agree with previously work of similarly-sized hooks (Ward et al. 2009; Cambie et al. 2012; Domingo et al. 2012). Results indicating significantly different species lengths based on hook type have been limited but include differences in some target and bycatch species. For example, Curran and Bigelow (2011) found larger mean lengths of swordfish, skipjack tuna, blue marlin, opah (*Lampris guttatus*), and sickle pomfret (*Taractichthys steindachneri*) when caught on circle hooks compared to tuna hooks. Studies comparing circle hooks to J-style hooks have also reported increased lengths of yellowfin tuna on circle hooks (Kerstetter and Graves 2006a; Amorim et al. 2015). Conversely, cases of larger albacore tuna *Thunnus alalunga* (Pacheco et al. 2011) and bigeye tuna (Coelho et al. 2012; Amorim et al. 2015) have been reported for J-style hooks compared to circle hooks.

The ability of circle hooks to keep the fish alive until harvest may reduce the degradation of the flesh quality (e.g., Pacheco et al. 2011). This presumption is especially relevant due to the high ambient water temperatures in tropical surface pelagic longline fisheries which export sushi-grade tuna. Approximately 80% of the highest quality fish (Grade 1) were alive at the time of haulback, a finding similar to the Brazilian bigeye pelagic longline fishery (Pacheco et al. 2011). Conversely, only 68% of tunas determined as Grade 2, were alive at haulback, suggesting mortality plays a role in the grade.

A limited but growing number of hook performance studies have similarly investigated the effects of implementing circle hooks on ex-vessel revenue (i.e., the first point of sale without value added processing) (Ward et al. 2009; Curran and Bigelow 2011; Coelho et al. 2012; Amorim et al. 2015). Ward et al. (2009) found the cost of changing to circle hooks in the Australian pelagic longline fishery operating in the Coral Sea corresponded to a 13% increase in the total value of the retained catch compared to similarly sized tuna hooks. However, the authors also noted the financial performance of each hook type per trip was highly variable depending on operational characteristics and catchability.

Curran and Bigelow (2011) estimated the mean annual gross ex-vessel value of the Hawaii-based tuna fishery, targeting bigeye tuna, would have decreased by 8.1% if the traditional size 3.6 sun tuna hooks were replaced by size 18/0 circle hooks. The decrease was due to an estimated reduction in secondary target species, including yellowfin tuna, swordfish, common dolphinfish, and opah *Lampris guttatis*. The implication that circle hook implementation may have little effect on the ex-vessel revenue of the fishery has been found in the Portuguese swordfish longline fishery. Coelho et al. (2012) reported no significant changes in economic impact when comparing performance of 9/0 J-style hooks to 17/0 circle hooks in the Portuguese swordfish pelagic longline fishery operating in the equatorial and south Atlantic Ocean. Amorim et al. (2015) found similar economic results with the same hooks and fishery operating in the south Atlantic Ocean.

The results of the present study here in combination with others should be considered carefully to extrapolate possible economic gains to fisheries as catch rates and market values are highly dependent on spatial and temporal factors. Other types of pelagic longline fishing operations with different mixes of species and variability in catchability will experience different catch rates and financial returns than those presented here, especially as global fisheries product markets and preferred product mixes change. Accordingly, the socio-economic effects of changing hook type in a fishery should be regarded as point estimates, with limited range for extrapolation to other fisheries, geographic locations, or time periods.

Few studies compare traditional J-style hooks and circle hooks in artisanal or small-scale pelagic longline fisheries (e.g., Falterman and Graves 2002; Cambiè et al. 2012; Andraka et al. 2013). In the western Atlantic region, most of the studies have focused on industrial scale tuna or swordfish fisheries, assessing the differences in catch and mortality rates of target and non-target species (e.g., Kerstetter and Graves 2006a; Pacheco et al. 2011; Domingo et al. 2012; Epperly et al. 2012), which makes direct comparisons of this study difficult. Compared to the 26 experimental longline fishing sets performed and analyzed during this study, the majority of previous research used larger sample sizes above 80 sets (e.g., Kerstetter et al. 2006a; Pacheco et al. 2011), while others have analyzed even considerably larger sample sizes near 1000 sets (e.g., Diaz 2008; Carruthers et al. 2009; Foster et al. 2012).

The inferences that can be made from this study may have been somewhat limited by sample sizes. To determine the if our lack of significant results were due to limited statistical power (1-β), we performed post hoc power analyses using G*Power (v. 3.1) (Faul et al. 2007). Power analysis indicated sufficient sample size was reached for the paired t.tests used to analyse differences in CPUE based on hook type for for yellowfin tuna (observed $t(111) = 0.82$) and sailfish (observed $t(29) = 0.80$), although the statistical power for common dolphinfish was lower (observed $t(78) = 0.4$). The power of the chi-squared tests used to analyse differences in mortality and yellowfin tuna grade by hook type were also relatively low, ranging from 0.4 to

0.05. However, sufficient sample sizes were obtained to perform statistically robust analyses of CPUE differences for primary target species yellowfin tuna, and sailfish. The results presented here can be used to better inform fisheries managers regarding the performance of circle hooks in the Greater Caribbean region and to contribute to the knowledge of circle hook performance in small-scale pelagic longline fisheries.

References

Afonso, A. S., & Hazin, F. H. (2014). Post-release survival and behavior and exposure to fisheries in juvenile tiger sharks, Galeocerdo cuvier, from the South Atlantic. *Journal of Experimental Marine Biology and Ecology*, *454*, 55-62. https://doi.org/10.1016/j.jembe.2014.02.008

Amorim, S., Santos, M. N., Coelho, R., & Fernandez-Carvalho, J. (2015). Effects of 17/0 circle hooks and bait on fish catches in a Southern Atlantic swordfish longline fishery. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *25*(4), 518-533. https://doi.org/10.1002/aqc.2443

Andraka, S., Mug, M., Hall, M., Pons, M., Pacheco, L., Parrales, M., ... & Ortega, D. (2013). Circle hooks: Developing better fishing practices in the artisanal longline fisheries of the Eastern Pacific Ocean. *Biological Conservation*, *160*, 214-224. https://doi.org/10.1016/j.biocon.2013.01.019

Cambiè, G., Muiño, R., Freire, J., & Mingozzi, T. (2012). Effects of small (13/0) circle hooks on loggerhead sea turtle bycatch in a small-scale, Italian pelagic longline fishery. *Bulletin of Marine Science*, *88*(3), 719-730. https://doi.org/10.3989/scimar.2010.74n2275

Clarke, S. C., Sato, M., Small, C., Sullivan, B., Inoue, Y., & Ochi, D. (2014) Bycatch in longline fisheries for tuna and tuna-like species: A global review of status and mitigation measures. *FAO fisheries and aquaculture technical paper*, 588, 1-199. http://www.fao.org/fishery/publications/technical-papers/en

Coelho, R., Santos, M. N., & Amorim, S. (2012). Effects of hook and bait on targeted and bycatch fishes in an Equatorial Atlantic pelagic longline fishery. *Bulletin of Marine Science*, *88*(3), 449-467. https://doi.org/10.5343/bms.2011.1064

Cooke, S. J., & Suski, C. D. (2004). Are circle hooks an effective tool for conserving marine and freshwater recreational catch-and-release fisheries? *Aquatic Conservation: Marine and Freshwater Ecosystems*, *14*(3), 299-326. http://dx.doi.org/10.1002/aqc.614

Curran, D., & Bigelow, K. (2011). Effects of circle hooks on pelagic catches in the Hawaii-based tuna longline fishery. *Fisheries Research*, *109*(2-3), 265-275. http://dx.doi.org/10.1016/j.fishres.2011.02.013

Diaz, G. A. (2008). The effect of circle hooks and straight (J) hooks on the catch rates and numbers of white marlin and blue marlin released alive by the US pelagic longline fleet in the Gulf of Mexico. *North American Journal of Fisheries Management*, *28*(2), 500-506. https://doi.org/10.1577/M07-089.1

Domingo, A., Pons, M., Jiménez, S., Miller, P., Barceló, C., & Swimmer, Y. (2012). Circle hook performance in the Uruguayan pelagic longline fishery. *Bulletin of Marine Science*, *88*(3), 499-511. https://doi.org/10.5343/bms.2011.1069

Epperly, S. P., Watson, J. W., Foster, D. G., & Shah, A. K. (2012). Anatomical hooking location and condition of animals captured with pelagic longlines: the Grand Banks experiments 2002-2003. *Bulletin of Marine Science*, *88*(3), 513-527. http://dx.doi.org/10.5343/bms.2011.1083

Falterman, B., & Graves, J. E. (2002). A preliminary comparison of the relative mortality and hooking efficiency of circle and straight shank (" J") hooks used in the pelagic longline industry. In *American Fisheries Society Symposium*, 30, 80-87. https://doi.org/10.1111/j.1467-2979.2004.00150.x

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175-191. doi:10.3758/BRM.41.4.1149

Gentner, B., Arocha, F., Anderson, C., Flett, K., Obregon, P., & van Anrooy, R. (2018). Fishery performance indicator studies for the commercial and recreational pelagic fleets of the Dominican Republic and Grenada. *FAO Fisheries and Aquaculture Circular*, (C1162), I-68. www.fao.org/3/i8833en/I8833EN.pdf

Godin, A. C., Carlson J. K., & Burgener V. (2012). The effect of circle hooks on shark catchability and at-vessel mortality rates in longline fisheries. *Bulletin of Marine Science.* 88(3), 469–483. https://doi.org/10.5343/bms.2011.1054

Grant, S., & Baldeo, R. (2006). History of surface longline fishing technology in Gouyave, Grenada*. Proceedings of the Gulf and Caribbean Fisheries Institute, 57*, 189-204. http://aquaticcommons.org/id/eprint/13847

Grant, S., Berkes, F., & St Louis, J. (2007). A history of change and reorganization: the pelagic longline fishery in Gouyave, Grenada. *Gulf and Caribbean Research*, *19*(2), 141-148. https://doi.org/10.18785/gcr.1902.17

Graves, J. E., Horodysky A. Z., & Kerstetter D. W. (2012). Incorporating circle hooks into Atlantic pelagic fisheries: case studies from the commercial tuna/swordfish longline and recreational billfish fisheries. *Bulletin of Marine Science*. 88, 411–422. http://dx.doi.org/10.5343/bms.2011.1067

Huang, H. W., Swimmer, Y., Bigelow, K., Gutierrez, A., & Foster, D. G. (2016). Influence of hook type on catch of commercial and bycatch species in an Atlantic tuna fishery. *Marine Policy*, *65*, 68-75. https://doi.org/10.1016/j.marpol.2015.12.016

International Commission for the Conservation of Atlantic Tunas. (2016). Report of the Standing Committee on Research and Statistics. ICCAT, Madrid. http://www.iccat.int/Documents/Meetings/Docs/2018_SCRS_ENG.pdf

International Commission for the Conservation of Atlantic Tunas. (2018). Report of the Standing Committee on Research and Statistics. ICCAT, Madrid. http://www.iccat.int/Documents/Meetings/Docs/2018_SCRS_ENG.pdf

Kerstetter, D. W., & Graves, J. E. (2006a). Effects of circle versus J-style hooks on target and non-target species in a pelagic longline fishery. *Fisheries Research*, *80*(2-3), 239-250. http://dx.doi.org/10.1016/j

Kerstetter, D. W., & Graves, J. E. (2006b). Survival of white marlin (Tetrapturus albidus) released from commercial pelagic longline gear in the western North Atlantic. *Fishery Bulletin*, *104*(3), 434.104:434–444. http://dx.doi.org/10.1577/M07-202.1

Kerstetter, D. W., & Graves, J. E. (2008). Post-release survival of sailfish caught by commercial pelagic longline gear in the southern Gulf of Mexico. *North American Journal of Fisheries Management*, *28*, 1578–1586. https://doi.org/10.1577/M07-202.1

Kerstetter, D. W., Luckhurst, B. E., Prince, E., & Graves, J. E. (2003). Use of pop-up satellite archival tags to demonstrate survival of blue marlin (Makaira nigricans) released from pelagic longline gear. *Fishery Bulletin*, *101*(4), 939. https://www.st.nmfs.noaa.gov/spo/FishBull/1014/22kerste.pdf

Largacha, E., Parrales, M., Rendon, L., Velasquez, V., Orozco, M., & Hall, M. (2005). Working with the Ecuadorian fishing community to reduce the mortality of sea turtles in longlines: The first year, March 2004-March 2005. (pp. 57). Honolulu, HI: Western pacific regional fishery management Council. www.wpcouncil.org/wp-content/.../Largacha-et-al_2005_Ecuador-first-year-results.pdf

Lerner, J. D., Kerstetter, D. W., Prince, E. D., Talaue-McManus, L., Orbesen, E. S., Mariano, A., ... & Thomas, G. L. (2013). Swordfish vertical distribution and habitat use in relation to diel and lunar cycles in the western North Atlantic. *Transactions of the American Fisheries Society*, *142*(1), 95-104. https://doi.org/10.1080/00028487.2012.720629

Løkkeborg, S., & Bjordal, Å. (1992). Species and size selectivity in longline fishing: a review. *Fisheries Research*, *13*(3), 311-322. https://doi.org/10.1016/0165-7836(92)90084-7

Musyl, M. K., Brill, R. W., Curran, D. S., Fragoso, N. M., McNaughton, L. M., Nielsen, A., ... & Moyes, C. D. (2011). Postrelease survival, vertical and horizontal movements, and thermal habitats of five species of pelagic sharks in the central Pacific Ocean. *Fishery Bulletin*, *109*(4), 341-368. http://fishbull.noaa.gov/1094/1094musyl.pdf

Pacheco, J. C., Kerstetter, D. W., Hazin, F. H., Hazin, H., Segundo, R. S. S. L., Graves, J. E., ... & Travassos, P. E. (2011). A comparison of circle hook and J hook performance in a western equatorial Atlantic Ocean pelagic longline fishery. *Fisheries Research*, *107*(1-3), 39-45. https://doi.org/10.1016/j.fishres.2010.10.003

Development Core Team, (2018). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, ISBN 3-900051-07-0. http://www.R-project.org/

Read, A. J. (2007). Do circle hooks reduce the mortality of sea turtles in pelagic longlines? A review of recent experiments. *Biological Conservation*, *135*(2), 155 -169. http://dx.doi.org/10.1016/j.biocon.2006.10.030

Reinhardt, J. F., Weaver, J., Latham, P. J., Dell'Apa, A., Serafy, J. E., Browder, J. A., ... & Blankinship, D. R. (2017). Catch rate and at-vessel mortality of circle hooks versus J-hooks in pelagic longline fisheries: A global meta-analysis. *Fish and Fisheries*. https://doi.org/10.1111/faf.12260

Rice, P. H., Serafy, J. E., Snodgrass, D. & Prince, E. D. (2012). Performance of non-offset and 10° offset 18/0 circle hooks in the United States pelagic longline fishery. *Bulletin of Marine Science*, *88*(3), pp.571-587. https://doi.org/doi/10.5343/bms.2011.1095

Romero, A., Hayford, K.T., & Romero J. (2002). The marine mammals of Grenada, WI, and their conservation status. *Mammalia*, 66(4), 479-494. https://doi.org/10.1515/mamm.2002.66.4.479

Sales, G., Giffoni, B. B., Fiedler, F. N., Azevedo, V. G., Kotas, J. E., Swimmer, Y., & Bugoni, L. (2010). Circle hook effectiveness for the mitigation of sea turtle bycatch and capture of target species in a Brazilian pelagic longline fishery. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *20*(4), 428-436. https://doi.org/10.1002/aqc.1106

Serafy, J. E., Cooke, S. J., Diaz, G. A., Graves, J. E., Hall, M., Shivji, M., & Swimmer, Y. (2012). Circle hooks in commercial, recreational, and artisanal fisheries: research status and needs for improved conservation and management. *Bulletin of Marine Science*, *88*(3), 371-391. https://doi.org/10.5343/bms.2012.1038

Serafy, J. E., Kerstetter, D. W., & Rice, P. H. (2009). Can circle hook use benefit billfishes? *Fish and Fisheries*, *10*, 132–142. https://doi.org/10.1111/j.1467-2979.2008.00298.x

Swimmer, Y., Arauz, R., McCracken, M., McNaughton, L., Ballestero, J., Musyl, M., ... & Brill, R. (2006). Diving behavior and delayed mortality of olive ridley sea turtles Lepidochelys olivacea after their release from longline fishing gear. *Marine Ecology Progress Series*, *323*, 253-261. https://doi:10.3354/meps323253

Swimmer, Y., Empey Campora, C., McNaughton, L., Musyl, M., & Parga, M. (2014). Post-release mortality estimates of loggerhead sea turtles (Caretta caretta) caught in pelagic longline fisheries based on satellite data and hooking location. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *24*(4), 498-510. https://doi.org/10.1002/aqc.2396

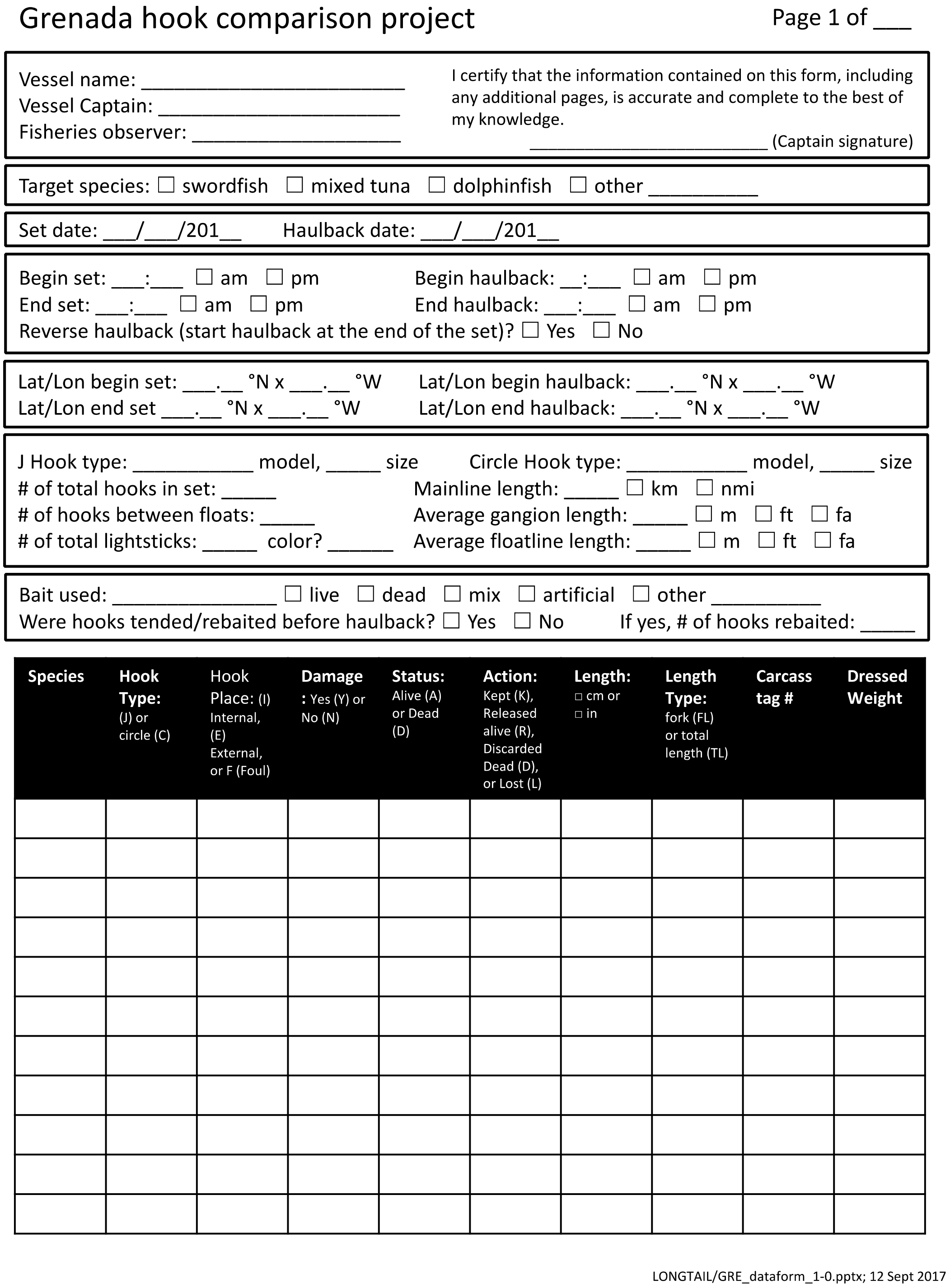
Watson, J. W., & Kerstetter, D. W. (2006). Pelagic longline fishing gear: a brief history and review of research efforts to improve selectivity. *Marine Technology Society Journal*, *40*(3), 6-11. https://doi.org/10.4031/002533206787353259

Watson, J. W., Epperly, S. P., Shah, A. K., & Foster, D. G. (2005). Fishing methods to reduce sea turtle mortality associated with pelagic longlines. *Canadian Journal of Fisheries and Aquatic Sciences*, *62*(5), 965-981. http://dx.doi.org/10.1139/f05-004

Ward, P., Epe, S., Kreutz, D., Lawrence, E., Robins, C., & Sands, A. (2009). The effects of circle hooks on bycatch and target catches in Australia's pelagic longline fishery. *Fisheries Research*, *97*(3), 253-262. http://dx.doi.org/10.1016/j.fishres.2009.02.009

Appendices

Appendix 1. Data sheet including: set details (top) and animal details (bottom). If needed for additional catches, the second sheet (next page) of additional animal details was also used.



Grenada hook comparison project

Page 1 of ___

Vessel name: _________________________
Vessel Captain: ______________________
Fisheries observer: ____________________

I certify that the information contained on this form, including any additional pages, is accurate and complete to the best of my knowledge.

________________________ (Captain signature)

Target species: ☐ swordfish ☐ mixed tuna ☐ dolphinfish ☐ other __________

Set date: ___/___/201__ Haulback date: ___/___/201__

Begin set: ___:___ ☐ am ☐ pm Begin haulback: __:___ ☐ am ☐ pm
End set: ___:___ ☐ am ☐ pm End haulback: ___:___ ☐ am ☐ pm
Reverse haulback (start haulback at the end of the set)? ☐ Yes ☐ No

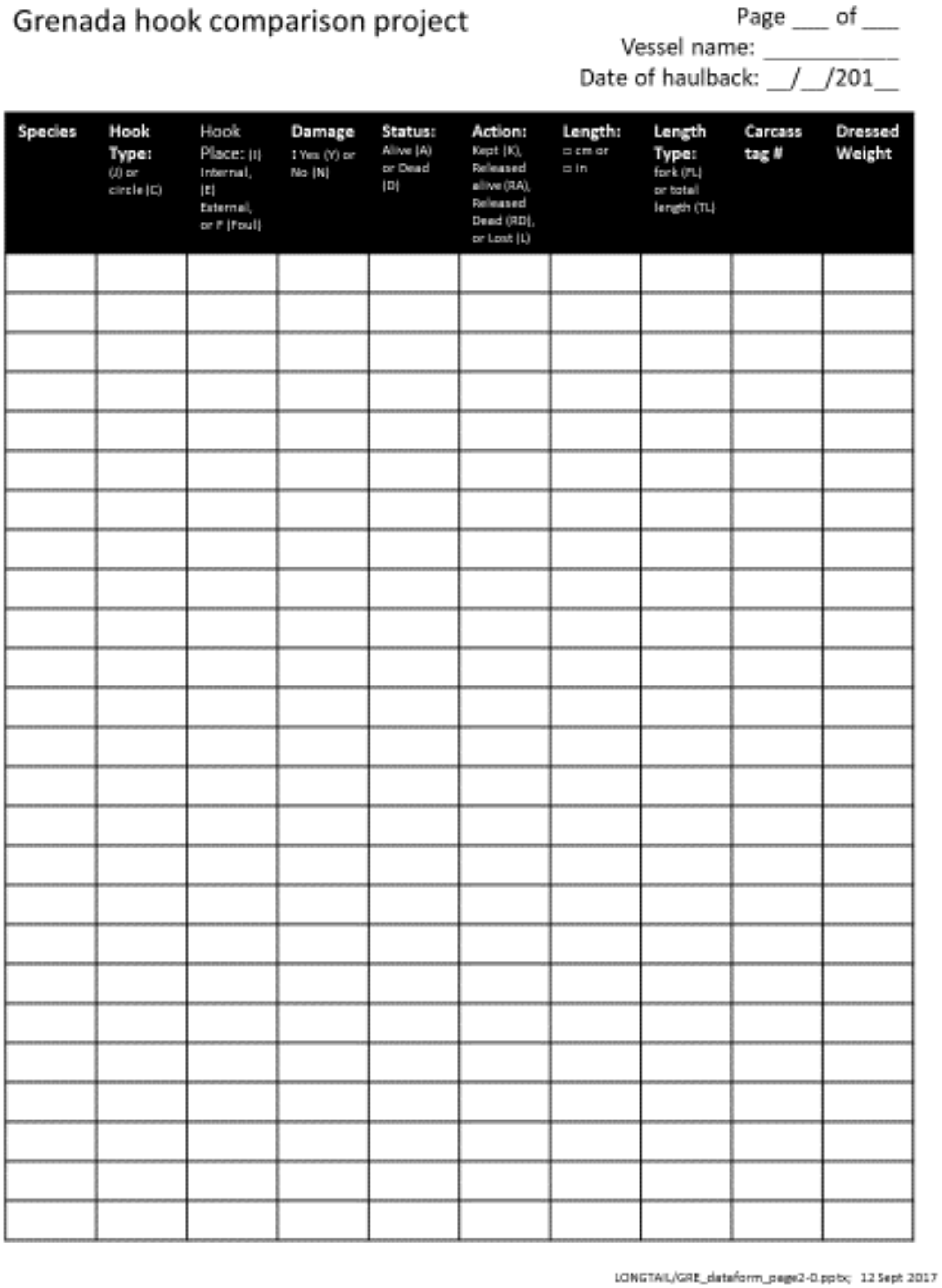
Lat/Lon begin set: ___.__ °N x ___.__ °W Lat/Lon begin haulback: ___.__ °N x ___.__ °W
Lat/Lon end set ___.__ °N x ___.__ °W Lat/Lon end haulback: ___.__ °N x ___.__ °W

J Hook type: ___________ model, _____ size Circle Hook type: ___________ model, _____ size
# of total hooks in set: _____ Mainline length: _____ ☐ km ☐ nmi
# of hooks between floats: _____ Average gangion length: _____ ☐ m ☐ ft ☐ fa
# of total lightsticks: _____ color? ______ Average floatline length: _____ ☐ m ☐ ft ☐ fa

Bait used: _______________ ☐ live ☐ dead ☐ mix ☐ artificial ☐ other __________
Were hooks tended/rebaited before haulback? ☐ Yes ☐ No If yes, # of hooks rebaited: _____

Species	**Hook Type:** (J) or circle (C)	Hook Place: (I) Internal, (E) External, or F (Foul)	**Damage:** Yes (Y) or No (N)	**Status:** Alive (A) or Dead (D)	**Action:** Kept (K), Released alive (R), Discarded Dead (D), or Lost (L)	**Length:** □ cm or □ in	**Length Type:** fork (FL) or total length (TL)	**Carcass tag #**	**Dressed Weight**

LONGTAIL/GRE_dataform_1-0.pptx; 12 Sept 2017



Grenada hook comparison project

Page ___ of ___
Vessel name: ___________
Date of haulback: __/__/201__

Species	Hook Type: (J) or circle (C)	Hook Place: (I) Internal, (E) External, or F (Foul)	Damage I Yes (Y) or No (N)	Status: Alive (A) or Dead (D)	Action: Kept (K), Released alive (RA), Released Dead (RD), or Lost (L)	Length: ☐ cm or ☐ in	Length Type: fork (FL) or total length (TL)	Carcass tag #	Dressed Weight

LONGTAIL/GRE_dataform_page2-0.pptx; 12 Sept 2017