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Research Note

Potential for Electropositive Metal to Reduce the Interactions of Atlantic Sturgeon with Fishing Gear

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Abstract: *Atlantic sturgeon (Acipenser oxyrhynchus) populations have been declared either endangered or threatened under the U.S. Endangered Species Act. Effective measures to repel sturgeon from fishing gear would be beneficial to both fish and fishers because they could reduce both fishery-associated mortality and the need for seasonal and area closures of specific fisheries. Some chondrostean fishes (e.g., sturgeons and paddlefishes) can detect weak electric field gradients (possibly as low as 5 Mv/cm) due to arrays of electroreceptors (ampullae of Lorenzini) on their snout and gill covers. Weak electric fields, such as those produced by electropositive metals (typically mixtures of the lanthanide elements), could therefore potentially be used as a deterrent. To test this idea, we recorded the behavioral responses of juvenile Atlantic sturgeon (31–43 cm fork length) to electropositive metal (primarily a mixture of the lanthanide elements neodymium and praseodymium) both in the presence and absence of food stimuli. Trials were conducted in an approximately 2.5 m diameter × 0.3 m deep tank, and fish behaviors were recorded with an overhead digital video camera. Video records were subsequently digitized (x, y coordinate system), the distance between the fish and the electropositive metal calculated, and data summarized by compiling frequency distributions with 5-cm bins. Juvenile sturgeon showed clear avoidance of electropositive metal but only when food was present. On the basis of our results, we conclude that the electropositive metals, or other sources of weak electric fields, may eventually be used to reduce the interactions of Atlantic sturgeon with fishing gear, but further investigation is needed.*

Keywords: ampullae of Lorenzini, avoidance, bycatch, Chondrostean, electroreceptors, electric fields, endangered, lanthanide, swimming

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Resumen: *Las poblaciones del esturión atlántico (Acipenser oxyrhynchus) han sido declaradas como en peligro o amenazadas bajo el Acta de Especies en Peligro de los Estados Unidos. Las medidas efectivas para repeler a los esturiones de los instrumentos de pesca serían benéficas para los peces y los pescadores ya que podrían reducir la mortalidad asociada a la pesca y la necesidad de los cierres temporales y de área de pesquerías específicas. Algunos peces chondrosteos (p. ej.: esturiones y peces espátula) pueden detectar gradientes débiles de campos eléctricos (posiblemente tan bajos como* $5\ \mu V\ cm^{-1}$*) debido a grupos de electroreceptores (ámpulas de Lorenzini) en su bocico y opérculos. Los campos eléctricos débiles, como aquellos producidos por metales electropositivos (comúnmente mezcla de elementos lantánidos), podrían entonces ser usados potencialmente como un disuasivo. Para probar esta idea, filmamos las respuestas conductuales de esturiones juveniles (31 – 43 cm de largo) a metales electropositivos (principalmente una mezcla de los elementos lantánidos neodimio y praseodimio) tanto en la presencia como en la ausencia de estímulos de alimento. Las pruebas*

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se realizaron en un tanque de ≈ 2.5 metros de diámetro x 0.3 m de profundidad, y las conductas de los peces se filmaron con una cámara digital de video colocada sobre el tanque. Las filmaciones después se digitaron (sistema de coordenadas x, y), se calculó la distancia entre los peces y el metal electropositivo y se resumió la información al compilar las distribuciones de la frecuencia con contenedores de 5 cm. Los esturiones juveniles mostraron clara evitación del metal electropositivo pero sólo cuando el alimento estaba presente. Basándonos en nuestros resultados, concluimos que los metales electropositivos, u otras fuentes de campos eléctricos débiles, puede ser usada eventualmente para reducir las interacciones del esturión atlántico con los instrumentos de pesca, pero es necesario llevar a cabo más investigaciones.

Palabras Clave: Ámpula de Lorenzini, campos eléctricos, captura incidental, Chondrosteo, electroreceptores, en peligro, evitación, lantánido, nado

Introduction

Due to overfishing and multiple stochastic factors, Atlantic sturgeon (*Acipenser oxyrhynchus*) populations have suffered significant range-wide declines (e.g., Smith & Clugston 1997; Secor & Waldman 1999; Secor 2002). As a result, the South Atlantic, Carolina, Chesapeake Bay, and New York Bight populations of Atlantic sturgeon were declared endangered and the Gulf of Maine population was declared threatened under the U.S. Endangered Species Act in 2012. Interactions with sink gill nets, drift gill nets, and otter trawl gear targeting other species have been deemed a source of concern for population recovery (Collins et al. 2000; Stein et al. 2004*a*, 2004*b*). For this reason, and because any bycatch now has substantial legal and fishery management implications, development of methods to reduce Atlantic sturgeon interactions with fishing gear is clearly warranted.

Electropositive (EP) metals (typically mixtures of lanthanide elements) produce weak electric fields in water (McCutcheon & Kajiura 2013) and deter feeding in captive juvenile sandbar (*Carcharhinus plumbeus*), spiny dogfish (*Squalus acanthias*), and dusky smooth hound (*Mustelus canis*) sharks (Stoner & Kaimmer 2008; Brill et al. 2009; Jordan et al. 2011). EP metals also affect the swimming patterns of juvenile sandbar sharks and significantly reduce their catch on bottom longline gear (Brill et al. 2009). Other studies, however, have shown less promising results with respect to the potential for EP metals to reduce the interactions of sharks with fishing gear (e.g., Tallack & Mandelman 2009; Robbins et al. 2011; Godina et al. 2013).

Chondrostean fishes (e.g., sturgeons and paddlefishes) possess arrays of electroreceptors (ampullae of Lorenzini) on the snout and gill covers (Teeter et al. 1980) homologous to those of the chondrichthyan fishes (sharks and rays). These allow sturgeon to detect electric field gradients possibly as small as 5 μV/cm (Jørgensen 1995). We therefore postulated that weak electric fields produced by EP metals have the potential to reduce the interactions of sturgeon with fishing gear but are unlikely to affect the catch rates of the targeted teleost fishes because they lack electroreceptors. Moreover, Gurgens et al. (2000) demonstrated that weak electric fields generated by aluminum rods are repulsive to paddlefish (*Polydon spathula*), a species whose electroreceptors are anatomically similar to those of sturgeon (Jørgensen et al. 1972; Teeter et al. 1980; Jørgensen 1995).

Methods

Our project and procedures were approved by the Institution Care and Use Committee of the College of William and Mary and followed all applicable U.S. laws and regulations. We obtained juvenile Atlantic sturgeon (31–43 cm fork length) from the Oxford Laboratory of Maryland Department of Natural Resources. Fishes were part of an aquacultured stock developed from eggs and larvae imported from Canada. Once at the Virginia Institute of Marine Science—Eastern Shore Laboratory (Wachapreague, VA, U.S.A.), fishes were kept in fresh water in a circular fiberglass holding tank maintained at approximately 24–26 °C. They were fed commercial food pellets every other day, but food was withheld from individuals for 48–72 h prior to use in an experiment.

Behavioral trials were conducted in a separate tank (approximately 2.5 m diameter × 0.3 m deep, hereafter filming tank) lined with a white cotton sheet (to provide the contrast necessary for the tracking software to follow fish movements) and enclosed in a canopy tent (to control ambient light levels and eliminate visual disturbance). A white LED light source suspended approximately 2.5 m above the filming tank provided constant illumination for the digital video camera (Logitech HD Pro Webcam c910, Logitech, Newark, CA, U.S.A.) used to record behavior. The EP metal we tested was a mixture of the lanthanide elements neodymium (76%), praseodymium (23%), and minor amounts (<0.04%) of cerium, lanthanum, samarium, and yttrium. Trapezoidal pieces (approximately 5 cm tall with 3 and 6 cm bases and 1 mm thick) were cut from the ingots supplied by the manufacturer (Hefa Rare Earth, Vancouver, Canada). Because of the relatively brief exposure to water, the metal pieces showed no significant degradation over the course of the experiments.

We conducted 2 sets of experiments, one in the absence and the other in the presence of food stimuli.

For the former, 2 EP metal pieces or 2 plastic pieces (similar in color, shape, and dimensions to the EP metal) were suspended approximately 7.5 cm apart against the wall of the filming tank. The upper piece was just under the water surface and the lower was approximately 12.5 cm above the bottom. A pulley system allowed the EP metal or plastic pieces to be deployed and removed from outside the canopy tent with minimal disturbance to the fish. After transfer to the filming tank, individuals were given a 5-h recovery period. This allowed the fish to be transferred in the morning and the filming trials to be conducted in the afternoon of the same day. The plastic pieces were lowered into the tank and the fish given 1 h to acclimate to the new visual stimulus. The plastic pieces were then removed and either the EP metal or the plastic pieces were placed back in the tank and video recording commenced. After 1 h, the plastic or metal pieces were replaced with the other type of piece for a second hour of video recording. The order of presentation was randomized. Upon completion of the trials, we removed the subject from the filming tank, measured its fork length, inserted a plastic ID tag in the dorsal musculature, and returned it to the holding tank. The water in the filming tank was then drained and replaced.

Fishes from the previous experiments were used for the trials conducted in the presence of food stimuli. Individuals were again given a 5-h recovery period after transfer to the filming tank. We then placed 2 plastic cups (approximately 5 cm deep and approximately 8 cm in diameter), without food pellets and without EP metal or plastic pieces, in predetermined locations on opposite sides of the tank and in proximity to the tank wall. After an hour (to allow the fish to acclimate to the new visual stimuli), the cups were removed from the tank, partially filled with equal amounts of food pellets, and covered with fiberglass window screen to prevent the fish from accessing the pellets. A piece of either EP metal or plastic was placed on top of the fiberglass window screen and the cups returned to their predetermined positions. The relative positions of the cups with the EP metal and the plastic piece were randomized. A 1-h video record of fish behavior was then made. Following a trial, the subject was returned to the holding tank and the water in the test tank drained and replaced.

Because we could detect no clear quantifiable aversive behaviors to the EP metal (e.g., flinches or rapid turns), our analysis procedures were based on those we used previously for a study involving the behavioral reactions of sandbar sharks to EP metal (Brill et al. 2009). Fish locations were digitized (x, y coordinate system) from each frame of the video record (30 frames/s) with the open-source software SwisTrack (available from http://sourceforge.net/projects/swistrack/files/latest/download). Data density was subsequently reduced to 1 location record per second. The distances between the fish and the EP metal or plastic pieces were calculated, and we used 5-cm bins to compile frequency distributions. We calculated fractional values (i.e., percentage) for each distance bin from the total number of position estimates for each fish and averaged these values across all fish. The data were subsequently arcsine transformed to normalize their distribution. The 2-way (treatment × distance bin) repeated measures analysis of variance (ANOVA) procedure in Sigma Stat (version 3.0.1, Systat Software, San Jose, CA) was applied to test for differences in the frequency distributions, with posthoc tests for significant differences between individual bins. The significance level for all tests was $P < 0.05$.

Results

In the first set of experiments (i.e., in the absence of food stimuli), 8 of 15 fish tested remained motionless on the bottom for extended periods and were excluded from further analysis. (The extended periods of inactivity observed in the filming tank reflected similar behaviors of sturgeon in the holding tank.) The other 7 fishes were almost continuously active and generally swam around the perimeter of the tank between midwater and the bottom. Exemplary results from an individual showing the latter behavior, in the presence of EP metal and visually equivalent plastic pieces, are shown in Figure 1(a). The frequency distributions summarizing the location data in relation to the EP metal or plastic pieces in the 7 active animals showed no statistically significant differences, demonstrating no avoidance of either (Fig. 1b). The frequency distributions under both circumstances increased with distance and truncated sharply at the greatest distances because of simple positional geometry and the limitations imposed by the dimensions of the circular test tank.

Ten of the 15 individuals tested in the presence of food stimuli either swam continuously around the perimeter or remained motionless on the bottom; results from these individuals were excluded from further analysis. The 5 fishes that showed clear interest in food spent a greater amount of time in proximity to the cup below the plastic piece, as opposed to the cup below the EP metal piece. Exemplary results from a single individual are shown in Figure 2(a). The frequency distribution data used to summarize fish locations showed that significantly more positions were recorded within up to 80 cm of the cup with a plastic piece than within 80 cm of the cup with an EP metal piece (indicated by * in Fig. 2b). Conversely, more positions were recorded at greater distances from the cup with EP metal (indicated by # in Fig. 2b).

Discussion

Our results provide the first evidence that weak electric fields produced by EP metal can affect sturgeon

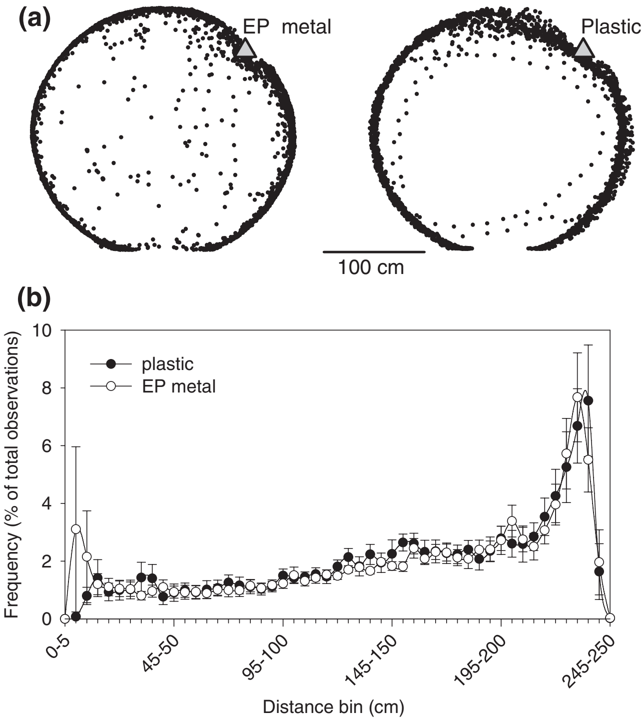

Figure 1. (a) Positions of a juvenile sturgeon (dots) recorded at 1 s intervals for 1 h in the presence of EP metal or visually equivalent plastic pieces. The triangles show the position where the EP metal or plastic pieces were suspended in the tank. (b) Summary frequency distributions (based on 5 cm bins) of the observed distances of juvenile sturgeon (n = 7) from EP metal or plastic pieces.

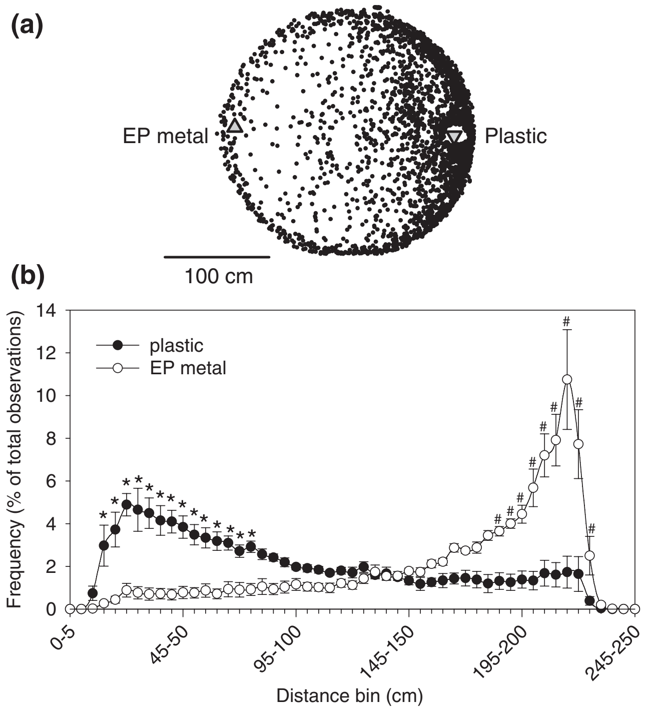

Figure 2. (a) Positions of a single juvenile sturgeon (dots) recorded at 1 s intervals for 1 h. The triangles show the locations of the plastic cups (containing food pellets and covered by fiberglass screen) on the bottom of the tank. The cups also had either an EP metal or plastic piece placed on top of the screen. (b) Summary frequency distributions (based on 5 cm bins) of the observed distances of juvenile sturgeon (n = 5) from cups with EP metal or plastic pieces on top.

behavior, albeit only under specific circumstances (i.e., only in individuals showing an interest in feeding). Our results therefore imply that input from electroreceptors influences behavior only when individuals are motivated to feed; or that there is some unknown negative interaction between the electroreceptor and olfactory systems. More important, we conclude that because weak electric fields can alter sturgeon behavior, this might eventually be exploited to reduce interactions with fishing gear. However, our results also imply that weak electric fields may be less effective in reducing sturgeon bycatch in net than in hook-and-line fisheries. This could be problematic as sturgeon bycatch primarily occurs in the former (Collins et al. 1996; Collins et al. 2000; Stein et al. 2004*a*).

Because sturgeon interact with fishing gear in marine, estuarine, and freshwater environments (e.g., Collins et al. 2000; Stein et al. 2004*a*), additional experiments employing a range of salinities are needed. Based just on anatomy, it is currently unclear if sturgeon electroreceptors are functional at higher salinities. Although electroreceptors are similar at the cellular level, the canals connecting electroreceptors with the body surface are much longer in chondrichthyan (sharks and rays) than in chondrostean (sturgeons and paddlefishes) fishes (Teeter et al. 1980). With chondrichthyan fishes in seawater, the skin has relatively low resistance and the fish can be considered transparent to an electric field. Therefore, a lengthy pore is necessary to create a potential difference (between the opening of the canal at the body surface and basal membrane of the receptor cell) sufficient to stimulate the receptor (Hofmann 2011). In contrast, chondrostean fishes in freshwater have a relatively high skin resistance, and internal body fluids assume a potential that is the average of the potentials across the skin. As a result, a potential difference between the opening of the canal at the body surface and basal membrane of the receptor cell (sufficient to stimulate the receptor) can be created with shorter canals, and overall receptor sensitivity is not a function of canal length (Hofmann 2011). It is therefore unclear if the electroreceptors of chondrostean fishes that are functional in freshwater remain so at higher salinities. Also, EP metals produce the highest electrical field gradients in freshwater, which decrease logarithmically with increasing salinity (McCutcheon & Kajiura 2013). EP metals may therefore have less effect on sturgeon behavior at higher salinities, even if there is no diminution of their electroreceptor sensitivity.

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