FINAL REPORT

Field Testing an Electric Decoy for Reducing Elasmobranch Bycatch in Longline Fisheries

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Overview

Although often considered target catch, elasmobranchs also constitute a large percentage of pelagic longline (PLL) bycatch in the Atlantic and elsewhere. Shark bycatch sometimes even surpasses the percentage of target tuna catch in the Atlantic (Beerkircher et al., 2002; Abercrombie et al., 2005). In some cases, bycatch has been identified as a principal threat to a species' survival, as with the Endangered Scalloped hammerhead shark (*Sphyrna lewini*) (Baum et al., 2013) that in 2014 was formally listed as endangered under the U.S. ESA (two populations endangered and two threatened) (Endangered and Threatened Wildlife Plants 2014), and the smalltooth sawfish (*Pristis pectinata*) that the U.S. lists as endangered within its territorial waters (Endangered and Threatened Species, 2003), including a portion of the population found outside US waters (USFWS 2015). Six elasmobranchs are listed as endangered under the ESA, from both targeted and incidental catch (NMFS 2017). Three sharks listed as "Species of Concern" under the US Endangered Species Act have fisheries bycatch indicated as a principal threat (Basking shark [*Cetorhinus maximus*]), Dusky shark [*Carcharhinus obscurus*], and Sand tiger shark [*Carcharias taurus*]).

Shark bycatch is also a problem for fishermen. There is the immediate problem of decreased profitability because hooks that could be used to catch target species are occupied by unwanted non-target species. In addition, there is the cost of damaged gear bitten through by sharks, and reduced profitability as a crew spends valuable time removing and handling the bycatch. Closely related to this is a real potential for crew injury during attempts to release sharks that often thrash violently and possess very sharp teeth. Capture rates of target species are reduced through depredation and hook occupancy directly decreasing revenue. Gear damage, gear replacement, and shark handling time increase operational costs. Gilman et al. (2007) reported that more than $1,000 is lost per set in the swordfish fishery off Chile as a result of gear damage and depredation by sharks.

Bycatch in any fishery is of greatest concern when the life histories of the bycaught species render them more susceptible to overfishing than the target species. Even though the primary shark species captured in pelagic long line fisheries are among the most productive of large sharks, their population doubling times are between 10 and 15 years (Smith et al. 1998), which is more than twice that for the most targeted species (e.g. <5 years for yellowfin and bigeye tunas). This discrepancy can lead to bycatch mortality that exceeds the maximum sustainable yield (MSY) while the target species catches remain sustainable. Clarke et al (2006) estimated that globally the MSY for blue sharks (*Prionace glauca*) was around 10 million sharks and current harvest levels are potentially approaching this benchmark.

Many shark species are vulnerable to fishing pressure due to their life history characteristics (slow growth, late maturity, long gestation, low fecundity). There is evidence that shark populations have been reduced by fishing, sometimes dramatically (Baum et al., 2003; Baum and Myers, 2004). Although these estimates strain credibility

(Burgess et al 2005), even conservative estimates indicate population declines (Cortes etal 2007). As apex predators in the marine environment, sharks play a vital role in maintaining ocean health. Therefore, reducing shark bycatch serves an additional, ecological benefit.

While for some shark species NMFS permits retention up to a certain number per vessel per trip by species group, the retention of other shark species is prohibited. PLL vessels must also use corrodible circle hooks. While measures to improve post-hooking survivability of sharks should be encouraged, resilience to longline capture varies greatly by species (Mandelman and Skomal, 2009; Morgan and Burgess, 2007; Ellis et al., 2016; Common Oceans 2017) and condition of the animal upon haulback (Musyl and Gilman 2018), with certain species historically demonstrating poor survival at gear retrieval. As such, there is a need to focus on avoiding bycatch in the first place, as indicated in the U.S. Magnuson-Stevens Act National Standard 9.

In contrast with other threatened non-target species, there are fewer effective bycatch reduction devices (BRDs) for elasmobranchs (Werner et al., 2006; Favaro and Côté, 2013). Mitigation of shark bycatch and depredation on pelagic long lines ideally needs to be achieved through methods that do not impact catch rates of target species. Development of technologies that decrease shark bycatch and depredation on pelagic long lines but do not decrease catch rates of target species is a priority. Knowledge of what sensory cues stimulate a shark to bite provides the basis for development of mitigation strategies (Jordan et al., 2013). Therefore, exploring the sensory cues available to sharks but unavailable to teleost fishes would provide a mechanism to selectively decrease shark bites while not affecting bites by the target species.

Although elasmobranch fishes share all of the sensory modalities found in marine teleosts, only the elasmobranchs possess an electrosensory system (the ampullae of Lorenzini) that enables them to detect electric fields in their environment. Sharks have been demonstrated to use their electric sense to accurately locate prey based only upon the weak field of direct electrical current field created by the potential difference between the prey tissues and the seawater environment (Kalmijn 1972; Kajiura and Holland 2002). The electrosensory system has been demonstrated to override other sensory modalities at the final bite, with sharks documented to ignore nearby food items to bite electrodes (Kalmijn 1972; Kajiura 2003). Their extreme sensitivity to very weak electric fields has also been exploited to develop electric shark deterrents such as the commercially available *Shark Shield*® by Ocean Guardian. Therefore, a mitigation strategy that would repel sharks by stimulating their electrosensory system may provide a mechanism to deter electroreceptive sharks from biting while not affecting teleost fishes.

Our group and other researchers have been studying the potential of electropositive metals as bycatch deterrents with mixed results. Much of this work has focused on repelling elasmobranchs from fishing gear using electrical signals to target their electrosensory system. Preliminary data have revealed that different elasmobranch species exhibit variable responses to the electric fields produced by lanthanide elements in laboratory experiments, with some species avoiding, and some displaying attraction, to these metals (Stoner and Kaimmer, 2008; Brill et al., 2009; Tallack and Mandelman, 2009 Robbins et al., 2011). In general, it is clear that these metals do not appear effective with all species tested, and that hungry individuals or feeding aggregations of elasmobranchs often overcome their initial aversion response and will still take bait from a hook even in the presence of an electropositive metal. A review by Porsmuguer et al. (2015) of trials involving magnets showed disparate results, and even an increase in blue shark catch. Although our research on electropositive metals is on-going, even if this technology proves effective it would likely be limited to certain species and fisheries.

Rather than use electric stimuli to repel sharks, a novel strategy would be to use the sharks' natural attraction to electric stimuli to attract sharks to a separate target (prey-simulating electrical signal) and divert attention away from the bait. All elasmobranch species are attracted to weak electric fields generated by their prey. These electrical signals can be mimicked using battery-powered electrodes, which elicit a strong attractive response from elasmobranchs to bite at the signal source, often ignoring nearby food (Kalmijn 1972; Kajiura 2003).

The strategy of attracting sharks away from bait with electric decoys rather than deterring them was investigated using a version of electric deterrents in demersal and pelagic longline field trials by Kerstetter et al. (2015). The demersal pilot testing, which was mainly composed of Atlantic sharpnose sharks (*Rhizoprionodon terraenovae*) and blacktip sharks (*Carcharhinus limbatus*), showed catch rates on hooks containing deterrents significantly lower than that of hooks without the deterrents.

Project Objectives

The overall goal of this project was to evaluate the potential of a battery-powered bait decoy to reduce the bycatch of sharks in a pelagic and a coastal bottom longline fishery. The approach capitalized upon differences in sensory physiology to selectively exclude elasmobranch fishes while not reducing the catch of target teleost species.

The objectives were to:

(1) Refine the design of a prototype device so that it is durable and practical enough for oceanic fishing conditions, and would also avoid damage to shark teeth from biting.
(2) Test the efficacy of the electric decoy for reducing shark capture in fisheries independent longline experiments.
(3) Deploy the device on commercial pelagic longline vessels to determine if there is a significant reduction in shark bycatch.

I. *Device design refinement and production*

The important design criteria for our electric decoy was that it be practical for fishermen, it produce an electric current of sufficient strength to attract sharks, and that any biting response by sharks does not result in damage to their teeth. In 2011, with support from the Bycatch Consortium, Steve Kajiura of Florida Atlantic carried out trials on different species of captive animals to determine an optimal charge to attract sharks even when presented with bait. He determined that an optimal output would be using a 1.5V battery and 15kOhm resistor produce a 100 µA (Kerstetter et al., 2015). The first field unit was constructed primarily of PVC plastic tubing covered by a neoprene sleeve that was attached using a plastic tie and was attached to a 6-inch leader and snap for attaching to the longline gangion. These devices were tested aboard the commercial pelagic longline vessel F/V *Day Boat One* (home port: Fort Pierce, FL), which targeted swordfish and yellowfin tuna in the Florida East Coast pelagic statistical area during five sets in October 2011 using nighttime-soaking gear that targeted a depth range of 30-40 fathoms (*ca.* 60-80 meters). Even though the boat captain found the longline configuration of the device practical and deployment relatively easy, there was a high degree of failure due to water leakage. Based on this experience, a new design was adopted to prevent water leakage by covering all of the electronic components in urethane except for the tips of two screws to function as battery leads.

In April, the PI worked with Dave Kerstetter of Nova Southeastern University to refine and produce electric decoys to be used for the field trials. Although the urethane coating resolved water incursion, a remaining design challenge was to figure out a coating for the decoys that would be durable but also enable detection of shark bites. After experimenting with a number of different coatings, we ended up using *Flex Tape*® (*Figure 1*). This tape was easy to apply and remained affixed to the decoys after several days of immersion in seawater. A layer of black tape was overlaid with a layer of white tape to facilitate visual detection of shark bites.

The materials used to construct the final decoys were:

- AA batteries
- Etcher
- 60/40 Rosin Core Solder
- 8x1/2" sheet metal screws
- #208 Zinc plated screw eyes
- 15K Ohm resistors
- Coated wires (any width)
- 50 mL Falcon tubes
- Release Spray – *Mann Release 200*
- Acrylic – *Smooth-On* Crystal Clear Cast Resin
- *Flex Tape*® (one sheet of white and one sheet of black for each device) – cut into ~3in-long sections

The process used for producing the devices was as follows:

- Find a device to hold battery to make it safer and easier to solder screws to each end of battery
- Etch each end of the battery (makes for a better solder hold)
- Cut 2 sections of wire (~2in long, each)
- Wrap one end of one wire around screw eye and other piece of wire around bottom of metal screw
- Place a drop of solder onto each end of the battery
- Solder screw eye to positive end of battery;
- Solder metal screw to negative end of battery
- Attach the wires from screws onto solder drop on battery with more solder
- Spray release spray into Falcon tube (this help the devices slide right out of tube when dried)
- Place completed internal component into the sprayed 50 mL Falcon tube (we used small pins through the screw eye to keep upright in tube)
- Mix *Smooth-On* urethane in a ratio of 10 parts A to 9 parts B in separate container
- Pour urethane into Falcon tube (roughly up to the 45mL line to prevent overflowing)
- Allow to dry overnight (roughly 16-24 hours)
- Tubes should slight right out of tube once dried – if they do not, use a grinder or some small tool to cut the top portion of the Falcon tube to loosen device.
- Coat the devices first with a white *Flex Tape*®, and then a black piece of tape (this allows for bite marks to become more visible)

Figure 1. Decoys drying in in their molds (left) and later covered using various coatings (right). The final decoy coating used was *Flex Tape*® (far left of the photograph on the right).

II. Demersal longline trial

A fishery-independent survey was conducted to field-test the efficacy of using electric decoys as a shark deterrent in a simulated demersal fishery. Dr. Dean Grubbs of Florida State University developed a longline survey designed to assess the abundance, diversity, and seasonal habitat use of adult and juvenile coastal sharks in the northeastern Gulf of Mexico.

The mainline was 4.0mm monofilament anchored at each end and marked by a buoy labeled with a Special Activities License number issued by the Florida Fish and Wildlife Conservation Commission. Gangions were placed on the mainline at 15-meter intervals and buoys marked the line at 20-hook intervals. A standard set consisted of 60 gangions. The gangion configuration consisted a stainless steel tuna clip with an 8/0 stainless steel swivel attached to 3.0m of 3.2mm (350kg) monofilament. A foam net float was attached to the gangion 2.0m from the clip. The floats were attached to each gangion to ensure the hooks (and electric decoys and control decoys) were suspended from the bottom. The terminal 25cm of monofilament was doubled and terminated with a 16/0 circle hook baited with Spanish mackerel (*Scomberomorus maculatus*). The hooks used are the same as those used in many pelagic swordfish and tuna fisheries. Soak times were approximately one hour. Gangions included three hook treatments. One-third of the hooks (20 16/0 hooks) had the electric decoy attached 75 cm above the hook. One third of the hooks had a non-electronic dummy decoy attached 75 cm above the hook to control for the alteration of hook behavior. One third of the hooks had nothing attached above the hook ("blank"). The three treatments were applied in sequence such that no adjacent hooks receive the same treatment.

The demersal trial off Florida began in May of 2017, operating almost entirely from the FSU Coastal and Marine laboratory in St. Teresa, Florida, and primarily sampling local soft bottom habitat adjacent to seagrass shoals, at depths of 3-7 meters, and with an average soak time of one hour. Dr. Dean Grubbs' team conducted 56 experimental longline sets testing electric decoys from May-August, 2017. Gangion type was recorded for all animals caught, and all decoys were visually checked for bite marks upon haul back. Decoys were rinsed in fresh water at the end of each fishing day, and active decoys were tested with a volt meter after each fishing day to ensure they were working properly. All statistical significance was assessed at $\alpha < 0.05$ level.

In total, 152 sharks representing 10 species of sharks and one batoid, were captured (*Table 1*). Overall, the catch was dominated by all life stages of Atlantic sharpnose sharks (*Rhizoprionodon terraenovae*), with juvenile and adult blacktip sharks (*Carcharhinus limbatus*) being the second most common species. In addition to Atlantic sharpnose sharks, the small coastal shark catch included blacknose (*Carcharhinus acronotus*) and finetooth sharks (*C. isodon*). The large coastal shark catch included, in addition to blacktip sharks, bull (*C. leucas*), spinner (*C. brevipinna*), lemon (*Negaprion brevirostris*), tiger (*Galeocerdo cuvier*), great hammerhead (*Sphyrna mokarran*), and nurse sharks

(*Ginglymostoma cirratum*). The single batoid species caught was a southern stingray (*Dasyatis americana*). Only five teleost fishes were captured: two gafftopsail catfish (*Bagre marinus*), one great barracuda (*Sphyraena barracuda*), one sand weakfish (*Cynoscion arenarius*), and one red grouper (*Epinephelus morio*).

Table 1. Total numbers captured in the demersal trial for each elasmobranch species.

Species	N
Carcharhinus acronotus (blacknose shark)	21
Carcharhinus brevipinna (spinner shark)	2
Carcharhinus isodon (finetooth shark)	7
Carcharhinus leucas (bull shark)	4
Carcharhinus limbatus (blacktip shark)	76
Dasyatis americana (southern stingray)	1
Galeocerdo cuvier (tiger shark)	2
Ginglymostoma cirratum (nurse shark)	8
Negaprion brevirostris (lemon shark)	1
Rhizoprionodon terraenovae (Atlantic sharpnose)	207
Sphyrna mokarran (great hammerhead shark)	3

Out of the 56 sets, 5 had no catch and 22 had 5 sharks or less. Average catch-per-unit-effort (CPUE, sharks/100 hook hours) was lowest on gangions outfitted with active decoys for all sharks combined and the small coastal complex (*Table 2*), however this pattern was not statistically significant (ANOVA, $F_{2,165} = 1.24$, $p = 0.29$). Average catch rates were highest on blank gangions for all sharks combined and the small coastal complex. Average catch rates of large coastal sharks were slightly higher on gangions with inactive decoys than active decoys or blanks (no device), for which average CPUE was equal. Therefore, while we did observe a relative decrease in catch rates on gangions outfitted with active decoys, these differences were not statistically significant.

Table 2. Mean CPUE (sharks/100 hook hours) and standard deviation for each gangion treatment for all sharks combined, the small coastal complex, and large coastal complex.

Treatment	All sharks	Small coastal	Large
Active decoy	10.50 (8.90)	7.25 (6.47)	3.25 (5.13)
Inactive decoy	13.75 (9.04)	9.75 (7.83)	4.00 (5.55)
Blank	13.75 (8.76)	10.50 (7.71)	3.25 (4.37)

III. Pelagic Longline trial

In the original proposal the plan was to test the electric decoy in a pelagic fishery off the northeast US. However, owing to substantial staff changes to proposal collaborator Blue Water Fishermen's Association after this project was awarded funds, it was no longer prepared within the timeframe of this project to implement field testing of the experimental device with this group's fishermen. We also reached out to fishermen in the Hawaii Longline Pelagic fishery however despite their initial interest none were prepared to dedicate time to testing the devices.

With a need to take electronic deterrents from a proof of concept stage to larger scale trials we explored other options and areas with high elasmobranch abundances. Shark abundances and samples sizes of such magnitude were needed to provide more validation of this gear modification. Without willing and available pelagic longline fishermen in the U.S, we formulated an alternative strategy to examine the performance of this device in a pelagic environment in an area of the Bahamas where sharks are abundant and diverse.

In collaboration with Cape Eleuthera Institute (CEI) located on Eleuthera Island, Bahamas, experimental pelagic longline trials began in early July and concluded in mid-August of 2018. Trials were conducted along a relatively shallow and narrow ridge known as "the bridge" (average depth = 15m) of sand, coral and rock located between Lighthouse beach, on the southern edge of Eleuthera and Half Moon Bay on Little San Salvador Island in the Bahamas (*Figure 2*). Cape Eluthera Institute researchers previously identified this area as having consistently high catch rates of sharks, and it is easily accessible by a two-hour boat ride from the research facility.

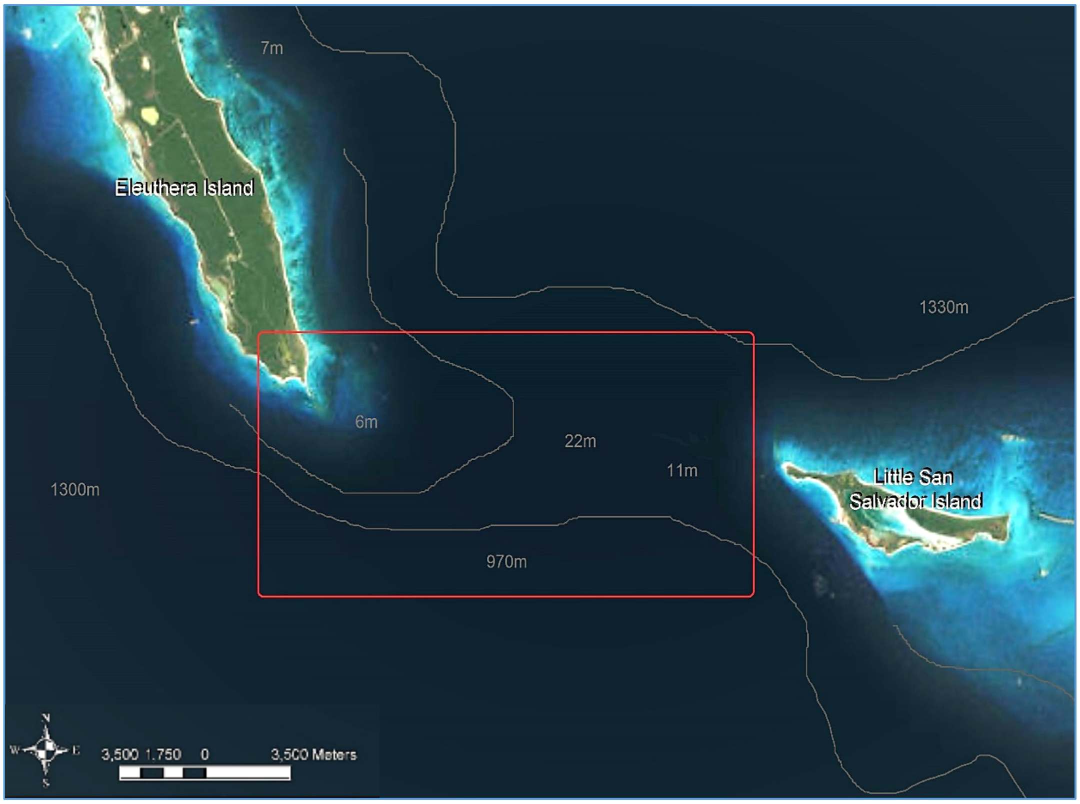

Figure 2. Location of pelagic longline deployments on “the bridge” located between Eleuthera Island and Little San Salvador Island, Bahamas.

In the original proposal the plan was to compare target catch and shark interactions between active and non-active decoys. Under the revised research plan this needed to be modified because the trial was no longer occurring in an active fishery, and past shark catch records from this area showed that gear sets using bait and gangion types better suited for maximizing the catch of bony fishes would catch fewer sharks, especially tiger sharks. Instead, we configured the gear to maximize catch of elasmobranchs, and examined catch of sharks on active versus inactive devices.

During 3 to 5-day survey trips researchers on a 28ft vessel two pelagic longline sets were deployed per day, generally setting one in the morning and one in the afternoon. Before each longline was set an untethered polyform buoy was released at each location to determine current flow. The direction of the current was used to deploy the longline so that it would drift over the ridge, also called the “the bridge”, of deep water on one side to deep water on the other (average deepest depth = 500m).

The total length of the 6.4mm diameter braided nylon longline with two highflyers at either end was approximately 1,466m. The length between each polyform float was generally 110m. Gangions were located 10m from each float and then at every 18m. At each end of the longline the polyform buoy had an additional 18m terminal segment of line in which a weighted highflyer was added. Owing to the high number of bottom snags observed during initial sets of the trial, the number of gangions between buoys was modified to 4-5 hook baskets, rather than 6 as originally intended. Generally, between 48-74 hooks were deployed on each longline, half of which consisted of an active decoy--labeled with a small green plastic tie--and half an inactive dummy decoy produced without any electrical components but having an identical weight as the active decoys. Active and inactive dummy decoys were alternated throughout the longline “active-inactive-active-inactive-active.”

Each gangion consisted of 4m length and 3.2mm diameter nylon braided rope terminating in 1m length of 1.6 mm diameter stainless steel wire leader (*Figure 3*). Decoys were clipped on to the rope just above the attachment point of the wire and rope. The decoys were attached using a heavy duty tuna clip (quick snap, 0.148 inch metal, 3/16-inch gape). Each Lindgren-Pitman 16/0 carbon circle hook was baited with an ample segment of flathead grey mullet, *Mugil cephalus*.

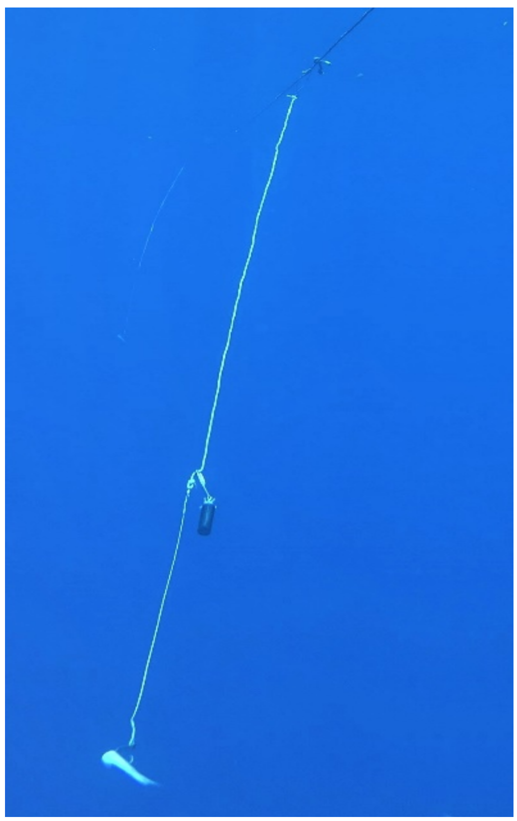

Figure 3. A complete baited gangion *in situ* with a suspended device.

Once deployed, the total length of the longline was constantly tended to detect any visual evidence of a hooked fish. Probable hookings were then investigated and when confirmed the gangion was hauled in alongside the boat. In addition to electronic decoy deterrent data biological data of each organism captured was recorded (as part of a separate longer term study by CEI). After sampling, the hook was removed and the shark released. The same procedure was followed for teleost fishes with the exception of tagging. The type of decoy (active or inactive) on the gangion was also recorded. When the entire gear was hauled in, a record was made of whether there was any animal caught, the type of decoy, the presence of obvious teeth marks on decoys, and if the bait was still on or off the hook. The time from longline deployment to when the fish was caught was also recorded. (See Appendix A for a copy of the field log sheet. At the end of each day, devices were rinsed. Once dry, the voltage of each active decoy was checked using a voltmeter. Test leads were applied by taking one side and contacting the melt screw exposed at the bottom of the device and applying the other lead to the screw eye at the top of the device. Most devices remained fully charged throughout the duration of the project, however any devices that had a current below 1.3V were retired and no longer used. Each device was visually inspected to identify the presence of elasmobranch bites.

A wide range of markings were seen which were most likely a result of the presence of various fish species. In some cases, deciphering each was not possible, however very obvious bites of non-shark species were disregarded (Figure 4). When the *Flex Tape*® on a device showed evidence of tooth marks, abrasion or wear and tear the device was put aside and recoated before its next deployment.

Figure 4. Visual inspection of devices showed (a.) shark bite marks and of (b.) bite marks other fish species.

Catch rates were expressed as catch-per-unit-effort (CPUE) values of the number of individuals caught per 100 hooks. Shark catch was compared using a one-way analysis of variance test (ANOVA) to assess the relationship between catch on active and inactive devices. Chi-square (x^2) tests were performed to determine if the presence of bite marks were significantly different among active and inactive devices on gangions that had bait remaining on the hook. All statistical significance was assessed at $\alpha < 0.05$ level.

Of the 24 longline sets a total of 1,318 hooks were deployed for an average soak time of 3 hours and 5 minutes. This totaled 673 active devices and 645 inactive dummy devices deployed throughout the field trials. A total of 125 sharks representing 7 species were captured and sampled (*Table 3a*). Catch was heavily dominated by Caribbean reef shark (*Carcharhinus perezii*) making up 87.2% of the total catch of sharks while tiger shark, *Galeocerdo cuvier,* was the second most common species representing 6.4% of shark catch. For the 32 teleost caught barracuda, *Sphyraena barracuda,* was the most dominant (*Table 3b*).

Table 3. Total numbers captured for (a.) elasmobranch species and (b.) other fishes

a.)

Species	*N*
Carcharhinus perezii (Caribbean reef shark)	109
Galeocerdo cuvier (tiger shark)	8
Ginglymostoma cirratum (nurse shark)	3
Carcharhinus acronotus (blacknose shark)	2
Carcharhinus falciformis (silky shark)	1
Rhizoprionodon terraenovae (Atlantic sharpnose shark)	1
Sphyrna mokarran (great hammerhead shark)	1

b.)

Species	*N*
Sphyraena barracuda (great barracuda)	26
Caranx latus (horse-eye jack)	3
Caranx lugubris (black jack)	1
Mycteroperca bonaci (black grouper)	1
Apsilus dentatus (black snapper)	1

We identified a total of 10 bite-offs throughout the trials, which referred to a gangion pulled up during hauling that had been completely cut anywhere above the baited hook to just above an inactive or active device. Though bite-offs were assumed to have been caused by sharks they were not included in capture data or device analysis.

Capture data of the 109 Caribbean reef sharks showed 59 were captured on gangions with active devices while 50 were caught on gangions containing inactive dummy devices. For the 8 tiger sharks captured 3 were caught on gangions with active devices and 5 were caught on inactive devices. When pooling all sharks, the average catch-per-unit-effort (CPUE, sharks/100 hook hours) and standard deviation for active and inactive devices was 10.36 (8.36) and 9.17 (6.18), respectively. Shark catch did not show a significant difference between active and inactive devices (ANOVA, $F_{1,46} = 0.25$, $p = 0.62$).

Gangions that had bait remaining on the hook at the time of collection showed similar results as 42.6% of active devices and 40.9% of inactive devices had bait remaining. Furthermore, we compared the number of bite marks on both types of device. When bait remained on the gangion at the time of collection, active and inactive devices did not show evidence of differences in the number of bite marks (Chi-square; $x^2 = 0.14$, $p = 0.70$). The total soak time of each longline set in relation to the number of bite marks on devices did not show a significant trend (*Figure 5*). Devices with bite marks occurred as frequently with short as with longer soak times.

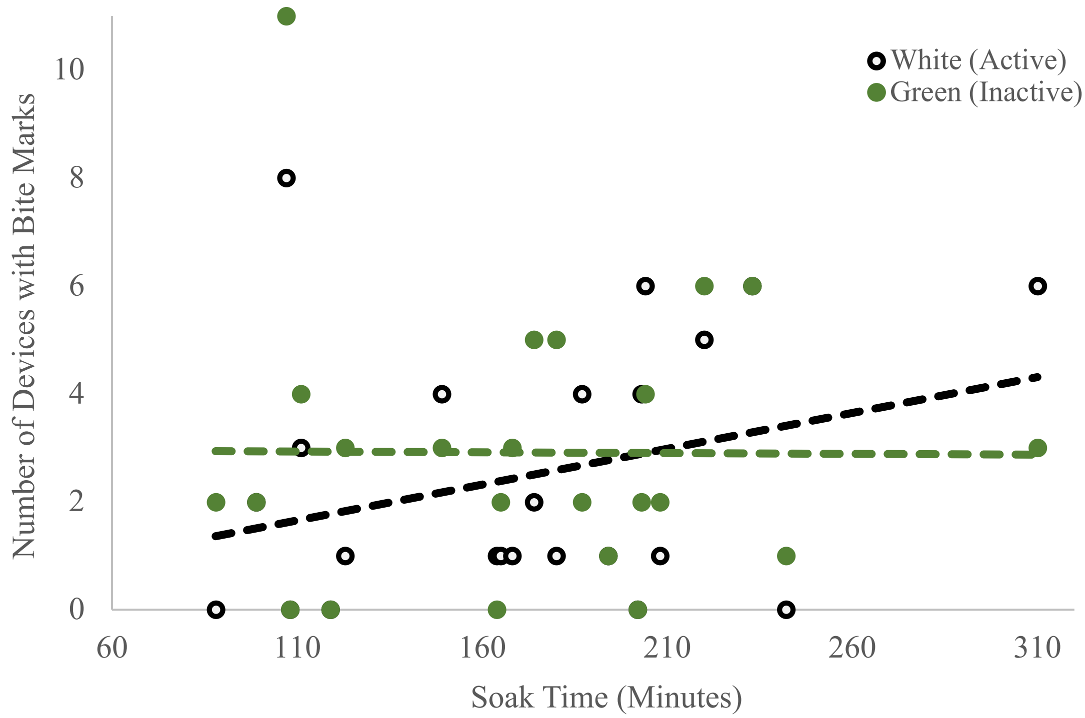

Figure 5. Number of devices with bite marks as a function of soak time.

IV. Optical Behavioral Trials

For additional insight into the electronic deterrent a small-scale trial approximately two miles off Cape Eleuthera was conducted to collect qualitative video data. The purpose of these recordings was to further investigate the overall interest or lack of interest sharks exhibit when presented with active and inactive devices. Our aim was to see if video data reviled any additional insight that could help interpret our findings from the pelagic trials. Here, a pelagic longline was deployed along the shelf ridge (averaging 50m deep) for a duration of four hours. The longline contained GoPro cameras on each gangion to observe behavioral characteristics as sharks approached each device.

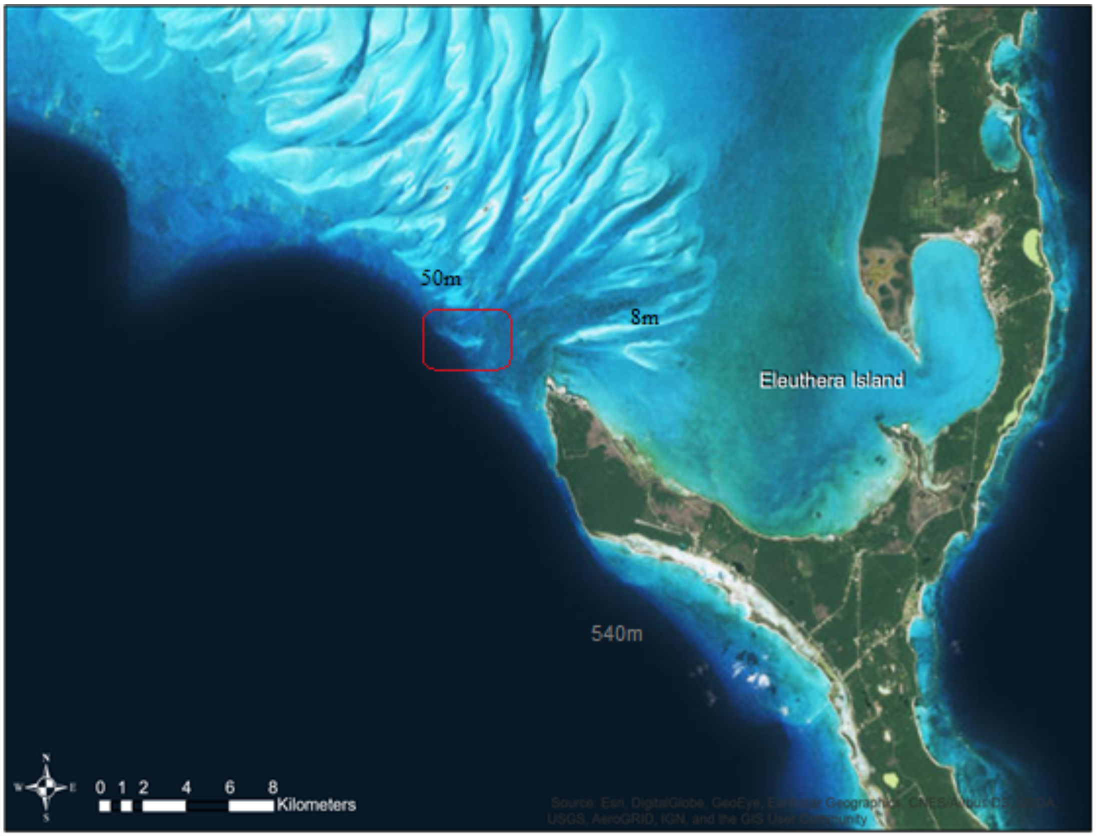

Figure 6. Pelagic longline set location during behavioral trials off Cape Eleuthera, Bahamas.

A 6.4mm diameter braded nylon pelagic longline of 250m in length was set and anchored on both ends. The longline contained four gangions with bait cages full of mullet (two mullet quartered in each cage, *Figure 7*). Gangions were placed about 14 m apart with a buoy preceding each gangion. Deterrents were placed 1m before the swivel to the bait cages, similar to the pelagic longline trials described in section III of this report, alternating active and inactive deterrents (active devices remained at a 1.3V or higher charge). The gangions were 4m long (tuna clip to bait cage) and the cameras were roughly 1m below the top of the gangion, recording for approximately 4 hours.

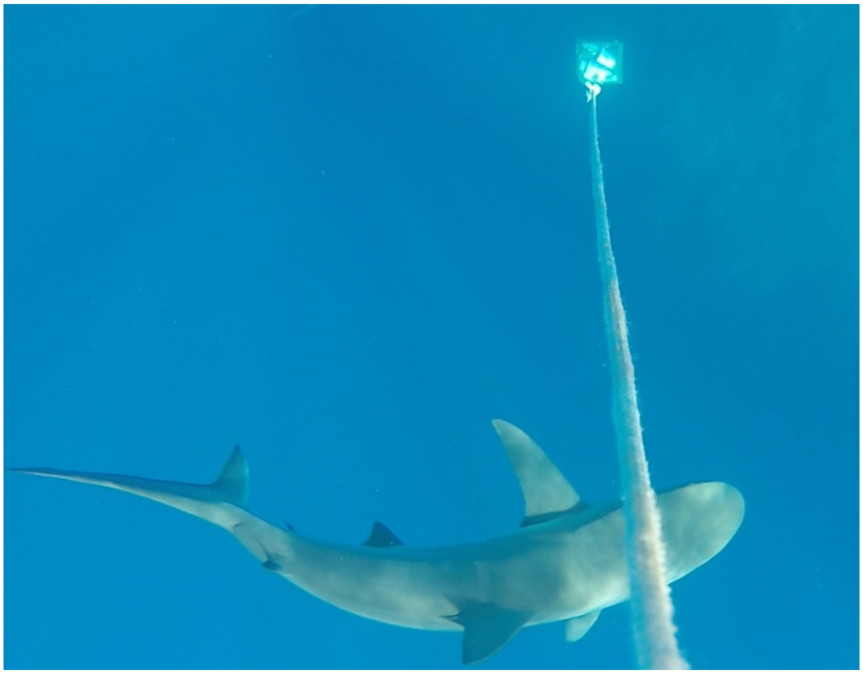

Figure 7. A video still of a Caribbean reef shark and complete gangion outfitted with device and bait box.

Video recordings revealed a total of 109 interactions consisting of Caribbean reef shark (*Carcharhinus perezii)*, lemon shark (*Negaprion brevirostris),* barracuda (*Sphyraena barracuda)* and triggerfish species (*Table 4*). For sharks, individuals displayed interest (close pass, bump or bite) 12 times when presented with the active decoys and 3 times when presented with the inactive decoy. Sharks displayed no interest (ignore, avoid) 4 times when presented with an active decoy and 12 times with an inactive decoy. Though a relatively low sample size was tested, active devices displayed a significant difference in comparison to inactive devices when considering both categories of "interest" and "no interest" (Chi-square; $x^2 = 9.38$, p = 0.002).

Table 4. Summarized count totals of exhibited behavior seen during video recordings for active/inactive devices. Italicized headings were classified as displaying no interest.

	Caribbean reef shark	Lemon shark	Barracuda	Triggerfish
avoid	*1/0*	*0/0*	*0/0*	*0/0*
ignore	*3/10*	*0/2*	*1/1*	*12/25*
close pass	6/2	0/0	0/0	2/20
bump	5/1	0/0	0/0	1/16
bite	1/0	0/0	0/0	0/0

V. Conclusion

The design and deployment of deterrents used in this project was shown to ensure the devices functioned reliably, could easily show the presence of bite marks, and incorporate a coating that is easy to re-apply in the field.

In regards to the effectiveness of the devices as shark bycatch deterrents, the results were not as positive as they were during previous trials within both demersal and pelagic fisheries. Results of the demersal trials showed a slightly lower catch rate in active decoys when compared to inactive and blank gangions, however this was not shown to be statistically significant.

Additional field trials in which pelagic longlines were configured similar to that of commercial fishing gear in shark abundant waters of Eleuthera Island produced similar results. During the pelagic field trials there was a slightly higher catch rate in gangions with active devices when compared to gangions with inactive devices, however none of the results had statistical significance.

Though a relatively small sample size, the categorical data captured with the behavioral trials provide some optimism for this bycatch reduction technique. Results displayed a significant difference when comparing the interest of sharks between active and inactive devices. Why this does not translate into actual fishing conditions as shown in this project merits further investigation.

The use of electropositive metals and electromagnetic deterrents to reduce elasmobranch bycatch in literature across various species appears inconsistent and shares the same uncertainty in data as we found here. Assuming the use of magnets and other electromagnetic technqiues were found to be promising as a bycatch reduction technique for elasmobranchs, they would likely be applicable within certain species, environmental and biological conditions, and fisheries (Porsmuguer et al., 2015; O'Connell et al., 2014; Grant et al., 2018).

Recently, other findings in elasmobranch bycatch have shown significant results and may play a role in studies such as ours. This includes bycatch reduction techniques such as reducing soak time. Foster et al. (2017) identified a difference in the mean capture time of sharks and red grouper under different soak times, suggesting that a reduction in soak time may be a worthwhile approach to reducing bycatch of sharks in some fisheries.

Outreach and Education

We have begun sharing our field work publicly. A blog on the pelagic trials can be viewed on our website (link below). Information on this research was communicated via many social media outlets on the New England Aquarium, Anderson Cabot Center and Cape Eleuthera Institute accounts including Instagram, Facebook, Twitter and Vimeo. A short video clip created by CEI was also created to share with their students.

NEAq - ACCOL Blog:
https://www.andersoncabotcenterforoceanlife.org/blog/field-testing-an-electronic-decoy-to-decrease-elasmobranch-bycatch-in-longline-fisheries/

CEI - Summary video
https://vimeo.com/294872547

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Appendix A – Field log sheet for each pelagic longline deployed

Set Number	BD_		New England Aquarium / Anderson Cabot Center for Ocean Life at the New England Aquarium / Cape Eleuthera Institute
Date		Recorder	

Longline Data

Deploy Start	Lat	Long	Deploy Start (Time)	
Deploy End	Lat	Long	Deploy End (Time)	
Retrieve Start	Lat	Long	Retrieve Start (Time)	
Retrieve End	Lat	Long	Retrieve End (Time)	
# of Hooks		Water Temp	Wind Direction and	

Biological Data

Species	#	PCL	FL	TL	Sex	Stage	Mating Scares	Dart#	Hook P	Bite?	White/Green	Release Cond	DNA/SI/Epibiont	Time Landed

DNA: Y-Yes, N-No	Hook Placement: CJ-Corner Jaw, G-Gut, T-Throat, SP-Soft Pallet, J-Jaw	Stage: IM-Immature, M-Mature	
Condition of Release: 1-Good, 2-Fair, 3-Poor, 4-Very Poor, 5-Dead	Gangion Type: Control / BD Off / BD On	S.I?: Yes / No	Epibiont?: Yes/No

Hauling Data: Device, Hook, Bait

White Deterrent, Bait On, No Bite	Green Deterrent, Bait On, No Bite
White Deterrent, Bait On, Bite	Green Deterrent, Bait On, Bite
White Deterrent, Bait Off, No Bite	Green Deterrent, Bait Off, No Bite
White Deterrent, Bait Off, Bite	Green Deterrent, Bait Off, Bite

**Tally the number of deterrents with bite marks for each gangion type