Gulf of Maine Research Institute

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Final Report

Submitted to the Northeast Consortium

Project Title	**Do rare earth metals deter spiny dogfish? A feasibility study on the use of Mischmetal to reduce dogfish catches in hook and lobster gear in Gulf of Maine.**	
Contract #	PZ07087	
Contracted	Gulf of Maine Research Institute	
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1. Abstract

Catches of spiny dogfish, *Squalus acanthias*, are considered to be unacceptably high by many inshore fishermen (commercial and recreational) during the summer and fall months in the Gulf of Maine. However, biologically, these species are considered vulnerable to overexploitation. Despite the range of views and opinions about dogfish, there is a strong common interest for finding a practical and economic dogfish deterrent for application in various fishing gears. Through an industry-science collaboration, a total of six research trips were executed during August and September 2007. Triangular slices of the rare-earth metal cerium/lanthanide alloy (or 'mischmetal') were incorporated into three commercial gear types (longlines, rod and reel gear and lobster gear) to assess the material's effectiveness at reducing dogfish catches. For each gear type, catches with mischmetal (treatment) were compared with a 'control' (i.e. no mischmetal present). *In situ* underwater video footage was captured to aid the interpretation of data. Field observations were inconclusive for the lobster gear since the traps caught no dogfish, regardless of treatment. For both hook gears, a slight reduction in dogfish catch was recorded (~6% for rod and reel, and ~5-10% for longline), but these results were not statistically significant. One complicating factor for the study was the high rate of mischmetal dissolution, which led to the rapid disintegration of the mischmetal slices in all gears. *In situ* video footage verified persistent dogfish feeding behavior on bait regardless of mischmetal presence and when one dogfish pursued the bait, the scene would generally escalate to frenzied feeding by multiple dogfish. Overall, there is little evidence to suggest that mischmetal has the potential to reduce the catch of dogfish in either commercial or recreational gear types in the Gulf of Maine.

2. Introduction

Spiny dogfish, *Squalus acanthias*, is generally considered to be a pest species. Its lack of popularity is in part due to its low marketability on the East Coast, but also due to the damage it causes to fishing nets when caught. Unfortunately, at certain times of year fishermen struggle to avoid dogfish and their schooling tendency means that they can easily dominate the catch, both commercial and recreational. Despite its apparent high abundance, *S. acanthias* is considered highly sensitive to overfishing owing to its K-selection characteristics of slow growth, late maturation (~6 years in males and ~12 years in females), high maximum age (35-40 years) and low natural mortality (M=0.09) (Sosebee, 2000).

Estimated annual commercial discards for the period of 1989-2005 range from 7,400 to 47,300 mt (NEFSC, 2006). While the 2007 dogfish stock assessment indicates an increase in biomass, the stock has not rebuilt to its target spawning biomass and poor pup recruitment is a continued concern with projected declines in population for 2010 (NEFSC, 2006). The current study was developed with the anticipation of developing a technique to reduce the unwanted catch of dogfish. If successful, this work would not only reduce dogfish discard mortality, but would also cause less frustration for the fishing industry since they would spend less time removing dogfish from their gear.

Elasmobranch species, including spiny dogfish, are able to detect and utilize magnetic fields through electroreception: an acute sensitivity to electrical fields. Electrical signals from the environment are transmitted via a series of pores (ampullae of Lorenzini) dispersed over the head. While electroreception is often used by elasmobranchs for navigation and prey location, research has also revealed that in the dogfish, *Scyliorhinus canicula*, strong magnetic fields (1000µV/m) repel the species, while E-fields ranging from 0.5µV/m - 10µV/m (which are comparable to intensities transmitted by prey species) are an attractant (CMACS, 2003). In an attempt to capitalize upon the extremely sensitive nature of elasmobranch electroreceptors, various types of electro-repellant have been designed. Deterrents currently focus on strong magnetic fields (Stroud, 2005), electrochemical reactions of rare earth metal alloys (Stroud, 2005) and also direct electric-field generation (Robinson, 2007; SharkShield, 2007).

At the ICES International Symposium on Fishing Technology in the 21st Century (Integrating Fishing and Ecosystem Conservation), the use of magnets was highlighted as a novel and effective approach to reducing bycatch of shark species on longline gears and this innovation received the top prize for the 2005 WWF Smart Gear Competition. The current study's research idea grew from this finding. However, subsequent laboratory studies on the Pacific Coast (Stoner & Kaimmer, 2008) showed that spiny dogfish "flinched" at rare earth magnets (NdFeB), but showed much stronger aversion and reduced consumption rates in response to 'mischmetal' (lanthanide/cerium alloy), a non-magnetic rare earth metal. The electropositive cerium/lanthanide alloy reacts in salt water, releasing electrons which are then attracted to the electronegative skin of the shark, inducing an electric field which is thought to deter the animal (Stoner & Kaimmer, 2008). The proposed study had planned to incorporate rare earth magnets into fishing gear to test in waters with high abundances of dogfish. However, on learning about Stoner and Kaimmer's work during the current study's planning stages, it was decided to change the focus from magnets to mischmetal for two reasons: 1) the aversive reaction and reduced bait consumption observed in dogfish during lab studies was stronger for mischmetal (Stoner & Kaimmer, 2008), and 2) the use of non-magnetic materials which would not fuse together and tangle the gear (particularly dangerous with hooks present) was likely to be more practical and thus, preferred by the fishing industry.

3. Project objectives and scientific hypotheses

This report refers to the Scope of Work contracted by the Northeast Consortium to undertake an industry-science study to assess the potential to reduce the catch of spiny dogfish in hook and lobster gears, using a rare earth metal alloy. Core goals and deliverables include:

- Work collaboratively with industry partners to assess the potential for cerium-lanthanide alloy to deter dogfish from hook and lobster gear.
- Undertake dedicated research trips during the summer of 2007 to complete the field work.
- Collect biological data (size, sex, spawning) from the catch to compare selectivity of each gear type when fished under the same environmental conditions.
- Analyze data and provide feedback to industry, science and management via presentations, a web site and/or final reports.
- Provide NEC with the raw data upon completion of the project.

4. Participants

The Primary Investigator responsible for the project design, implementation, analysis and presentation was Dr. Shelly Tallack (GMRI). Graham McKay (GMRI) played a substantial role as research technician preparing gear, collecting data at sea and entering the data. Christopher Andrews, Eric Tomazin and Eric O'Connor are the three industry partners who collaborated with GMRI from FV Survivor (Permit # 240736, Hull # 619131, Portland, ME).

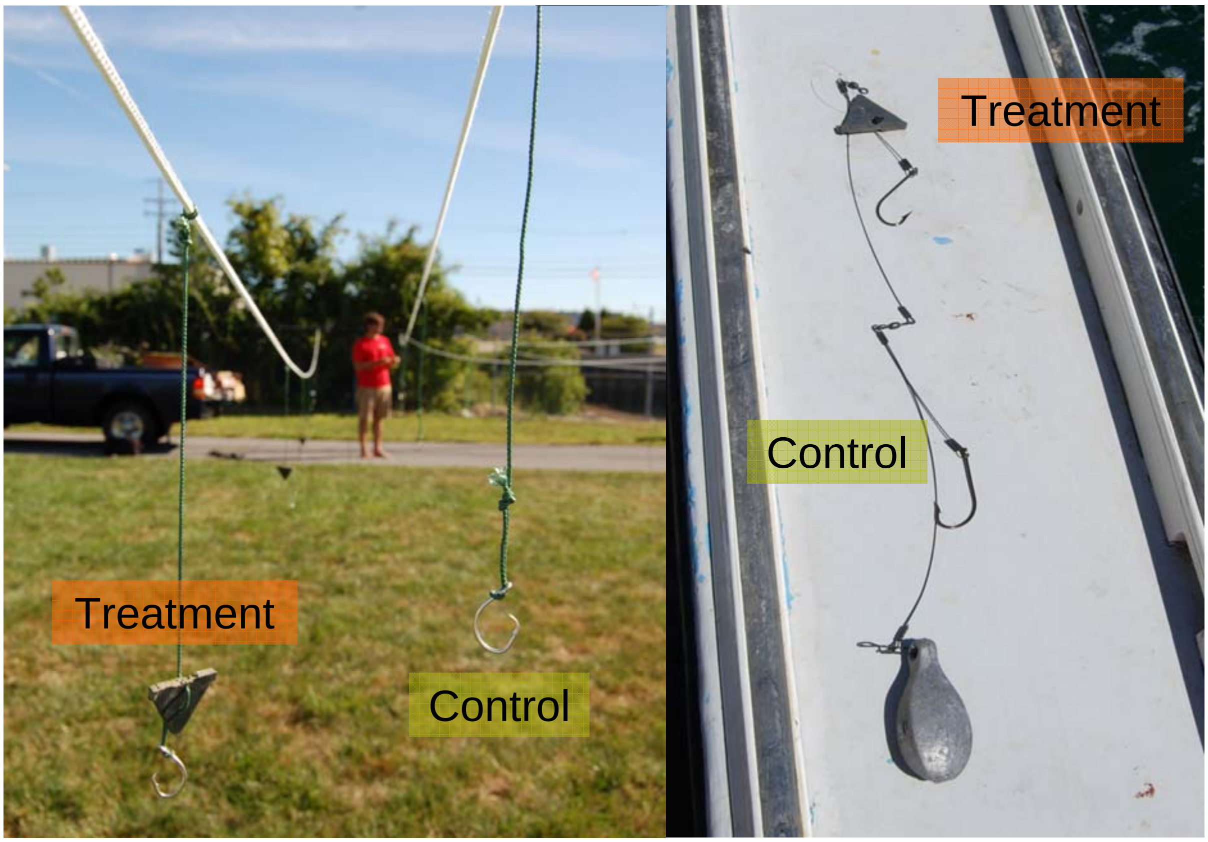
During the course of this research, GMRI also collaborated with John Mandelman (New England Aquarium), Allan Stoner (Alaska Fisheries Science Center,) Steve Kaimmer (International Pacific Halibut Commission,) and Eric Stroud (Shark Defense).

5. Methods

In total, six dogfish research trips were undertaken, during August and September of 2007. The commercial lobster vessel, *FV Survivor* (13 m), was utilized as the research platform, which afforded extensive deck space and winch gear for efficient operation of the longline and jig gear.

To prepare for deployment on fishing gear, industry standard trapezoidal mischmetal ingots (HEFA Rare Earth Canada Ltd., Richmond, BC, Canada) measuring ~45 mm x ~45 mm x ~45 mm x ~130 mm were sliced into pieces measuring ~45 mm on each side, by ~5 mm thickness. For attachment to fishing gear, ~2 mm holes were drilled at ~5 mm up from the bottom edge and ~5 mm down from the top corner of each mischmetal slice; the slices were then attached to jigging gear using 2 mm zip ties, and to the longline gear by threading the twine leaders through the drilled holes. On both jigging gear and longline gear, the mischmetal was secured ~10 cm up from the hook and bait (Figure 1).

Figure 1: The attachment of mischmetal slices on longline (left) and jig gear (right); the mischmetal was placed ~10 cm up from the hook and bait.



A total of four (100 hook) longlines were built, each consisting of 50 control hooks (just hook and bait) and 50 treatment hooks (hook, bait and mischmetal). The hooks were arranged along the longline in alternating groups of 10 (i.e. 10 control, 10 treatment, etc.)as a means of efficiently verifying that equal numbers of treatment and control hooks were attached to each longline; this approach also enabled effective gear maintenance in the field where deck space is limited. Four longlines with 100 hooks were set on trips 1-3; at this time one longline was lost overboard. On trips 4-6, three longlines were set, two with 100 hooks each and one with 140 hooks. The additional hooks were added to make up for the lost longline, but mischmetal availability limited this increase to 40 hooks. In total, during six sampling days 21 longlines were set, totaling 2080 hooks (50% control and 50% treatment). All longlines were set at similar depths on each day (~60-100 m), in close proximity to one another to ensure similar fishing conditions between each set. Soak times ranged from 1-2 hours.

Jigging using rod and reel took place on each of the six vessel days, to test the effectiveness of mischmetal at deterring dogfish from recreational hook gear. Jigging was undertaken during the soak-time for each longline. Each rod and reel (n=3) was set up with two hooks (2-4 hooks is typical while fishing for groundfish), with one treatment and one control hook; 73 jig-lines were set, comprising a total of 146 baited hooks (50% control (C) and 50% treatment (T)).

All animals caught by both jig and longline gear were noted for: hook type (i.e. treatment or control), bait presence, species, size (total length, TL) and sex where possible. The catch was then released.

In addition, wire lobster gear was deployed on two days. Two strings were set for 24 hour soak times, each string comprising 16 traps in total. Control (n=8) and treatment (n=8) traps were alternated along each string. All traps were baited, and the treatment traps had three pieces of mischmetal attached around the trap entries. The total catch was counted and quantified by species; only fish species were measured, and where possible, such as in the case with elasmobranchs, sexed.

5.1.1 ***In situ video footage***

In situ video footage was obtained through collaboration with the University of New Hampshire's Atlantic Marine Aquaculture Center (Durham, NH). A PVC camera frame was deployed to ~20 m depth, with control and treatment baits (hookless). The camera had a live feed umbilical cord which enabled bait monitoring and camera panning to capture observations of dogfish approaching and removing the baits. For this part of the study, no hooks were used; the bait was simply secured by twine and control and treatment conditions were replicated. This footage was reviewed to supplement both field and laboratory trials, for better understanding of how dogfish react to the mischmetal baits (versus the control baits), thereby helping interpretation of dogfish catch rates in the longline and jig data.

5.1.2 ***Mischmetal dissolution rate***

To assess the rate of dissolution for a typical slice of mischmetal used during both field and laboratory experiments, we used time-lapse photography. One slice of mischmetal was suspended by nylon in seawater (collected at ambient temperature of ~10°C, which warmed to room temperature (~18°C) during the course of the experiment) and a Nikon D40x 10.1 megapixel camera was set on a tripod and was programmed to take one frame every 15 minutes for a total of 48 hours. A sub-sample of these images (frames at 60 minute intervals until the mischmetal dissolved off the nylon) was analyzed in MATLAB. A tailor-made program was written to calculate the 2D area (mm^2) of mischmetal remaining in each hourly interval image; from these data, an approximate dissolution rate (%) was estimated.

5.2 Equipment design and equipment purchase

GMRI consulted with John Mandelman (NEAQ), Al Stoner and Steve Kaimmer on the design of the alloys, how to handle them (the alloy filings are highly flammable) and rigging in the longline gear. Alloys were purchased from HEFA Rare Earth Canada Co. Ltd. (Richmond, BC) during June/July 2007; the alloy ingots were cut by Sawtech Ltd, (Massachusetts) during July and August 2007. Graham and Shelly completed gear preparations in early August 2007.

5.3 *Project timeline*

Feb 07: LOA applications submitted and approved; IACUC application submitted.

Apr 07: NEC contract received.

Jun 07: NEPA review approved, IACUC application approved, vessel contracting, experiment planning, gear purchase, and mischmetal purchase/cutting.

Aug 07: Gear preparation.

Sep 07: Dedicated research trips.

Oct-Nov 07: Initial data evaluation and analysis; preliminary presentations at invited seminars.

Dec 07: Presentation of data at NEC participants meeting.

Feb 08 Presentation as part of a GMRI public lecture on 'Dogfish: Fishermen's Best Pest?'

Apr 08: Presentation at the NOAA Shark Bycatch Mitigation Workshop (Boston). GMRI dogfish mischmetal website uploaded.

Jul-Sep 08: Final evaluation, analysis, and manuscript preparation.

Sep 08: Final report writing.

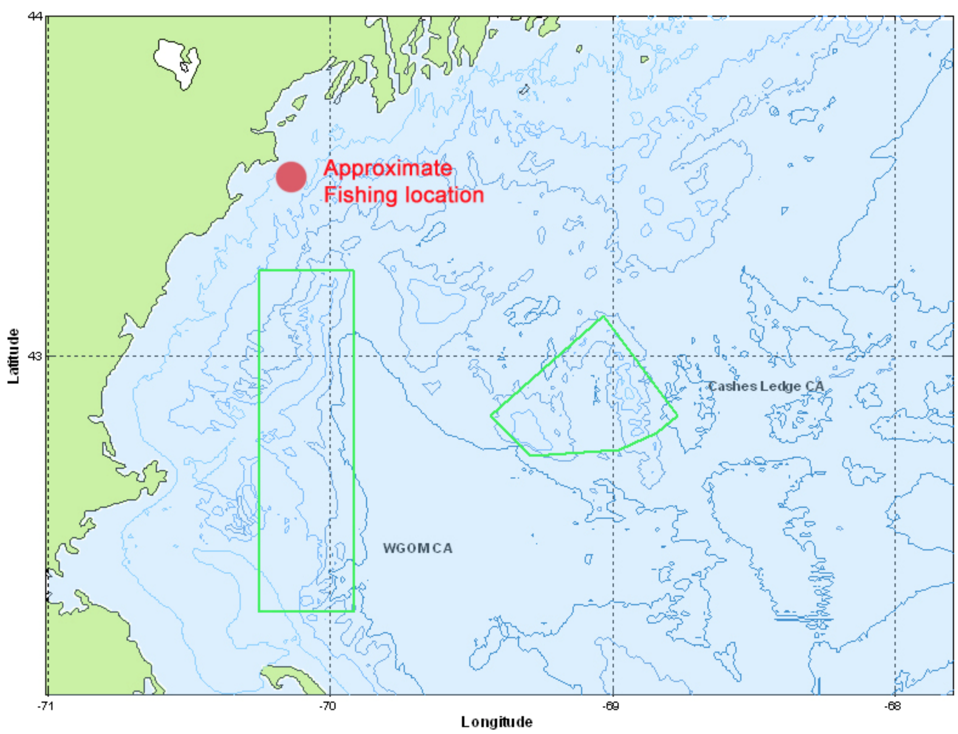
5.4 *Data analysis*

Data analysis was undertaken by GMRI from October 2007 onwards. Analyses were performed using a combination of SPSS 15.0 software (SPSS, Inc, Chicago, IL), MATLAB (The MathWorks, Inc., Natick, MA) and Grapher 6 (Golden Software, Inc., Golden, CO). The categorical frequency data recorded for dogfish caught by control versus mischmetal hooks was analyzed using Chi-square analysis.

5.5 *Study areas*

The study location was in inshore Maine waters (~43°33'N, 70°15'E, Figure 2). This study area was selected for its accessibility for day trip research, anticipated abundance of dogfish, and relative suitability for avoiding conflicting fishing gears (e.g. trawling, gillnetting and trap fishing).

Figure 2: Approximate study location for mischmetal trials.



5.6 Building on prior research

A number of studies have been undertaken in the past 24 months or so involving various forms of rare-earth metal alloys (Brill, 2008; Wang *et al.*, 2008). However, when the proposal for the current study was submitted, no deterrent work had been undertaken on spiny dogfish.

The ICES International Symposium on Fishing Technology in the 21st Century (Integrating Fishing and Ecosystem Conservation) (Boston, October 2006) gave rise to the research idea for both Tallack, and Kaimmer (IPHC). Kaimmer was able to quickly fund research on the west coast in collaboration with Allan Stoner (AFSC) and by the time the current study received its contract and was preparing to purchase the originally planned rare earth metal magnets, communications with Kaimmer and Stoner indicated that the lanthanide/cerium rare-earth metal alloy (mischmetal) caused a stronger aversive response in laboratory settings (Stoner & Kaimmer, 2008). Thus, the current study was re-designed, substituting the magnets with mischmetal.

GMRI's assessments of mischmetal in actual fishing gear were mirrored by IPHC and the AFSC in the fall of 2007, after this study's fieldwork was completed.

5.7 Limitations in project design/methodology

Before finalizing the experimental design, GMRI worked collaboratively with a number of scientists looking at a similar questions for other shark species (e.g. Stroud, SharkDefense) but also for spiny dogfish specifically, e.g. Mandelman (NEAQ) on the East coast and Stoner and Kaimmer on the West coast. A number of conference calls and emails eventuated to ensure that all studies would have comparable experimental designs in terms of size and composition of materials used; this was important to enable the comparison of findings from both lab and field studies on both East and West coasts upon study completions. As such, we believe our study design was appropriate; furthermore, GMRI took advantage of additional research opportunities as they became available (e.g. use of an underwater camera with UNH) to maximize the current study's data collection.

5.8 Changes from the original scope of work / unexpected difficulties

The most notable change from the originally approved scope of work was the decision to move away from assessing magnets to instead assessing the cerium/lanthanide alloy. However, this was an appropriate decision to make based on the results being obtained on the West coast by Kaimmer and Stoner (2008). The NEC was notified of the new findings and consequently approved the modification to the study before research materials were purchased. Our research then proceeded without additional modification.

5.8.1 Low sample numbers

Dogfish research trips were undertaken as planned, during August and September of 2007. Despite dogfish typically be predominant in inshore waters during this time of year, this year was a little different with more dogfish being reported from more offshore locations (e.g. Cashes Ledge) and for two trips, very few dogfish were caught. The poor catch of dogfish in the early trips led to disappointing sample numbers, despite setting the planned number of gear sets. Later trips were more successful in finding dogfish.

5.8.2 Dissolution rates of alloys

When the electropositive cerium/lanthanide alloys are in contact with salt water, the resulting hydrolysis means that the alloys are disintegrating and unfortunately, the rate of dissolution proved to be very rapid. As such, over the course of the study, the triangular slices of alloy disintegrated at an alarming rate (Figure 3).

Over time, this meant that the alloys attached to the gear practically disappeared (particularly in the lobster gear where soak times were longer). The mischmetal deterioration meant that GMRI was able to undertake just 6 of the 7 planned research trips. However, GMRI was able to carry out an additional sea day on the UNH vessel which tends the cod farming cages; during this trip, it was possible to obtain video footage on how dogfish are interacting with the alloys underwater. The video camera was lowered to the sea floor in ~10 m water. Equipped with live feed and panning capacity, the video camera was able to capture multiple dogfish/bait interactions.

Figure 3: Dissolution effects in the alloys: a fresh piece of alloy (A) and a piece of alloy showing dramatic disintegration (B).

A) 

B) 

6. Data

GMRI designed four datasheets (Annex 1) and an associated database for the collection and management of this study's data. These data were submitted to the Northeast Consortium Fisheries & Ocean Database in September 2008. Data collected as part of this project are outlined below.

Biology

- Fish length (tip of snout to tip of caudal fin)
- Sex (male/female)

Experiment related

- Presence of hook and/or bait?
- Alloy hook or control hook?
- **Stamina Index (1-4):**
  1. Alive, strong, much resistance to being handled
  2. Alive, but moderate resistance to being handled
  3. Alive, but weak, showing little resistance to being handled
  4. Dead
- **Comments** – anything notable about that individual fish

7. Results and conclusions

7.1 Research trips and sample numbers

In total, six dogfish research trips were undertaken, during August and September of 2007.

7.1.1 ***Jig gear***

Since jigging was frequently interrupted by the need to set or haul longlines, the total catch from jig gear amounted to just 32 animals. The jig catch was dominated by dogfish (93.8%, n = 30), with redfish, *Sebastes fasciatus* (3.1%, n = 1) and sea raven, *Hemitripterus americanus* (3.1%, n = 1) being the only other species caught. With so few animals caught by jig gear collectively, analysis by trip for jig data could not be analyzed statistically, and will not be presented. However, of the pooled dogfish caught by jig, most were female (65%) ranging from 73-94 cm total length, with males ranging from 69-81 cm. The total number of dogfish caught with mischmetal present (n = 14) and absent (n = 16) was virtually identical.

7.1.2 ***Longline***

The control and mischmetal hooks were attached to the longlines in groups of 10. Catch data pooled across trips gave loose indication that hooks closest to each end of the line may catch fewer dogfish than hooks in the middle section (Figure 5). However, this did not likely bias the results because experimental (mischmetal) and control hooks were evenly distributed at either terminus of each longline, and thus both treatments had an equal probability of catching dogfish.

Dogfish catch rates and thus sample sizes varied between trips (Table 1); sample sizes were low in the first two trips, but subsequent trips, aside from trip 4, saw a substantial increase. The total catch amounted to 472 animals, largely dominated by dogfish (98.5%, n = 465), with haddock, *Melanogrammus aeglefinus* (0.8%, n = 4) and sea raven (0.6%, n = 3) being the only other species caught (Table 1). The dogfish catch per unit of effort (cpue, standardized to 100 hooks) ranged from 0.3 to 57.0 across all trips, with an average cpue of 22.4 dogfish per 100 hooks for the entire study (Table 1).

The longline dogfish catch was predominantly male (75%) ranging from 65-87 cm total length, with females ranging from 68-97 cm. Analysis of Variance (ANOVA) applied to fish lengths by treatment showed that the presence or absence of mischmetal did not have a significant impact on the size of dogfish caught; this is also evident in the size-frequency distributions for longline gear (Figure 4).

The relative effectiveness of mischmetal on each longline set varied considerably in the early trips when sample sizes were low (Figure 6). Consequently, initial statistical analysis on differences in dogfish catch rates between control and mischmetal hooks considered only longline data where the catch exceeded 40 dogfish. These data showed that fewer (~5-10%) dogfish were caught on mischmetal hooks than on control hooks for five out of eight longlines; however, chi-square analysis confirmed that these differences were not significant (χ^2 = 1.510, df = 7, p = 0.982). When looking at the effectiveness of mischmetal across all longline hauls, treatment hooks caught 4.95% fewer dogfish overall; however, chi-square analysis (data pooled for 10 longlines with <5 observations per treatment) again confirmed no significant difference between control and mischmetal hooks (χ^2 = 4.60, df = 10, p = 0.917).

This study faced one major practical challenge: mischmetal dissolution. Over the course of the field experiment (six vessel days, across a ten-day window) the deterioration of the mischmetal slices was considerable (Figure 7); some slices were barely present while others had dissolved away completely.

Table 1: The catch composition from longline gear, categorized by species and the experimental condition, i.e. absence (C = control) or presence of mischmetal (T = treatment). CPUE (for dogfish only) is standardized for lines of 100 hooks.

	Species							
	Haddock		Sea raven		Dogfish			
Control (C), Treatment (T)	C	T	C	T	C	T	Total	Total cpue (100 hks)
Trip 1			1		19	17	**36**	9.0
Trip 2	1			1	6	2	**8**	2.0
Trip 3	1				59	59	**118**	39.3
Trip 4					1	0	**1**	0.3
Trip 5	2				69	62	**131**	38.5
Trip 6			1		90	81	**171**	57.0
Total	**4**	**0**	**2**	**1**	**244**	**221**	**465**	**22.4**

Figure 4: Standardized size frequency for male and female dogfish caught by longline on both control (no mischmetal present) and treatment (mischmetal present) hooks.

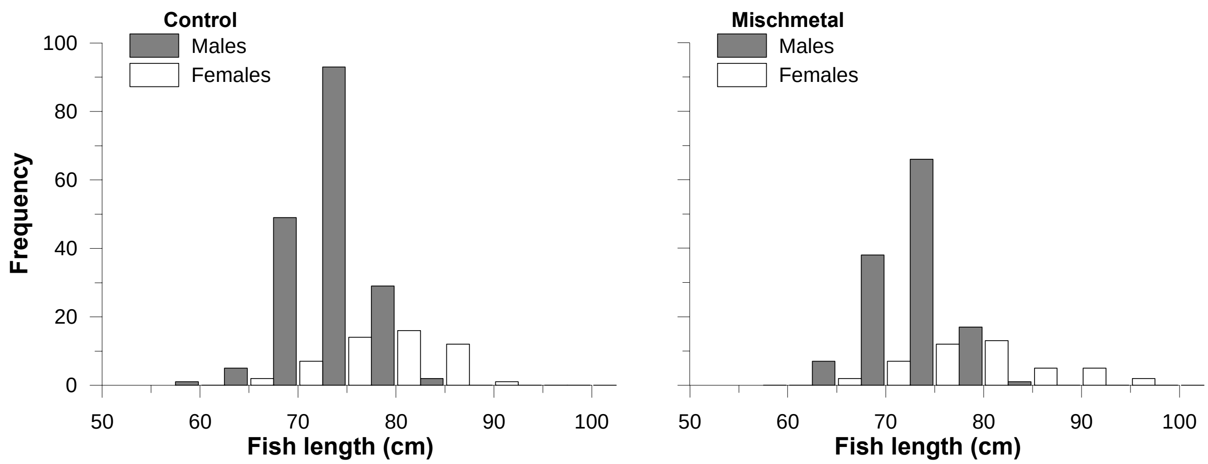


Figure 5: The relative performance of each sequential set of 10 hooks. Hooks nearest each end show a drop-off in both total number of dogfish caught and the average number of dogfish caught (●).

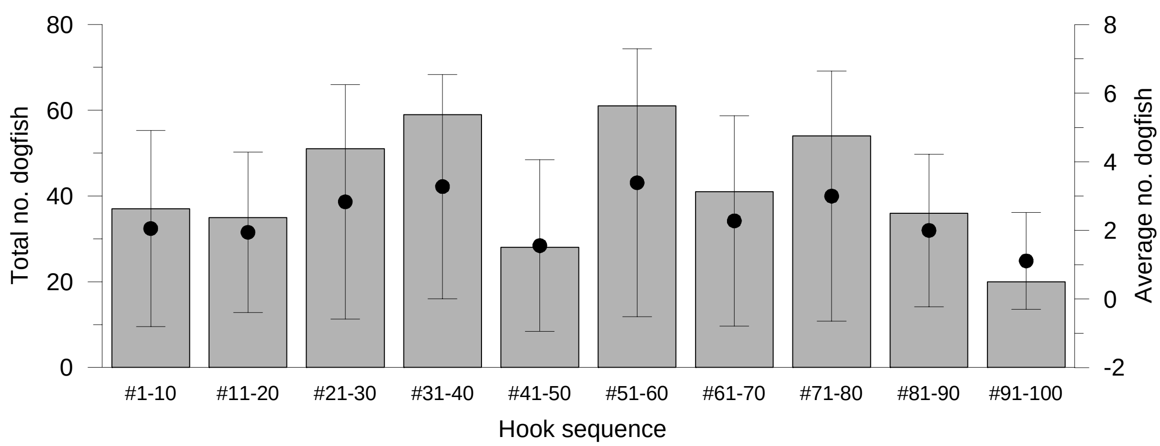


Figure 6: The relative consistency in the relationship between sample size per longline and the difference (%) in the number of dogfish caught by control hooks versus mischmetal hooks. Dogfish catches >40 yielded a mean of reduction in catch of 3.8% (SD = 6.36) while dogfish catches <40 showed a mean reduction of 18.9%, but with SD = 59.7.

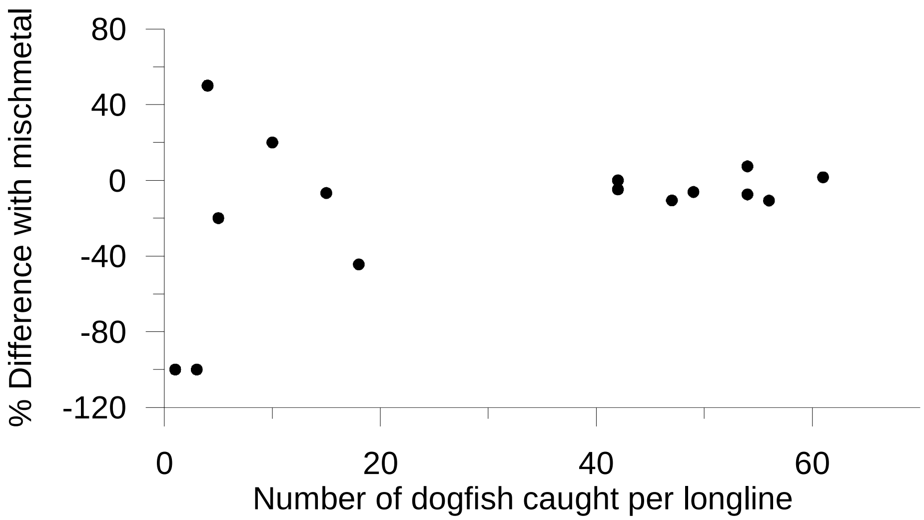
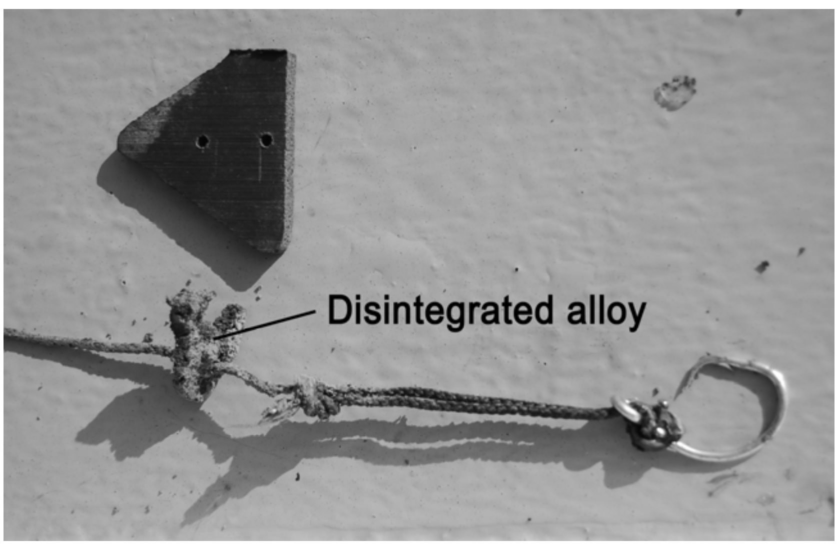


Figure 7: A new, un-used slice of mischmetal (top), compared with the dissolved remainder recorded on Trip 3, i.e. after just three longline usages (bottom).



7.1.3 ***Lobster gear***

The species composition of the catch from these 32 traps consisted of Jonah crab, *Cancer borealis* (n=47), lobster, *Hommarus americanus* (n=16), and sea raven (n=3). No dogfish were caught. The trap studies were discontinued, because dissolution of the mischmetal was so extensive that many mischmetal slices disappeared and those which remained were so small that their effectiveness was doubted. There is no evidence that the mischmetal was responsible for deterring dogfish from the traps, since no dogfish were caught by the control traps either.

7.1.4 ***In situ video***

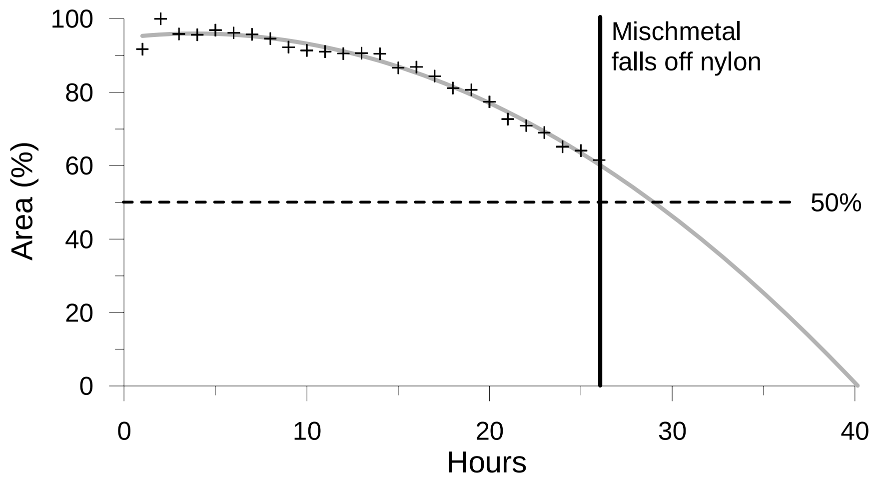
A total of ~2 hours of *in situ* video footage was recorded. A qualitative assessment showed that responses of dogfish towards the bait with mischmetal were essentially no different than those towards bait without. One instance of right-angled change in direction on approach to the mischmetal was observed, and this was considered to be aversive behavior. However, all baits with mischmetal attached were consumed (Figure 8). Furthermore, the activity of one dogfish feeding on the bait (both control and treatment) often drew in numerous other dogfish (up to ~10) and bouts of more aggressive feeding would ensue.

Figure 8: A sample frame from underwater footage of dogfish feeding on baits with mischmetal present.

7.1.5 ***Dissolution***

Laboratory-based dissolution studies confirmed that the cerium/lanthanide mischmetal dissolves at a fast rate when submerged in saltwater of ~10-18 °C. Estimates of the dissolution rate (%) were derived from image analysis on time-lapse photography of a submerged piece of mischmetal (Figure 3). A total of 26 hours were captured before the mischmetal dissolved off the nylon and sunk into the precipitate where it continued to dissolve and bubble away; since the mischmetal became hidden at this point, additional image analysis was not possible and thus, the data is limited to 26 hours of submersion. At 26 hours, the 2D surface area of mischmetal had decreased by ~40%. The estimates of percent dissolved during the first 26 hours, indicate that the rate of dissolution speeds up as the slice gets smaller and thinner, though the increase in dissolution could also have been influenced by the seawater gradually warming to room temperature. Thus, by applying polynomial regression analysis to these data to project dissolution beyond 26 hours, it was estimated that a typical slice of mischmetal will be 50% dissolved at ~30 hours and 100% dissolved at ~40 hours (Figure 9) under the condition of continuous contact with saltwater.

Figure 9: Image analysis on hourly time-lapse images shows a fast decrease in the 2D area (%) of a slice of mischmetal submerged in saltwater.



7.1.6 ***Summary***

In the field, three gear types were tested: jig gear, longline gear and lobster gear. Results from both the jig gear and longline gear indicated a slight reduction in the catch rate of dogfish by hooks with mischmetal present versus those without. However, this reduction was very small and in neither gear was the result significant. While the fast dissolution (Stoner & Kaimmer, 2008) of this alloy may have reduced its effectiveness as a deterrent, there is no evidence to suggest that earlier trips (when mischmetal was more intact) deterred dogfish better than later trips (when mischmetal slices were greatly disintegrated). Furthermore, *in situ* video footage supported these data with dogfish showing considerable determination to eat the bait presented, whether guarded by mischmetal or not. The lobster gear caught no dogfish and thus, the effect of mischmetal in lobster gear remains unknown, but based on the findings from hook gear, mischmetal is unlikely to have had a strong effect on the catch of dogfish. Overall, while some evidence of aversive behavior has been observed in laboratory settings (Stoner & Kaimmer, 2008; Tallack & Mandelman, in review), this behavior did not significantly reduce the catch of dogfish in the field assessments.

In the event that dogfish had been significantly repelled by mischmetal, the fishery would have been faced with additional practical and logistical hurdles with regard to this rare earth metal alloy. The hydrolysis resulting from the cerium/lanthanide alloy in saltwater caused extremely rapid dissolution, as evidenced by the dissolution rate analysis and observations from the longline and lobster gear. To minimize dissolution the alloy would need to be stored dry between usages. However, drying off and aridly storing individual pieces of mischmetal between sets would be both cumbersome and impractical and thus, not likely to accepted by industry as good use of time, particularly without overwhelming evidence that mischmetal will completely deter dogfish. The cost of mischmetal (plus a cutting cost) meant that replacing the mischmetal during the course of this study was not possible. Finally, were mischmetal to be used on a large scale by industry, additional questions would likely arise regarding the potential environmental impact of the insoluble hydroxide precipitate resulting from dissolution. Indeed, the safety of individuals working with this material (which produces highly flammable filings during the cutting process) would also be a logistical hurdle to overcome (Stoner & Kaimmer, 2008).

8. Partnerships

GMRI officially partnered with the captain and crew of *FV Survivor*, who enjoyed the research experience and were interested to hear the findings after analysis.

GMRI also partnered opportunistically with John Mandelman from the New England Aquarium (Boston, MA) and the University of New Hampshire's Atlantic Marine Aquaculture Center (Durham, NH). All partnerships were fruitful and productive in terms of finalizing the experimental design, completing research trips, trouble-shooting procedures as needed and obtaining *in situ* video footage of dogfish feeding on baits with and without mischmetal present.

9. Impacts and applications

Findings have been disseminated to both the fishing and science community by taking advantage of a number of opportunities to present the findings at relevant forums (see p.16). We have also made the findings available online, via the GMRI website (http://www.gmri.org/mini/index.asp?ID=19) and GMRI's blog ('Today in the Gulf of Maine', 2 October 2007).

Two Commercial Fishing News articles have focused on this study to date, in September 2007 (see Annex 2) and more recently, the special report on dogfish (May 2008). Overall, with fishermen's general frustration about dogfish bycatch, this project has generated a great level of interest with both commercial and recreational fishermen.

This study's findings were also presented at the *Shark Deterrent and Incidental Capture Workshop* (Boston, April 08). This was a particularly fruitful workshop with representation by most US researchers who are currently working with elasmobranch deterrent/repellant concepts. All presentations were compiled into a technical report, including the findings from this study (Tallack, 2008).

This final report will be distributed to all project participants (pending NEC approval), but may also be of interest to other researchers or fishery managers working specifically with spiny dogfish.

10. Related projects

The findings of the current study led to Shelly Tallack applying to the Mount Desert Island Biological Laboratory for a New Investigator Award. Shelly was successful in obtaining additional limited funds to undertake a collaborative study (with Dr. Steve Kajiura, Florida Atlantic University) in August 2008. This collaboration intended to investigate the comparative olfactory and electroreception senses of captive spiny dogfish. Unfortunately, despite numerous attempts, no olfactory readings were recorded and it is suspected that the sensory system in dogfish which have been stressed and in captivity for a few days-weeks may be severely impaired.

11. Presentations

The first presentation of initial analysis took place in poster format at the Northeast Consortium Project Participants Meeting in December 2007. This topic has been of great interest to many fishermen and as such, we anticipate continuing to present this work in the months to come. Shelly has presented the findings of this study as follows to date:

- Dogfish: Fishermen's best pest? GMRI Presentation at Prout's Neck Yacht Club. Scarborough, ME. August 13 2008.
- *NOAA Technical Workshop on Shark Bycatch Mitigation:* Can rare earth metals reduce the catch of spiny dogfish? Applications in commercial hook gears in the Gulf of Maine. New England Aquarium, Boston, MA. April 11 2008.

- Unwanted dogfish catch: Assessments of dogfish discard mortality and catch reduction. Presentation at the University of New England's Forum on Dogfish, Biddeford, ME, Mar 29 2008.
- Dogfish: Fishermen's best pest? Sea State 2.0: GMRI Public Seminar Series. Gulf of Maine Research Institute, Portland, ME. February 7 2008.
- Can rare earth metals reduce the catch of spiny dogfish in commercial hook gears? Presentation at the NEC Program Participants Meeting, Portsmouth, NH, Dec 6.

12. Student participation

No students were involved in this project.

13. Published reports and papers

Complementary to these NEC development fund field trials, parallel laboratory trials were executed by John Mandelman (NEAQ). Tallack and Mandelman worked to ensure that the two studies were consistent and fully complimentary, and then prepared and submitted a joint manuscript to the ICES Journal of Marine Science (Tallack & Mandelman, in review).

14. Future research

In light of the current study's findings, future research might attempt to measure the relative response of dogfish to stimuli targeting the different senses, in particular, electroreception versus olfaction. Such a study could guide future research and development of repellents which are more likely to trigger a strong aversive behavior in dogfish, with the improved potential for practical application in the Gulf of Maine fishery.

15. Acknowledgements

GMRI would like to thank our funding agency, the Northeast Consortium, for supporting this research concept and enabling the work to be undertaken. Thanks are also extended to John Mandelman, Allan Stoner and Steve Kaimmer for their input during the development of this project.

Special thanks go to our industry partners, Chris Andrews and Eric Tomazin who worked with us for the second time, providing a great research platform in the form of FV Survivor.

Graham McKay is thanked for his role as primary field and data technician; in addition, I would like to thank Eric O'Connor (FV Survivor) and Gregg Caporossi for their assistance in the field.

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17. Images

Graham McKay preparing longlines rigged with and without alloys

Dogfish caught by a mischmetal hook

Baited longline

Large female dogfish caught

Annex 1: Sample datasheets

Data sheet 1: Trip & Location **Vessel:** FV Survivor **Crew:** Christopher Andrews, Eric Tomezin **Date:** ________ **Trip #:** ____

Science crew		**Bait used**		**Moon state**	
Sea State		**Air Temp**		**Wind Speed & Direction**	

Longline information

Line #	Start/Set location				End/Haul location				Water Temp	# Hooks on Line	# Alloys on Line
	Time 24hr, EST	Depth (ft/fm)	Lat	Lon	Time 24hr, EST	Depth (ft/fm)	Lat	Lon	Surface		
1											
2											
3											
4											

Trap information

Line #	Start/Set location				End/Haul location				Water Temp	# Traps sampled	# Traps with alloys
	Time 24hr, EST	Depth (ft/fm)	Lat	Lon	Time 24hr, EST	Depth (ft/fm)	Lat	Lon	Surface		
1											
2											

Jig information

Set #	Start/Set location				End/Haul location				Water Temp	# Rods active	
	Time 24hr, EST	Depth (ft/fm)	Lat	Lon	Time 24hr, EST	Depth (ft/fm)	Lat	Lon	Surface		
1											
2											
3											
4											

Dogfish Alloy trials

Continued? Y / N
Page __ of __

Data sheet 2: Jig Date: _______ Trip #: ___

Set #	Jig #	Alloy? (Y/N)	Species	Sex (M/F)	Length (cm)	Stamina index (0-4)	Comments
	1	A					
		No-A					
	2	A					
		No-A					
	3	A					
		No-A					
	4	A					
		No-A					
	5	A					
		No-A					
	6	A					
		No-A					
	7	A					
		No-A					
	8	A					
		No-A					
	9	A					
		No-A					
	10	A					
		No-A					
	11	A					
		No-A					
	12	A					
		No-A					
	13	A					
		No-A					
	14	A					
		No-A					
	15	A					
		No-A					
	16	A					
		No-A					
	17	A					
		No-A					
	18	A					
		No-A					
	19	A					
		No-A					
	20	A					
		No-A					

Dogfish Alloy trials Continued? Y/N Page __ of __

Data sheet 2: Longline Line #: _____ Date: _______ Trip #: ___

Hook #	Hook absent?	Alloy? (Y/N)	Species	Sex (M/F)	Length (cm)	Stamina index (0-4)	Comments
1							
2							
3							
4							
5							
6							
7							
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40							

Dogfish Alloy trials Continued? Y/N Page __ of __

Data sheet 2: Trap Date: _______ Trip #: ___

Line #	Trap #	Alloy? (Y/N)	Species	Sex (M/F)	Length (cm)	Stamina index (0-4)	Comments

Dogfish Alloy trials

Continued? Y/N Page __ of __

Annex 2: Article from Commercial Fishing News, November 2006

Can mischmetal stave off dogfish hordes?

PORTLAND, ME – Spiny dogfish continue to be a contentious topic of discussion between fishermen who find them to be a nuisance species and the managers who limit their harvest.

Few will dispute that there are plenty of dogfish out there. The problem from the management perspective is that females don't reach maturity until they are anywhere from 12 to 25 years of age. This makes the dogfish particularly vulnerable to overfishing.

So if fishermen are not allowed to harvest the species, there are really only a couple of options – either avoid dogfish altogether through area or seasonal closures or make fishing gear more selective.

Over the past several years, several different cooperative research projects funded by the Northeast Consortium have looked at the dogfish problem. Project goals have generally focused on providing managers with improved discard mortality estimates and more comprehensive descriptions of their habitat use and migration patterns.

In particular, Shelly Tallack of the Gulf of Maine Research Institute has focused her efforts on the dogfish dilemma, collaborating last summer with the Cape Cod Commercial Hook Fishermen's Association and various industry partners.

Currently, Tallack is working with Christopher Andrews and Eric Tomevin of the fishing vessel Survivor out of Portland on a project development award from the Northeast Consortium.

The research partners are taking an unusual approach to avoiding dogfish bycatch in the hook-and-line and lobster pot fisheries by using mischmetal as a deterrent.

Mischmetal is a "mixed metal" alloy that is also called cerium mischmetal. A typical composition includes approximately 50% cerium and 45% lanthanum. Its most common use is in the "flint" ignition device found in most lighters.

Eric Tomevin photo

Shelly Tallack photo

Shelly Tallack and Joe Tomevin remove a hook from a spiny dogfish.

The ampullae of Lorenzini, visible as dark spots on the skin, are small pores around the head of the spiny dogfish that are filled with electrically conductive jelly and used for electroreception.

Fisherman Chris Andrews hauls in a longline set for dogfish discard mortality assessments.

Shelly Tallack photo

Sensory overload

The spiny dogfish and many other shark species possess an organ called the "ampullae of Lorenzini" that detects weak electrical fields at short ranges.

The ampullae of Lorenzini are small pores around the head that form a sensory network. When asked, "Why magnets and metal alloys?", Tallack noted that magnetic devices have been investigated as shark deterrents for several years and specifically cited the work done by SharkDefense LLC researchers.

"It's believed the fields produced by magnets may overload the shark's sensory system and cause the animal to move away from the source," she said.

She added that even the surfing industry has attempted to incorporate magnetic material into surfboards to minimize the chance of a shark attack while people are surfing.

Recently, electropositive metals such as mischmetal have been shown to cause similar shark avoidance behaviors.

Tallack said her interest in shark deterrents was sparked while attending the ICES International Symposium on Fishing Technology in the 21st Century, which was organized by the Northeast Consortium and held in Boston last fall.

The use of magnets was highlighted during the symposium as a novel and effective approach to reduce bycatch of shark species – specifically lemon shark – on hook gear.

This kind of innovation actually received the World Wildlife Foundation's Smart Gear Competition's top prize in 2006.

Nonstick material

Given the controversy surrounding dogfish management, it was not difficult for Tallack to enlist the support and collaboration of commercial fishermen Andrews and Tomevin.

Their original plan was to test the effectiveness of magnets to deter spiny dogfish from hook and lobster gear in Gulf of Maine waters.

However, recent laboratory studies on the Pacific coast revealed that the spiny dogfish had a much stronger aversion to mischmetal than to magnets. In fact, when exposed to the alloy, dogfish either avoided hook gear altogether or consumed less bait when an interaction did occur.

"Since finding an industry feasible deterrent is the aim, it made more sense to use the nonmagnetic materials, which will not stick together and tangle the gear," Tallack said. "This is particularly preferable for gear with hooks."

Bycatch reduction

This study will compliment Tallack's recent dogfish study, also supported by the Northeast Consortium, on discard mortality from hook gears, which was conducted in collaboration with the Cape Cod Commercial Hook Fishermen's Association.

"If you can modify fishing gears to reduce the dogfish bycatch in the first place, then not only are you minimizing negative impacts on the resource, you also are helping fishermen by reducing their interactions with a species that has earned itself a negative reputation as a pest," said Tallack.

Fieldwork

As of late July, the project was in the gear preparation stage.

"We are due to hit the water in late August or early September for field trials and to test the gear," explained Tallack.

A total of seven research trips have been planned and the experimental design will be relatively simple. Three gear types will be compared – manual rod-and-reel, longline, and lobster pots. For each gear type, an alloy-rigged gear will be compared against a control setup with no mischmetal. For hook gear this means rigging the alloy close to the baited hook. On lobster gear, pots will be rigged with the alloy around the trap entries.

A parallel lab study, which is observing the behaviors of spiny and smooth dogfish in response to both magnets and mischmetal, is currently underway under the direction of John Mandelman of the New England Aquarium. Mandelman will be replicating the West Coast lab work to verify their findings on the East Coast populations since biological differences may exist between Pacific and Atlantic dogfish populations.

Tallack, Andrews, and Tomevin plan to share their findings. The two studies will compliment each other because, while behaviors are more readily observed in the lab, practical application to the fishery is best assessed in the field.

Because the study is operating as a Northeast Consortium Research Development Fund project, its budget is very limited, Tallack explained.

"We look on this study as a potential stepping stone to a more in-depth evaluation," she said. "If the findings are favorable and the alloys show good signs of being a deterrent for spiny dogfish, we would like to look into refining the gear design to be as practical and affordable as possible for application to commercial and recreational fisheries."

Tallack said she hopes results will become available towards the end of the year.

Ken La Valley

Ken La Valley is an extension specialist with University of New Hampshire (UNH) Cooperative Extension/New Hampshire Sea Grant who is working to connect commercial fishermen interested in cooperative research with scientists who want to work with fishermen. He encourages anyone with ideas to get in touch.

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