Project 9 Final Report

Efficacy of Electropositive Metals to Reduce Shark Bycatch in Longline Fisheries

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Methods and Results

Before either assay could be initiated, it was first necessary to test the various candidate metals, as well as controls, to determine which was the most suitable to be used for subsequent experiments. Six lanthanide-based electropositive metals (Cerium (Ce), Praseodymium (Pr), Neodymium (Nd), CeLa mischmetal, PrNd mischmetal, and PrNd metal alloy) and two control metals (Lead and stainless steel) were purchased. Local machine shops were identified that could process the metals and all of the metals were machined to a uniform size of 1”x1”x1/4”.

At FAU, electric field measurements were conducted for all of the metals at ambient seawater temperature and salinity. Each metal (n=6 for each of the 8 metals) was dipped into the seawater at 10 distances from the recording electrode (1, 2, 3, 4, 5, 10, 15, 20, 25, and 30cm). The data were analyzed and all of the electropositive metals produced significantly greater electric fields than the control metals at distances ≤ 10cm (Figure 9-1). The electric field magnitude did not differ significant among the six electropositive metals in part because the electropositive metals demonstrated a large amount of variance in their generated electric fields (Figure 9-2).

The metals were also tested using the same assay but at different temperatures and salinities. The metals were tested in full strength seawater at 12 °, 18 °, and 24 °C and were also tested at 24 °C at salinities of 0, 12, 24, and 36ppt. The measured voltage did not vary with temperature (Figure 9-3), but increased dramatically with decreasing salinity (Figure 9-4).

The metals were also tested for dissolution rate in seawater. The mode of action of the metals relies upon oxidative reaction with seawater, which generates an electric field around the metal and results in the release of hydrogen gas and an oxide precipitate. The metal itself is slowly dissolved in the process. Different metals dissolved at different rates and would thus remain effective for greater or lesser periods of time (Figure 9-5).

Based upon output voltage (uVolts/gram), dissolution rate, machinability, and cost, it was decided to conduct subsequent experiments with the lanthanide element Neodymium (Nd) (Figure 6).

Behavioral assays

Behavioral trials were conducted at the Florida Atlantic University marine lab on the lemon shark (*Negaprion brevirostris*) and the bonnethead shark (*Sphyrna tiburo*) which represent two families (Carcharhinidae and Sphyrnidae, respectively) within the Order Carcharhiniformes. Trials were also conducted at the Marine Biological Laboratory in Woods Hole, MA, on the piked dogfish (*Squalus acanthias*) and the smooth dogfish (*Mustelus canis*). Although these are both commonly called dogfish, the piked dogfish is in the Order Squaliformes whereas the smooth dogfish is in the Order Carcharhiniformes, like the species tested from Florida. (For more detailed information on the methods used to conduct the behavioral assays on *S. acanthias* and *M. canis* see Jordan et al 2011, Appendix 8; for methods on *N. brevirostris* and *S. tiburo* see McCutcheon 2012, Appendix 9).

Behavioral assays were performed on several individuals (n=4-13) of each species. Trials consisted of a choice test in which sharks were presented simultaneously with baits affixed to one of four treatments: acrylic, stainless steel, lead, or Neodymium. The treatment samples were in turn affixed to a 1m^2 acrylic plate that enabled the samples to be equidistantly spaced. When the plate was introduced to the tank, it was noted from which treatment the bait was removed. Sharks were tested both individually and in groups of 2-4 conspecifics, because shark density has been observed to influence behavior (Robbins et al 2011). Piked dogfish and lemon sharks were unable to be tested individually. When maintained in isolation, individuals of these species demonstrated stressed swimming behavior and would not feed. Therefore, only group feeding results are available for these two species.

The percentage of bites at each of the treatments for bonnethead and lemon sharks are illustrated in Figure 9-7. For each of the species and treatments, the results of whether the lanthanide metal appears to be effective at reducing bites on bait, are presented in Table 9-1. For the species with large sample sizes (bonnethead n=12, and lemon shark, n=13) the Nd was ineffective at reducing bait removal from the metal. Neodymium appeared to be effective with the smooth dogfish when tested individually only, and the piked dogfish when tested in groups, but for the piked dogfish in particular, the sample size was small with only 4 individuals tested. (For more detailed results on the experiments with Nd see Jordan et al 2011, Appendix 8 and McCutcheon 2012, Appendix 9).

In addition to tests of the efficacy of various metals, experiments were also conducted on the response of the sharks to prey-simulating electric fields. Both the piked dogfish and smooth dogfish demonstrate similar behavioral responses to weak electric fields and their responses are similar to those of other species previously reported in the literature. These experiments confirm the electrosensitive nature of the test species and also confirm that the responses are typical of other shark species (Table 9-2).

Neurophysiological assays

In preparation for these assays, FAU carefully dissected the cranial nerves on representatives of four species, the Atlantic stingray, *Dasyatis sabina*, the bonnethead shark, *Sphyrna tiburo*, the lemon shark, *Negaprion brevirostris*, and the piked dogfish, *Squalus acanthias*. These anatomical familiarization studies were a necessary prerequisite to be able to successfully perform neurosurgery on live animals. FAU has also consulted with a human surgeon and a veterinarian on additional refinements to its techniques.

The neurophysiology experiments became fraught with technical difficulties and satisfactory recordings from the primary afferent neurons or the anterior lateral line nerve (ALLN) were never achieved. Although the principal investigator (SMK) has successfully recorded from the visual, olfactory, and electrosensory systems in the past, the challenging nature of presenting an electrical stimulus to a conductive seawater environment and attempting to record from electrosensory neurons proved to be overwhelming. The principal investigator (SMK) has been granted a sabbatical leave to spend several months starting in March 2013 working with a colleague (Dr Tim Tricas) at the University of Hawaii learning single unit recording techniques. Through this new procedure, we can apply a different neurophysiological recording technique and finally address the efficacy of the lanthanide metals as stimulants of the elasmobranch electrosensory system. This work will be completed at no additional cost to the Consortium and a final report that includes completed neurophysiological assays will be provided by June 2013.

Conclusion

The results of these studies provide additional evidence that sensitivity to electric fields is comparable across elasmobranchs. However, despite that similarity, the behavioral responses to Nd varied between species. Although Nd may be a successful deterrent for some species, other factors were important in determining responses, including hunger level and competition. The results from Jordan et al. (2011) suggest that Nd may be a more successful repellant in fisheries where solitary species are the majority of the bycatch. The results from McCutcheon 2012 were less favorable, suggesting that the sharks were able to detect the voltage produced by the Nd, but they were not deterred by its presence.

Outputs

The results of the behavioral trials with the piked dogfish and smooth dogfish were published in the Journal of Experimental Marine Biology and Ecology. "Behavioral responses to weak electric fields and a lanthanide metal in two shark species", by Laura K. Jordan, John W. Mandelman, Stephen M. Kajiura. These data were also presented as an oral presentation at the joint meeting of the American Society of Ichthyologists and Herpetologists and the American Elasmobranch Society conference in July 2011. All three authors were in attendance and the talk was presented by Laura K. Jordan.

The results of the behavioral trials with the bonnethead and lemon sharks were completed as part of the graduate MS thesis by Sara M. McCutcheon at Florida Atlantic University. The thesis was successfully defended on February 29, 2012 and a draft of the thesis is attached. This work was submitted to the journal Fisheries Research as "Efficacy of lanthanide metals as shark repellents" by Sara McCutcheon and Stephen Kajiura and is currently being revised based on reviewer comments. These data were also presented as an oral presentation by SM McCutcheon at the joint meeting of the American Society of Ichthyologists and Herpetologists and the American Elasmobranch Society conference in August 2012.

Table 9-1. Efficacy of the lanthanide element Neodymium (Nd) at deterring sharks from biting at bait. Sharks were tested either individually or in a group of 2-4. Although the results are mixed, in 4 out of 6 treatments the Nd metal is ineffective at deterring the sharks from removing bait.

Species	**Individual**	**Group**
Lemon shark (n=13)	Not tested	Not effective
Bonnethead shark (n=12)	Not effective	Not effective
Smooth dogfish (n=8)	Effective	Not effective
Piked dogfish (n=4)	Not tested	Effective

Table 9-2. Sensitivity of sharks to prey-simulating, electric stimuli. There was no significant difference in sensitivity between the two species for the median detected e-field, minimum detected e-field, or maximum orientation distance.

Species	**Median detected e-field (nV/cm)**	**Minimum detected e-field (nV/cm)**	**Maximum orientation distance (cm)**
Smooth dogfish (n=8)	28.71	2.78	25.8
Piked dogfish (n=4)	13.61	1.47	30.1

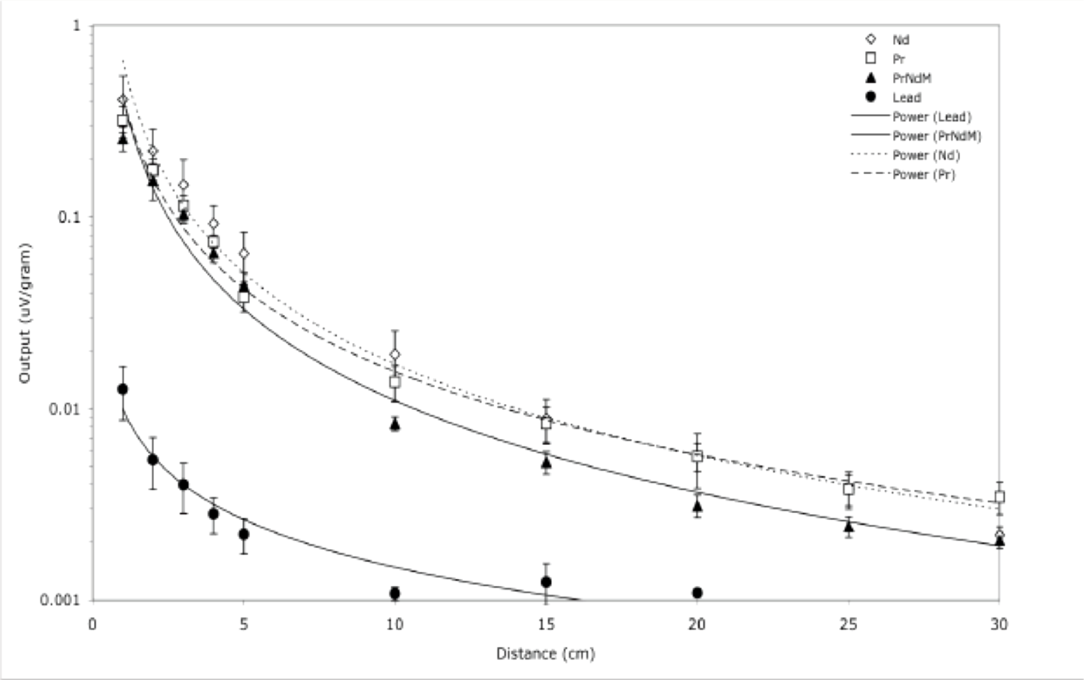

Figure 9-1. Electrical output (uV/gram) decreased with distance from the recording electrode. Similar slopes were obtained for all metals, but the output of the electropositive metals was more than 10x greater than a lead control.

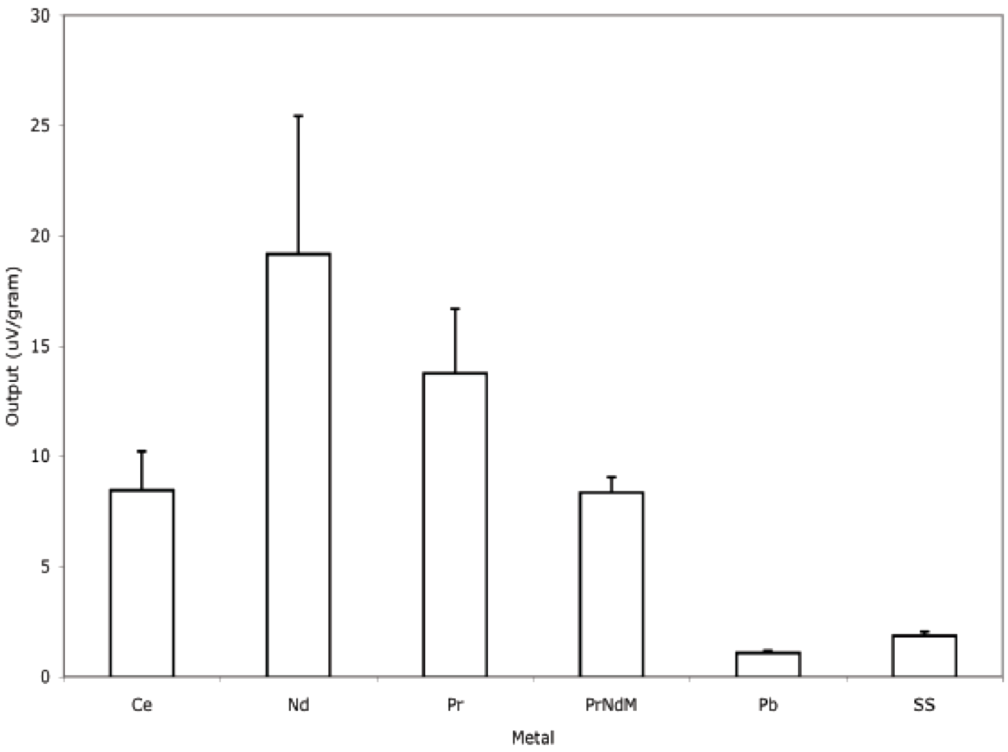

Figure 9-2. Electrical output (uV/gram) compared among electropositive metals and controls at a distance of 10cm from the recording electrode. The electropositive metals all produced a significantly greater electric field than the controls.

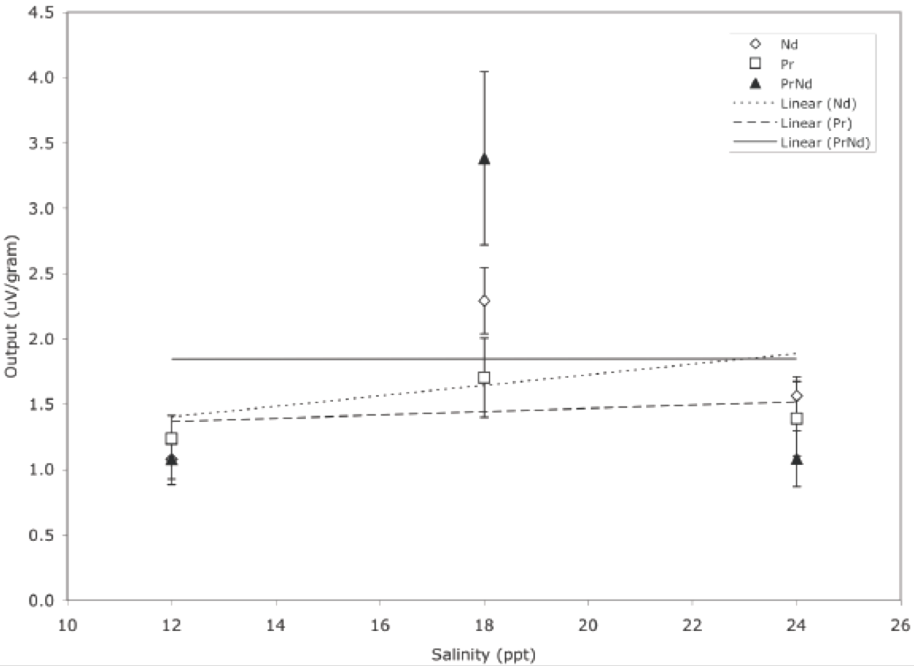

Figure 9-3. Electrical output (uV/gram) did not vary predictably with temperature over the tested range.

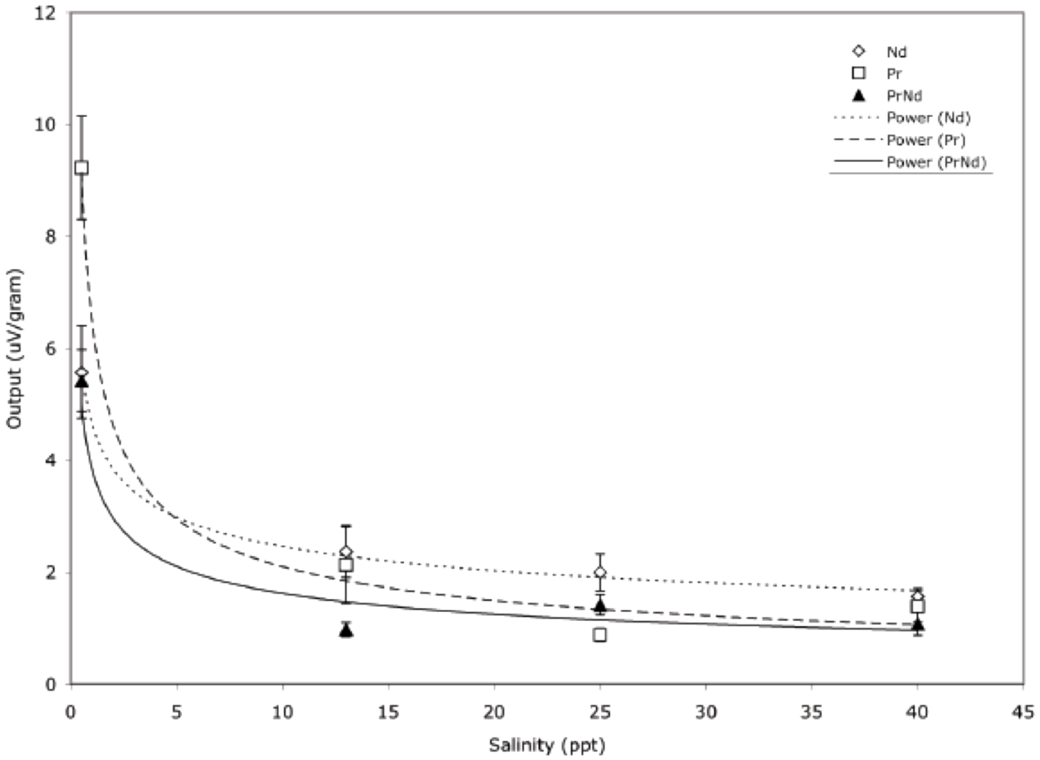

Figure 9-4. Electrical output (uV/gram) decreased with increasing salinity due to the grounding effect of the electrolytic seawater.

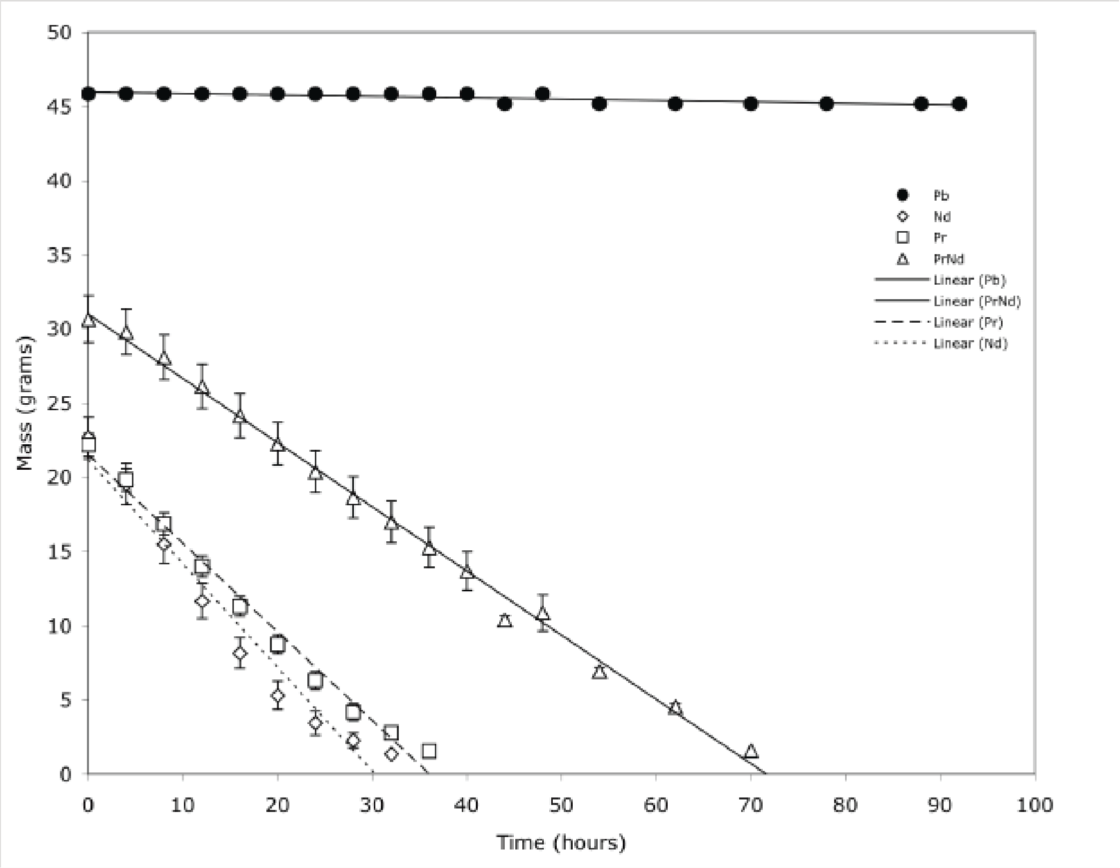

Figure 9-5. Total mass of various electropositive metals decreased with exposure time in seawater as the samples dissolved. In contrast, the control treatment (lead) did not dissolve over that same time period.

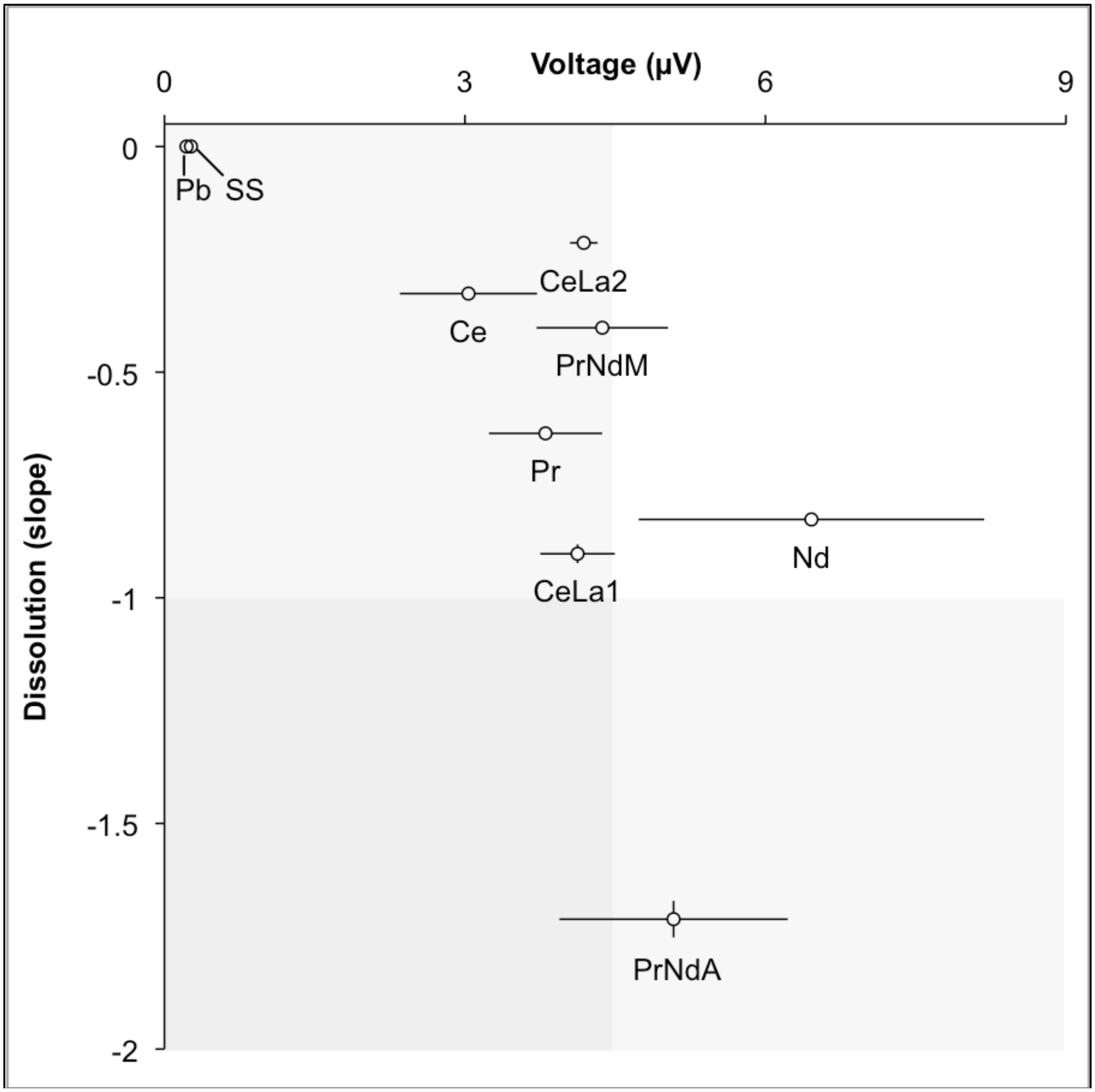

Figure 9-6. To determine the best candidate metal for shark behavioral trials, voltage (mean ± s.e.m.) was plotted against dissolution rate (mean ± s.e.m.) for seven lanthanide metals and two controls. The best metal candidates produce the greatest voltage and possess the slowest dissolution rate (slope close to 0) and occur in the upper right quadrant. Based upon these criteria, Neodymium (Nd) was chosen for the shark behavioral trials.

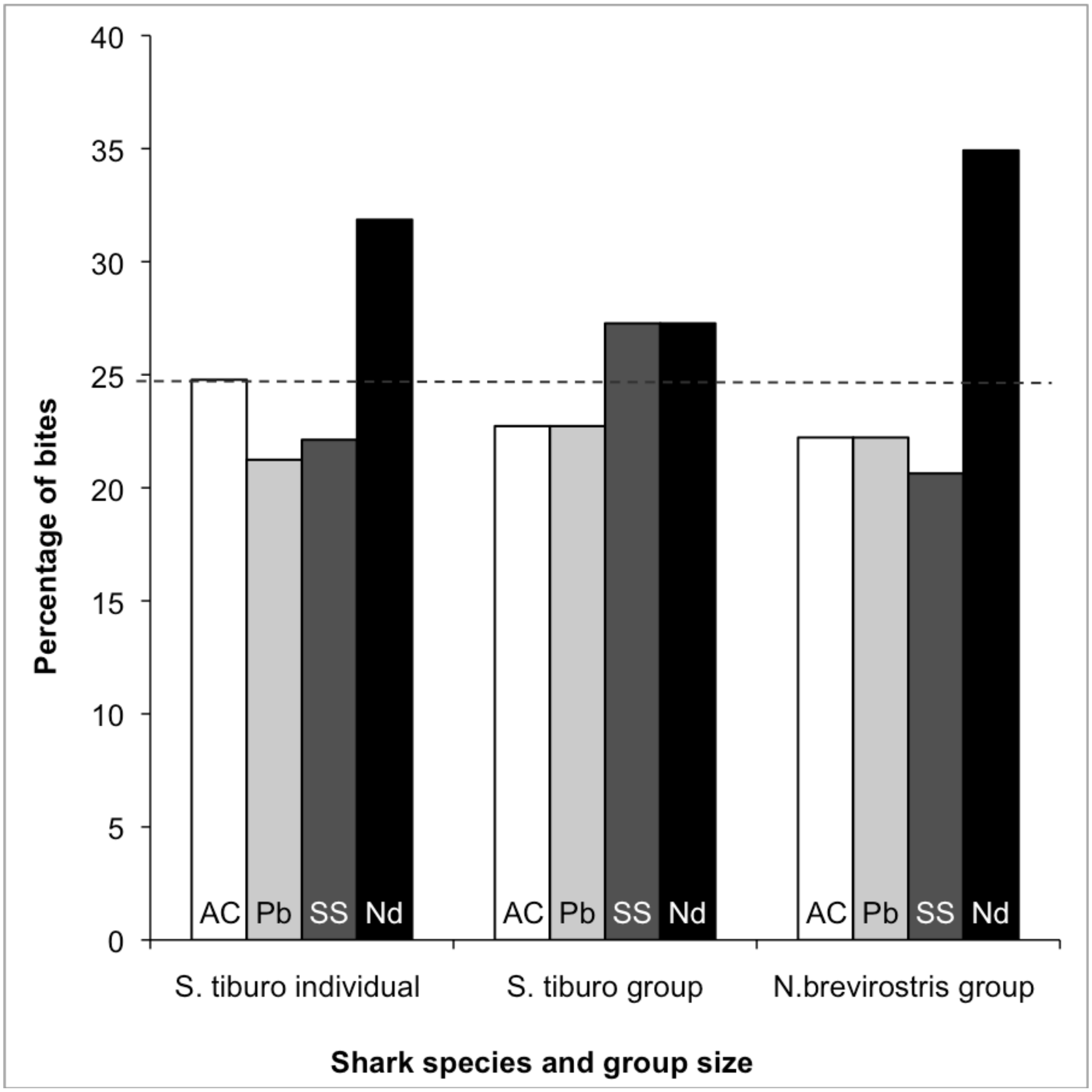

Figure 9-7. An acrylic array with each of the sample materials (acrylic: AC, lead: Pb, stainless steel: SS, and Neodymium: Nd) was placed into the tank with the sharks and the frequency with which bait was removed from each material was recorded. The sharks were tested individually or in groups: *Sphyrna tiburo* individually (N=12 sharks, n=113 bites), *Sphyrna tiburo* in groups (N=12 sharks, n=110 bites), and *Negaprion brevirostris* in groups (N=13 sharks, n=126 bites). *Negaprion brevirostris* were tested individually, but would not feed in isolation. Each treatment has an equal chance of being removed (25%, as indicated by the dashed line). The sharks did not preferentially feed from or avoid any of the treatments (*S. tiburo* individually X^2=3.1416, p=0.3703; *S. tiburo* group X^2=0.9091, p=0.8232; *N. brevirostris* group X^2=6.6984, p=0.0822).

References

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