FISHERY RESEARCH

PROJECT 5—WHITE STURGEON RESEARCH

Grant F-73-R-34

Report Period July 1, 2012 to June 30, 2013

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IDFG Report Number 14-04
March 2014

ANNUAL PERFORMANCE REPORT

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Project 5—White Sturgeon Research

Subproject 1: White Sturgeon Investigations: Hatchery White Sturgeon

Subproject 2: Hook Investigations: Hook Corrosion

Subproject 3: Ingested Metal Investigations: Metal ingestion and x-ray Comparison

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IDFG Report Number 14-04
March 2014

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State of: Idaho

Grant No.: F-73-R-34 Fishery Research

Project No.: 5

Title: Sturgeon Research

Subproject #1: White Sturgeon Investigations: Hatchery Sturgeon

Contract Period: July 1, 2012 to June 30, 2013

ABSTRACT

Angling for White Sturgeon *Acipenser transmontanus* is popular in Idaho, leading managers to consider the effects angling pressure or ingested fishing tackle may have on populations. I implanted circle and J hooks in offset and inline configurations at three levels (1 hook, 5 hooks, and 5 hooks with a monofilament leader and a swivel) into the stomachs of 118 White Sturgeon to assess the effects of ingesting hooks on growth and stress response. After 17 months of the experiment, I have found little differences in the fork length, vent length, pectoral girth, pelvic girth, or hematocrit levels of fish with the different treatments. Examination of x-rays has also shown that only seven of the fish have completely passed or digested the implanted hooks. Hooks in study fish that received multiple hooks appear to corrode faster than when a single hook is present, likely because hooks are abrading each other and scratching the protective finish on the hooks. Although few differences are currently apparent, the study is not yet completed.

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INTRODUCTION

Sturgeon *Acipenser spp.* populations have been declining worldwide for decades (Rochard et al. 1990; Birstein et al. 1997). Primary reasons include habitat alterations from dam construction and irrigation diversions (Parsley et al. 1993; Beamesderfer and Farr 1997) and overharvest from commercial and recreational fishing for meat and the desirability of eggs for caviar (Boreman 1997). Five of the eight sturgeon species in the United States are currently listed as threatened or endangered under the Endangered Species Act (Williams et al. 1989; Secor et al. 2002). White Sturgeon *Acipenser transmontanus* have the ability to live more than 100 years (Semakula and Larkin 1968), usually spawning for the first time between 15 and 30 years of age, and oftentimes with 10 years between spawning events (Semakula and Larkin 1968). Because sturgeon are long-lived and spawn infrequently, populations are vulnerable to decline via overfishing or mortality from the associated effects of angling (Rieman and Beamesderfer 1990; Boreman 1997).

In Idaho, populations of White Sturgeon have been in decline due to overharvest and habitat fragmentation from dam construction for at least 100 years (Cochnauer et al. 1985), but populations have stabilized over the past two decades. Sport fisheries for White Sturgeon still exist in Idaho, although under strict catch-and-release and barbless hook regulations since 1971 (Idaho Department of Fish and Game 2008). Due to the popularity of White Sturgeon fisheries and the potential sensitivity to increased mortality rates, managers are concerned about the effects on populations from angling pressure and ingested fishing tackle. More specifically, fishery managers are concerned that the terminal tackle used to catch White Sturgeon may be reducing reproductive success or increasing mortality rates due to chronic stress from deep-hooking injury or the ingestion of lost tackle. Kozfkay and Dillon (2010) documented that individual White Sturgeon were caught an average of 7.7 times in a one-year period for a population that lives below C.J. Strike Dam in southern Idaho. In the Hell's Canyon reach of the Snake River, sampling has identified that approximately 30% of White Sturgeon contain hooks or other metal fishing tackle in their digestive systems (J. DuPont, Idaho Department of Fish and Game, personal communication; K. Lepla, Idaho Power Company, personal communication).

Studies demonstrate that fishing with bait often results in increased deep hooking rates than using other terminal tackle, and survival is typically decreased when deep hooked fish are released (Muoneke and Childress 1994). Considering that White Sturgeon in Idaho are caught almost exclusively using bait, and in some reaches are caught multiple times per year, a reduction in deep hooking rates could benefit populations. Recent studies suggest that using circle hooks reduces deep hooking injury in many fish species (Cooke at al. 2003a, 2003b; Cooke and Suski 2004; Fobert et al. 2009) and reduces the mortality of caught and released fish compared to conventional J hooks (Prince et al. 2002; Aalbers et al. 2004; Graves and Horodysky 2008; Serafy et al. 2008). However, the majority of these studies were conducted on marine fish in commercial long-line fisheries. Several studies also suggest that when a fish is deeply hooked, cutting the line and releasing the fish results in lower post-hooking mortality (Schill 1996; Tsuboi et al. 2006; Fobert et al. 2009). However, few studies have examined longer term effects on mortality rates, reproductive fitness, or body condition when hooks are left in fish, and those that do, focus on deeply hooked fish (e.g. Mason and Hunt 1967; Marnell 1969; Hulbert and Engstrom-Heg 1980; Broadhurst et al. 2007; Butcher et al. 2007). To our knowledge, no published studies exist where authors purposely inserted hooks into the digestive system of a fish to examine how long hooks persist in the digestive system or whether hooks have an effect on mortality, growth rates, or reproductive success of any fish species.

The digestive system of White Sturgeon is similar to other chondrosteans (Buddington and Christofferson 1985). The alimentary canal length (ACL) is short, ranging from 70-100% of fork length. The alimentary canal consists of the esophagus (5% ACL); the stomach, composed of two regions (40-50% ACL); the intestine (20-25% ACL); the spiral valve (20-25% ACL); and a short rectum (2-3% ACL). The two regions of the stomach form a loop, consisting of an anterior fore-stomach and a muscular pyloric organ, often referred to as a gizzard. The fore-stomach is capable of distending 3-5 times the empty state when food is present. The muscle wall of the gizzard is hypertrophic and aids in grinding up hard food items such as fish bones or shells for further digestion (Buddington and Christofferson 1985).

Circle and J hooks differ in design and function. All J hooks are designed with the point parallel to the shank (Figure 1A), whereas circle hooks are designed with the point perpendicular to the shank (Figure 1B). The design of a circle hook is intended to keep the point from piercing tissue in the esophagus, gills, or inside the mouth until the hook is pulled through the mouth opening, whereby the point may pierce the lip and encircle the mandible (Huse and Fernö 1990; ASMFC 2003; Cooke and Suski 2004). Hooks may also be designed with an inline or offset point. Inline hooks are constructed with the front of the hook in the same plane as the shank (Figure 2A), whereas offset hooks have the front bent at an angle compared to the shank (Figure 2B). The amount of offset often ranges between 4-18 degrees from the line of the shank and can vary greatly between manufacturers. Hooks with an offset point are designed to penetrate more quickly, and when circle hooks have an offset point, the benefits of reduced deep hooking may be lost (Aalbers et al. 2004; Graves and Horodysky 2008).

The objectives of this study were to determine the effects that common hook types used for White Sturgeon angling in Idaho have on the growth and stress response of White Sturgeon after hooks reach the stomach. I assessed the length of time hooks persist in the digestive system, the breakdown of the hook material, and whether hooks dissolved, were sequestered inside the body, or passed through the digestive tract. I also measured growth parameters to assess whether the presence of hooks affected White Sturgeon fitness.

OBJECTIVES

1. Assess the disposition (dissolved, regurgitated, passed through the digestive system, etc.) of inline and offset circle and J hooks after implantation into White Sturgeon stomachs.

2. Assess the effects of inline and offset circle and J hooks on the growth and stress response of White Sturgeon after one hook, five hooks, and five hooks with monofilament leader and swivel are implanted into stomachs.

METHODS

To conduct the study, I acquired 118 White Sturgeon from a commercial hatchery operator from the Hagerman Valley in south-central Idaho. The White Sturgeon were 6-9 years old and ranged in length from 1.0-1.5 m and weighed between 15-35 kg. The study fish resided in a single concrete raceway (25 x 4 m) supplied with a constant water flow of 0.042 m^3/s at a temperature of 12°C with slight seasonal variations. Study fish fed volitionally on Rangen 450/sinking, 8-mm pellets throughout the study period. All study fish were tagged with a passive integrated transponder (PIT) tag to allow identification of individual fish during subsequent handling.

I implanted hooks with different shapes (circle/J hooks) and sets (inline/offset) at three treatment levels (1 hook, 5 hooks, and 5 hooks with 480 mm of 60# test monofilament leader and a size 1 brass barrel snap swivel; Table 1) into the stomachs of study fish on 15 September 2011. The hooks were similar to those commonly used by sturgeon anglers in Idaho and were constructed from high-carbon steel with similar wire diameter, dimensions, and finish. The model of hooks used were Gamakatsu Octopus circle hooks (size 7/0, black nickel finish, model # 208417) and Gamakatsu Octopus J hooks (size 7/0, black nickel finish, model # 02149), in both inline and offset configurations. To simulate current Idaho sturgeon fishing regulations, barbs were removed from all hooks before implantation by pinching the barb down with pliers. Each combination of hook type and treatment level (Table 1) was implanted into nine White Sturgeon. The hooks were implanted into White Sturgeon stomachs using a flexible vinyl tube. Hooks were imbedded into a small piece of fish flesh and placed into the end of the tube. The tube was inserted into the mouth and gently pushed down the esophagus (approximately 120 mm) into the stomach. Using a plunger, the hooks were pushed out of the tube into the stomach, and the tube was removed. I also used 10 fish as a control group that were treated as study fish, including inserting a piece of fish, but without hooks.

Hooks in the digestive tract were monitored using a portable x-ray machine (Sound-Eklin tru/DRLX System) and growth parameters were measured at regular intervals over the study period. Measurements were repeated every four to six weeks during the first 344 days and then, because of the slow progression of hook digestion, approximately every 12 weeks until the study ended. I recorded several growth metrics including pelvic girth (mm) directly anterior to the pelvic girdle, pectoral girth (mm) directly posterior to the pectoral girdle, the distance between the mouth and the anal vent (mouth-vent length; mm), and the distance between the tip of the nose and the anal vent (nose-vent length; mm). The x-ray system consisted of an x-ray generator and a plate that receives the x-ray beam, compiles the received information, and sends a digital image to a computer. The protocol settings on the x-ray generator were consistently set at 96 kilovolts (kVp) and 2.00-second exposure (mAs) to produce an acceptable image. An aluminum rack with adjustable brackets was used to hold the x-ray equipment, aid alignment with the study fish, and allow workers to stay a minimum of 2 m away from the x-ray generator during use, the safe distance required to avoid x-ray scatter (D. Dowden, Sound-Eklin, personal communication).

I measured hematocrit level, a common stress response parameter, to determine whether the presence of hooks in the alimentary tract caused a stress response in our study fish. Blood was collected first, and as quickly as possible after fish were removed from the raceway for measurement and x-ray procedures. Whole blood was sampled from the caudal vein, directly posterior to the anal fin, using a 38 mm, 22-gauge hypodermic needle and a heparinized- 3 cc syringe. A small amount of whole blood was placed into a hematocrit tube and centrifuged until the plasma and hemoglobin stratified (1-2 min), after which the percent hemoglobin was recorded.

I used Analysis of Variance (ANOVA; $\alpha = 0.1$) and Tukey pairwise comparisons to determine differences between treatment groups to compare the effects of hook shape (circle/J hooks), set (inline/offset), and number (1 hook, 5 hooks, and 5 hooks with 480 mm of 60# test monofilament and a size 1 brass barrel snap swivel) on the growth and hematocrit measurements. The sampling unit was an individual fish with a particular hook type and treatment. The response variables were the proportional differences between the initial and final growth and hematocrit measurements and the measurements taken most recently (14 May 2013). All analysis were conducted using Minitab 2010.

To evaluate the corrosion level over time, I rated the hooks, based on x-ray images, with a scale of zero (no corrosion seen) to seven (hook completely gone) with intermediate numbers describing different states of corrosion (Table 2). X-rays for individual fish were rated by two individuals from each sampling period. Ratings were averaged for each treatment combination for each sample period. I compared the average ratings over time to identify differences in corrosion levels.

RESULTS

The White Sturgeon in this study passed or digested the hook material slowly. Seventeen months after implantation, only three fish completely eliminated the hooks and material from their digestive system. According to x-rays, the hooks moved to the gizzard within a month and remained there. Only two fish appeared to have material that moved past the gizzard into the intestines.

Differences were minimal in the growth parameters between White Sturgeon with the different hook treatments. All fish increased in fork length (Figure 3) and no effect from the shape was apparent. However, number of hooks was significant (F = 2.75, df = 2, P = 0.07), but only explained 6% of the variability in the model. Vent length (Figure 4) and pectoral girth (Figure 5) increased for all fish with no apparent effect from shape, set, or number of hooks. Shape was significant for pelvic girth (F = 5.56, df = 2, P = 0.02), but not set or hook number (Figure 6). Hook shape only explained 6% of the variability in pelvic girth. Likewise, hematocrit levels were not different for shape, set, or number of hooks (Figure 7). I did not detect differences in any first or second order interactions between shape, set, and number of hooks. Likewise, no differences were apparent when comparing individual treatments (effectively second order interactions; Figures 8-12).

The number of hooks appeared to affect the corrosion rate of hooks. The average corrosion rates of study fish with five hooks and five hooks with monofilament and a swivel were approximately double those of fish with a single hook (Figure 13). The majority of hooks in study fish with a single hook appeared only lightly corroded; however, many appeared to have no corrosion whatsoever. In contrast, although a few hooks in fish with five hooks also appeared to have no or slight corrosion, the majority corroded considerably and broke into pieces. No differences in corrosion were apparent due to the shape (Figure 14) or set (Figure 15) of hooks.

DISCUSSION

After 17 months with hooks in their digestive systems, according to the x-rays, the hooks remained in the gizzards of 95% of the study fish. Likely, the hooks are too large to pass through the pyloric sphincter and will remain in the gizzard until sufficiently corroded or weakened to the point the grinding action of the muscular gizzard will break the hooks into smaller pieces, allowing passage into the intestine. Broadhurst et al. (2007) reported a small number of yellow bream *Acanthopagrus australis* passed hooks through the anus in 12 d or less in a deep hooking experiment. Four other yellow bream contained hooks after 105 d; all were found in the stomach wall and had lost only 4.5% of their weight to corrosion. Likewise, Borucinska et al. (2002) reported 6 of 211 blue sharks *Prionace glauca* retained hooks that were sampled after being caught and released by recreational fishermen. Of those, three were embedded in the esophagus and only lightly corroded; three were in the anterior stomach and were heavily corroded. Two hooks in the stomach had pierced the gut wall and lacerated the liver. However, the hooks in these studies were not ingested freely from the environment after being lost by anglers, but were introduced into the fish through angling and fish were deep-hooked. Consequently, most hooks were lodged in esophageal or stomach tissue and not available for chemical digestion in the digestive system. I could find no studies where hooks were ingested or implanted into the digestive system of fish to study the mechanisms fish employ to pass hooks, or the effects ingested hooks would have on fish health.

The presence of multiple hooks inside the digestive systems of white surgeon may have an effect on the growth and health of the study fish. Although the number of hooks was significantly related to differences in fork length, and hook shape was significantly related to differences in pelvic girth, those factors only explained 5.6% of the variation in the respective models and are probably not meaningful because of a small effect size (<2%). Several of the fish with monofilament and swivels digested or passed the hooks, but both the swivels and line remained in the digestive tract with no obvious corrosion to the swivels. The presence of the monofilament may be impeding the sphincter between the gizzard and intestine, thereby delaying or reducing the passage of food items into the intestine. Furthermore, the presence of monofilament and a swivel may increase the likelihood of having hooks pierce the stomach wall. Ingested hooks may pierce the gut wall at any point along the alimentary canal and possibly lacerate other internal organs (Borucinska et al. 2002). The peristaltic action of passing the swivel could orient the hook point so it faces posteriorly and any pressure applied to the swivel or line could cause the hook to penetrate surrounding tissue.

The presence of multiple hooks is likely increasing the speed at which hooks are corroding in the digestive system. What likely happens is that, when multiple hooks are present, the hooks are rubbing and abrading each other, effectively scratching the surface finish and allowing digestive chemicals greater access to the steel cores of the hooks. The hatchery White Sturgeon are fed pelletized food that lacks any material abrasive in nature like those in the diets of wild fish. I have identified clams, crayfish, and possibly stones in the digestive tracts of wild White Sturgeon that may increase corrosion and passage rates of fishing gear. X-rays of the study fish with a single hook reveal that many have only slight or no corrosion whatsoever.

Overall, regardless of differences in growth and stress parameters reported on at present, these results are preliminary. In addition, comparing results from hatchery sturgeon may not be applicable to fish in the wild because of diet and behavioral differences. In a companion study, White Sturgeon captured from the wild are being x-rayed to identify the movement and elimination of fishing tackle through the digestive tract. The outcomes of these studies should provide information that will allow improved estimation of potential negative effects due to the ingestion of fishing tackle and help ascertain whether these events are having population level effects.

RECOMMENDATIONS

1. Finish the current study to determine the disposition of implanted hooks and the time required for White Sturgeon to break down and eliminate hooks from the digestive system and potential effects hooks may have on fish.

2. Compare hatchery White Sturgeon results with hook passage in wild White Sturgeon by x-raying a minimum of ten sturgeon containing metal after a one-year period.

ACKNOWLEDGEMENTS

I would like to thank Dennis Daw, John Cassinelli, Ryan Schiferl, Daniel Madel, Kristy Stevenson, Matt Belnap, Erin Larson, Brent Hardy, Debbie Jenson, Heather Hume, Liz Mamer, Phil Mamer, Brad Wright, Joe Chapman, Joe Kozfkay, and Ron Roberts for assistance in data collection. Special appreciation also goes to Lynn Babington, Doug Babington, and Andy Baker from ARK Fisheries, Inc. for providing the study fish and assisting with the project. Idaho Power Company provided partial funding for purchasing the x-ray system. I also thank Joe DuPont and David Venditti for constructive comments and suggestions on the manuscript. Cheryl Zink formatted the report.

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Table 1. Nomenclature of the 13 different hook configurations implanted into White Sturgeon stomachs, including the number of hooks, set (inline/offset), hook shape (circle/J), the presence of monofilament and a swivel, and number of fish.

Treatment	# Hooks	Set	Shape	Monofilament	# Fish
1IC	1	Inline	Circle	none	9
1IJ	1	Inline	J	none	9
1OC	1	Offset	Circle	none	9
1OJ	1	Offset	J	none	9
5IC	5	Inline	Circle	none	9
5IJ	5	Inline	J	none	9
5OC	5	Offset	Circle	none	9
5OJ	5	Offset	J	none	9
5MIC	5	Inline	Circle	Mono	9
5MIJ	5	Inline	J	Mono	9
5MOC	5	Offset	Circle	Mono	9
5MOJ	5	Offset	J	Mono	9
CONTROL	none	none	none	none	10

Table 2. Rating and criteria used to evaluate, from x-rays, the corrosion levels of hooks placed in the digestive tracts of hatchery White Sturgeon.

Rating	Criteria
0	No sign of corrosion
1	First sign of corrosion
2	Corrosion in at least 2 places or on more than one hook
3	Corrosion widespread and/or points gone
4	At least one hook broken in pieces
5	Multiple hooks in pieces
6	Pieces are missing/passed
7	Nothing remains

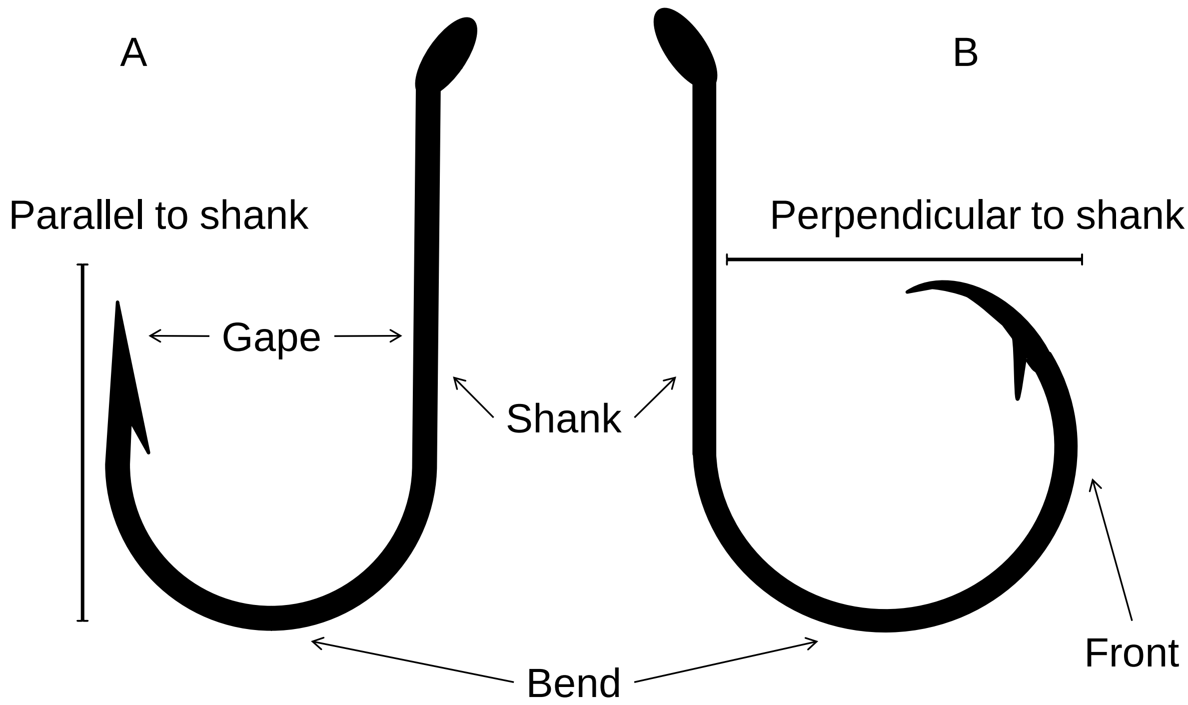

Figure 1. Example of a J hook (A) and a Circle hook (B) with the different parts labeled.

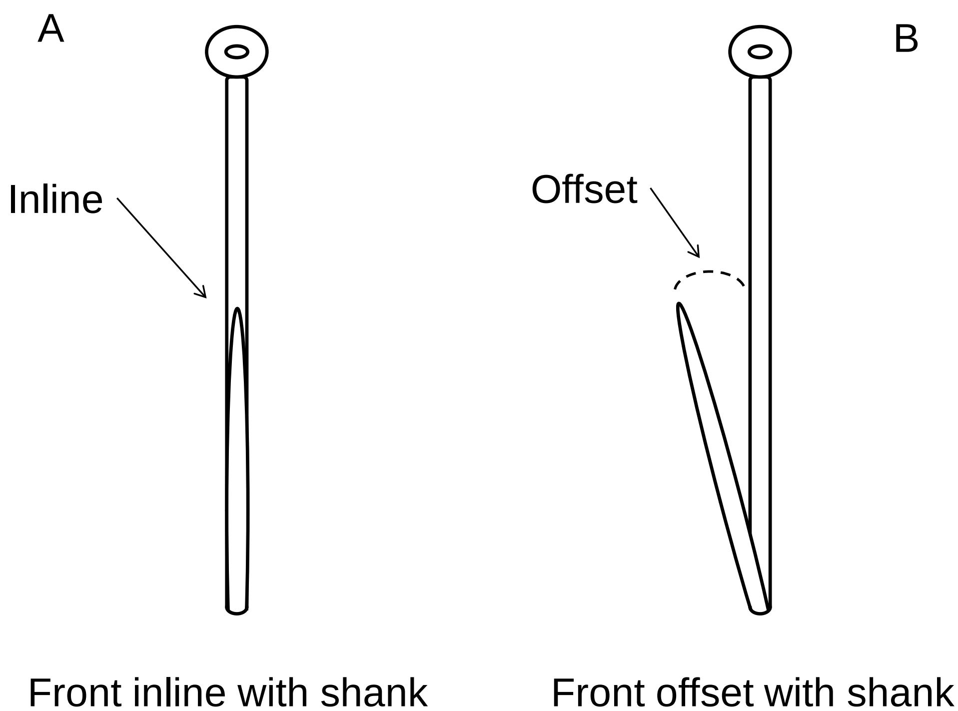

Figure 2. Example of an inline hook (A) and an offset hook (B).

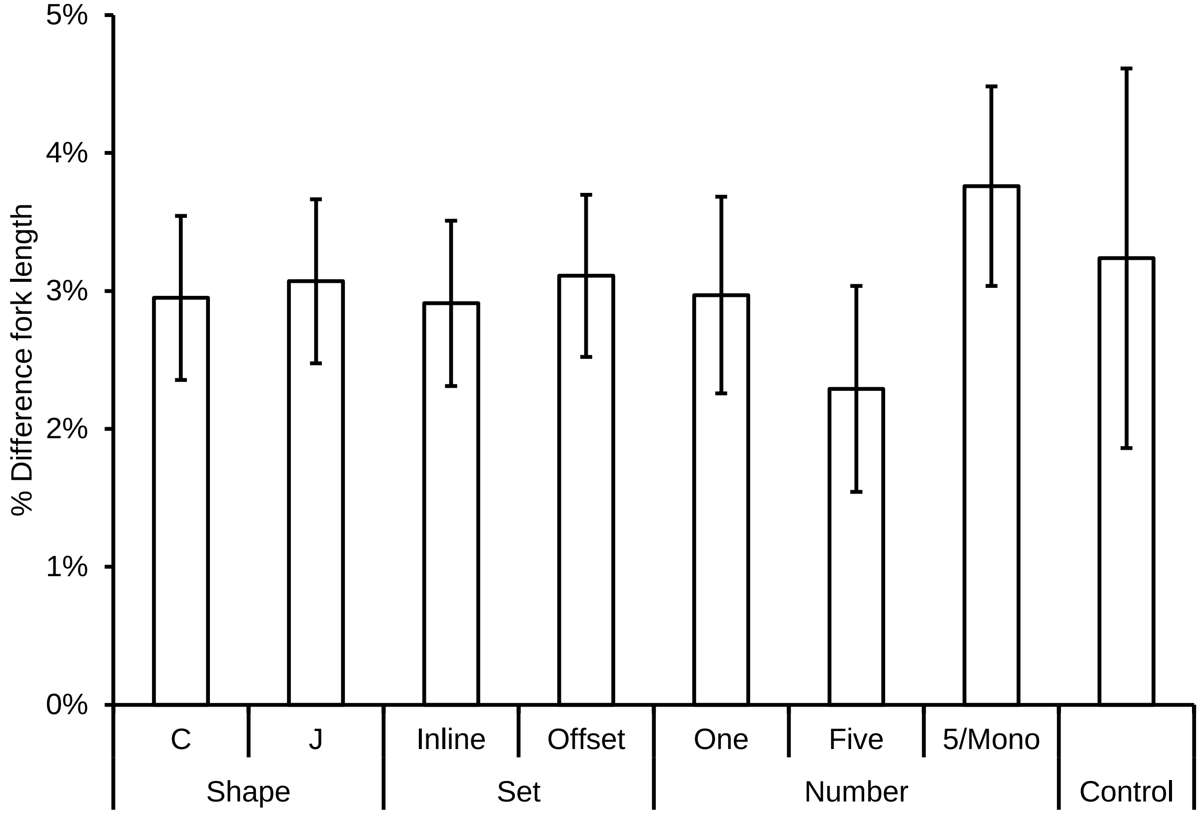

Figure 3. The mean percent differences in White Sturgeon fork length for the three hook variables (shape, set, number) seventeen months after implantation. Error bars are 90% confidence intervals.

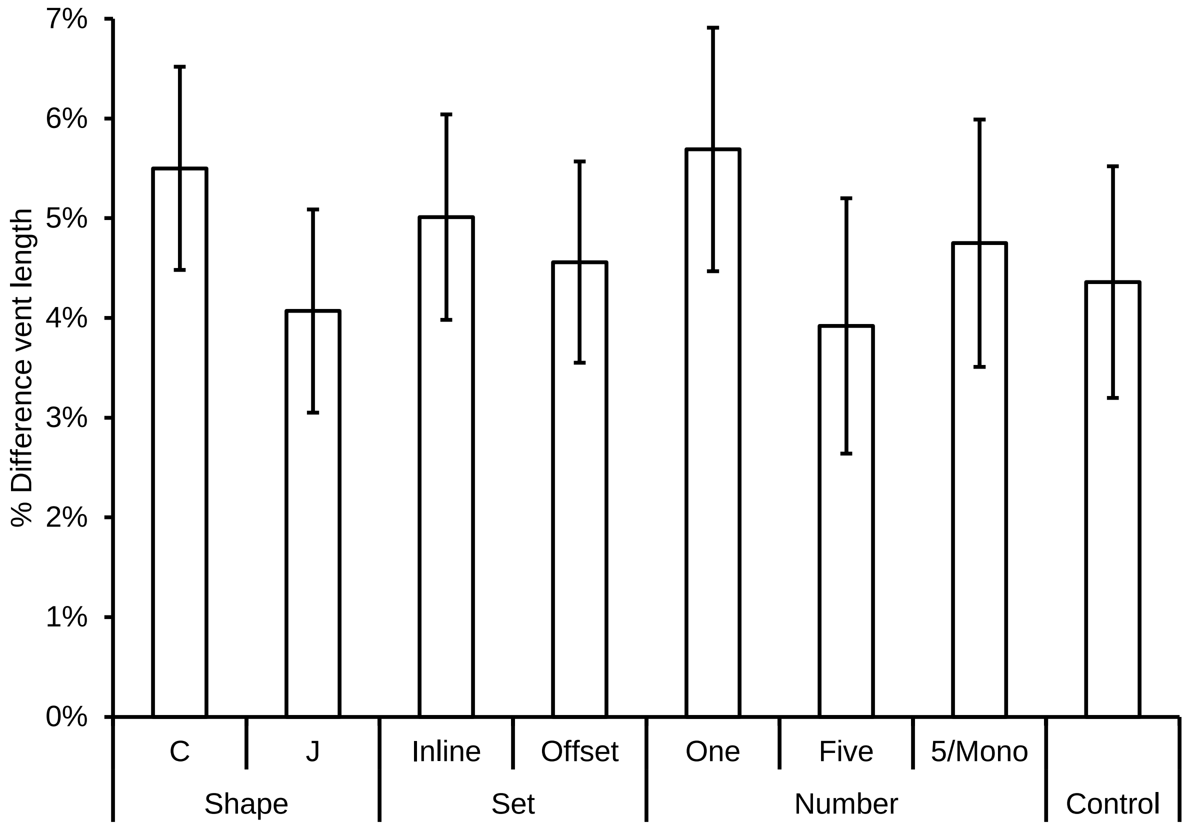

Figure 4. The mean percent differences in White Sturgeon vent length for the three hook variables (shape, set, number) seventeen months after implantation. Error bars are 90% confidence intervals.

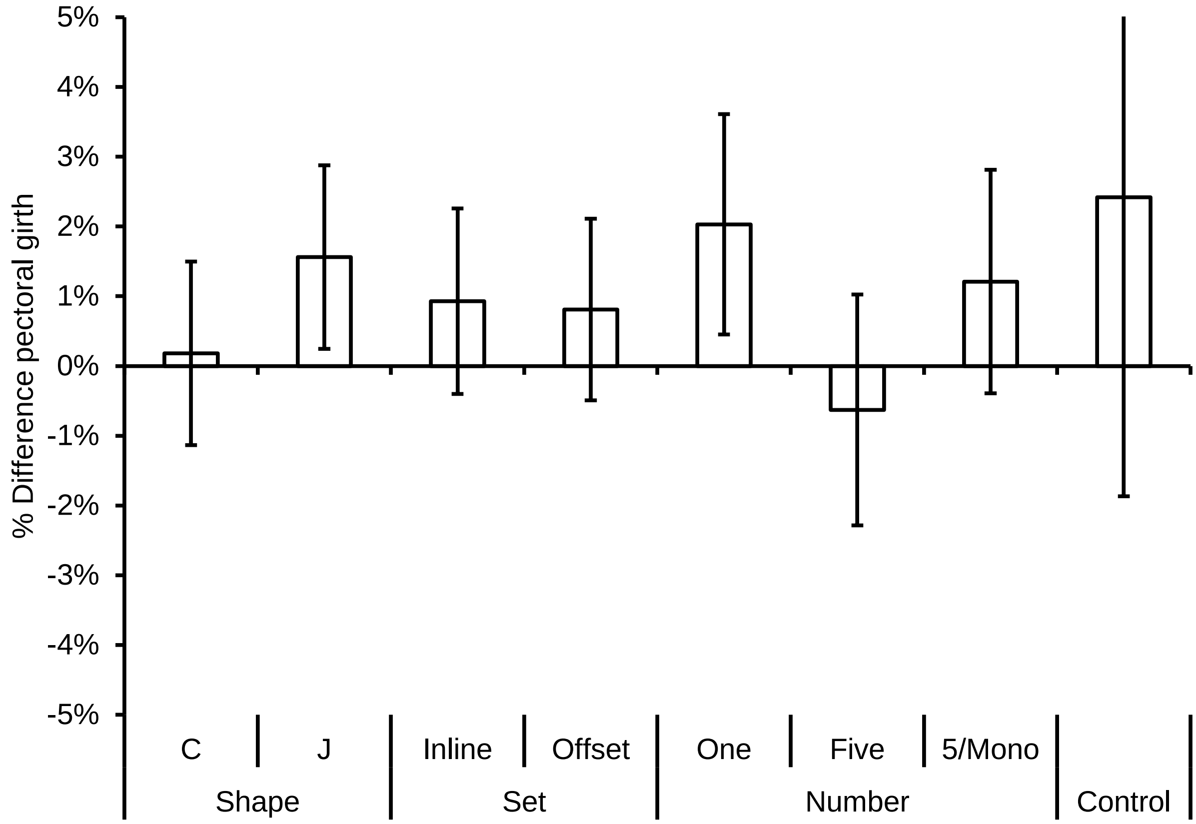

Figure 5. The mean percent differences in White Sturgeon pectoral girth length for the three hook variables (shape, set, number) seventeen months after implantation. Error bars are 90% confidence intervals.

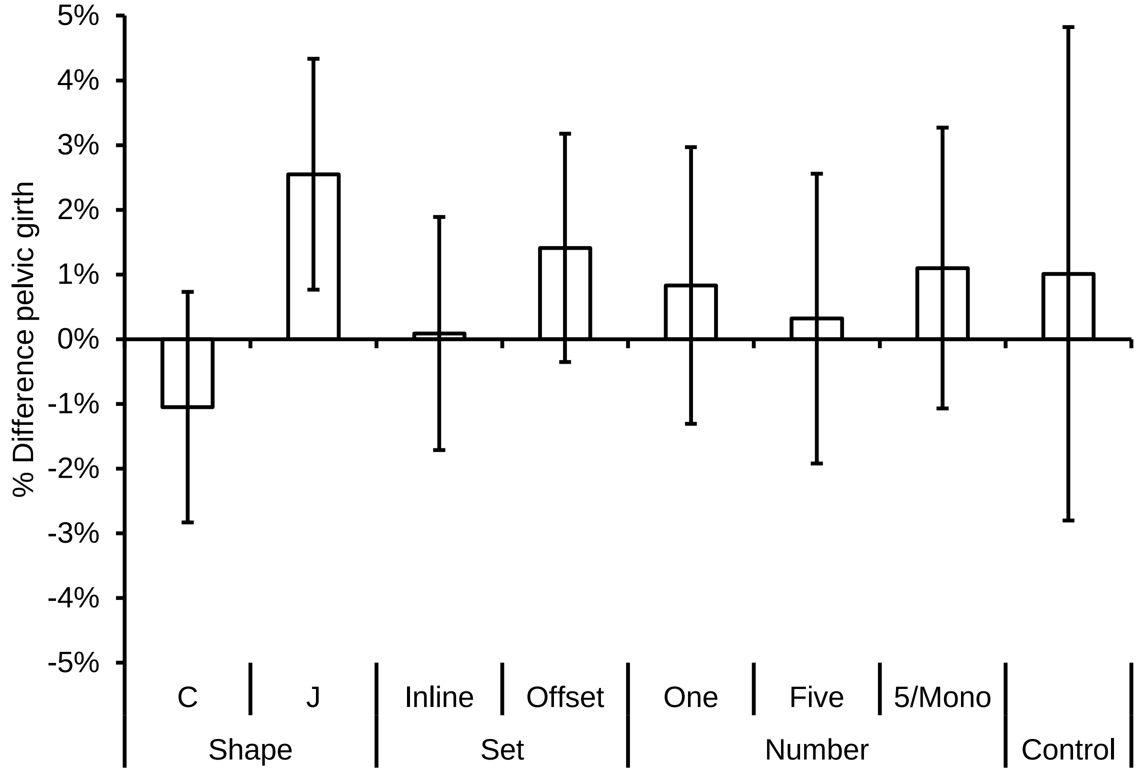

Figure 6. The mean percent differences in White Sturgeon pelvic girth length for the three hook variables (shape, set, number) seventeen months after implantation. Error bars are 90% confidence intervals.

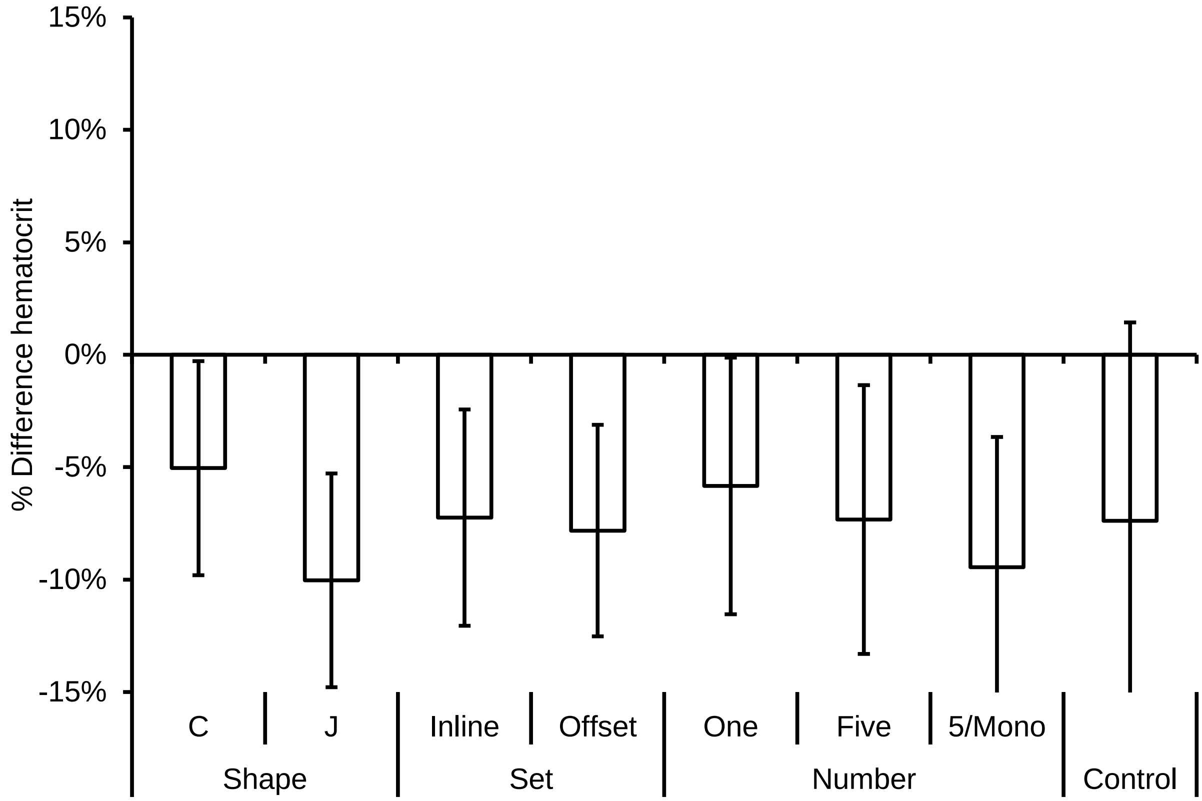

Figure 7. The mean percent differences in White Sturgeon hematocrit level for the three hook variables (shape, set, number) seventeen months after implantation. Error bars are 90% confidence intervals.

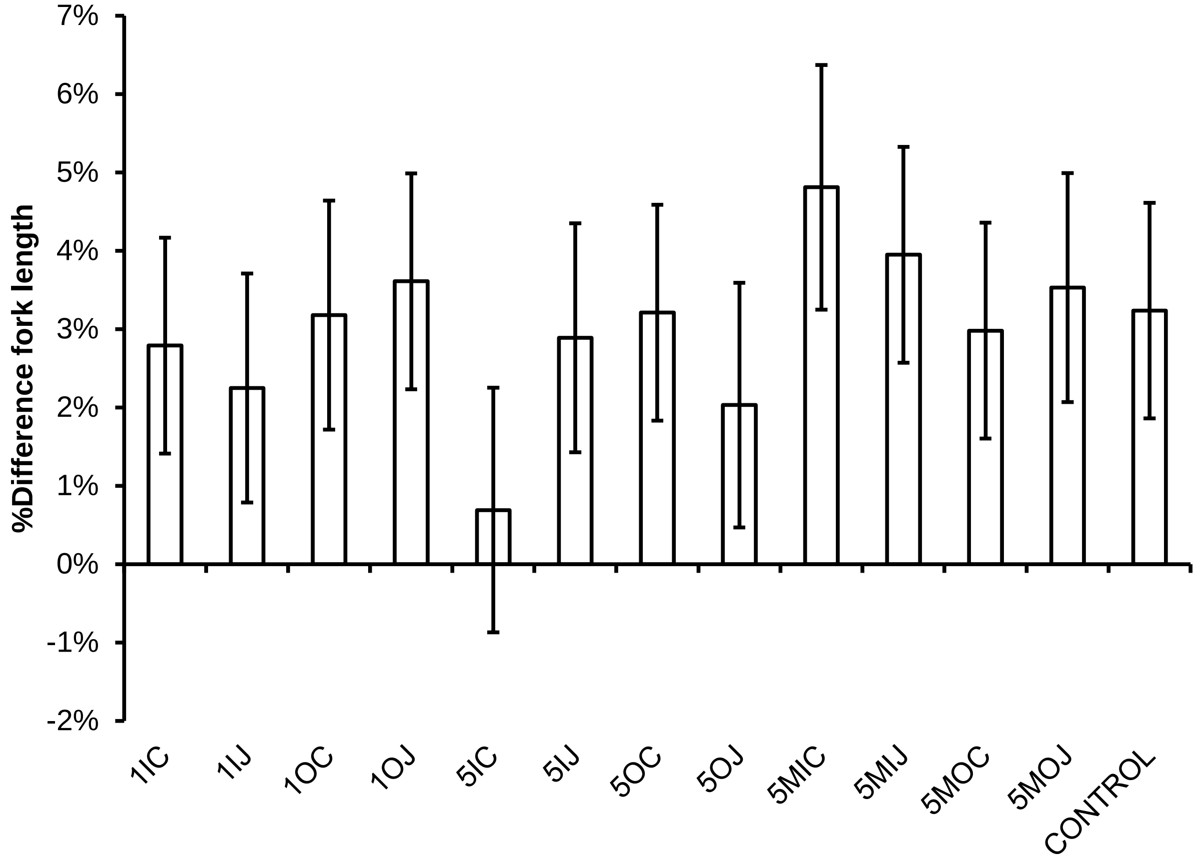

Figure 8. The mean percent differences in White Sturgeon fork length for the different combinations of hook variables seventeen months after implantation. Error bars are 90% confidence intervals.

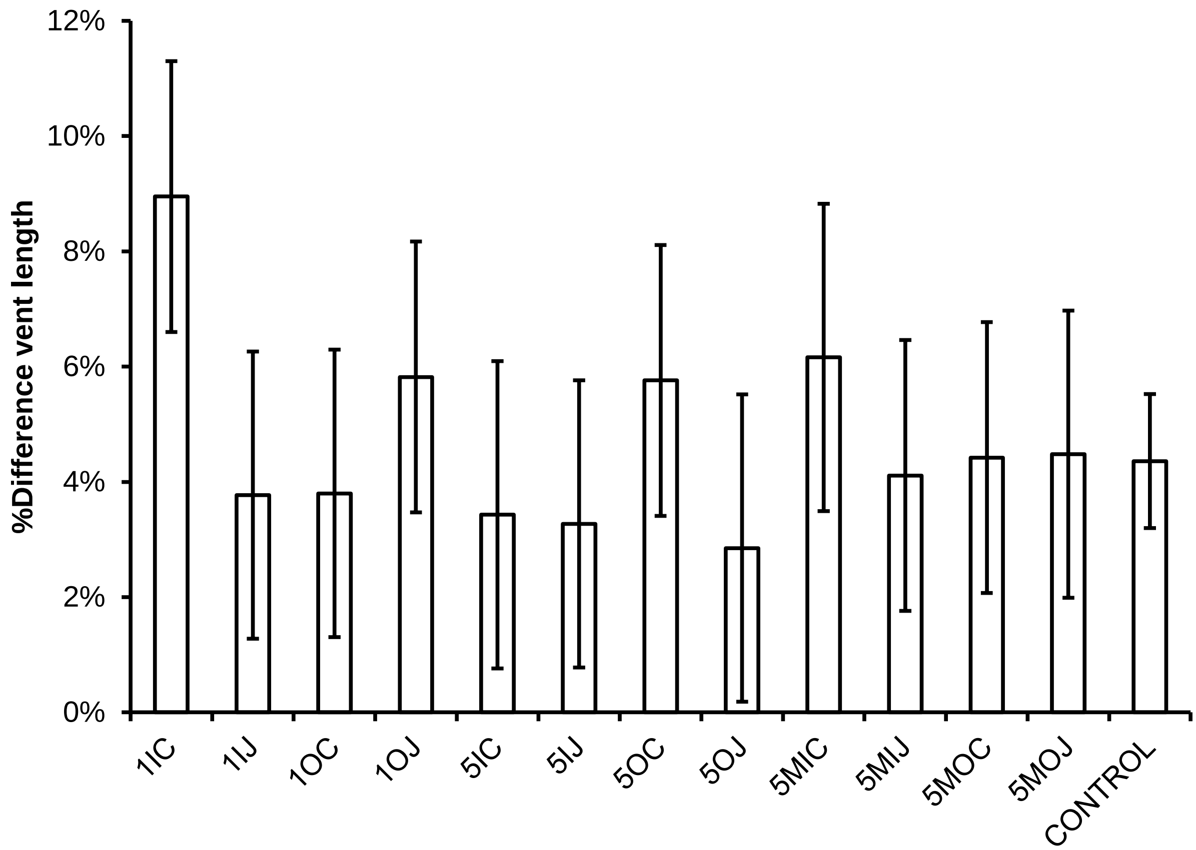

Figure 9. The mean percent differences in White Sturgeon vent length for the different combinations of hook variables seventeen months after implantation. Error bars are 90% confidence intervals.

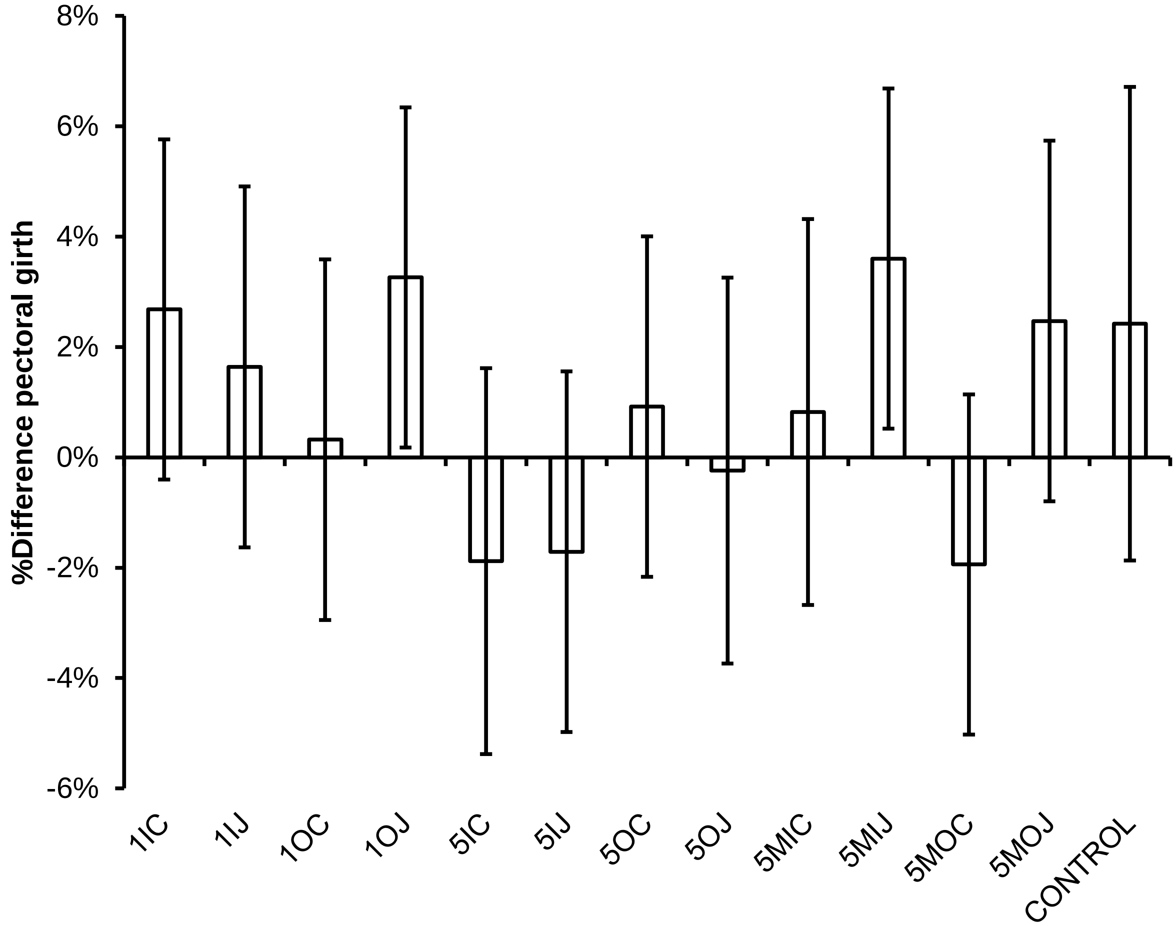

Figure 10. The mean percent differences in White Sturgeon pectoral girth for the different combinations of hook variables seventeen months after implantation. Error bars are 90% confidence intervals.

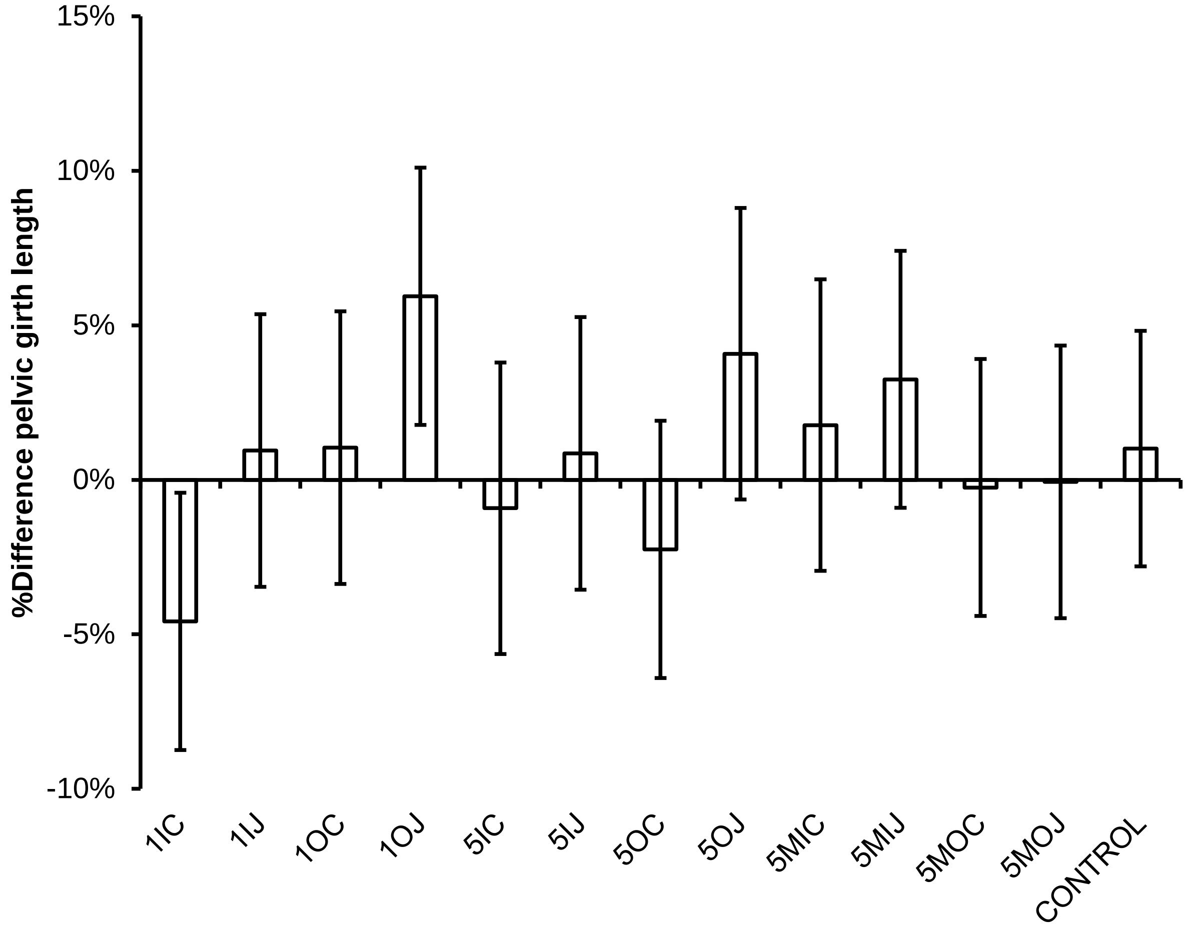

Figure 11. The mean percent differences in White Sturgeon pelvic girth for the different combinations of hook variables seventeen months after implantation. Error bars are 90% confidence intervals.

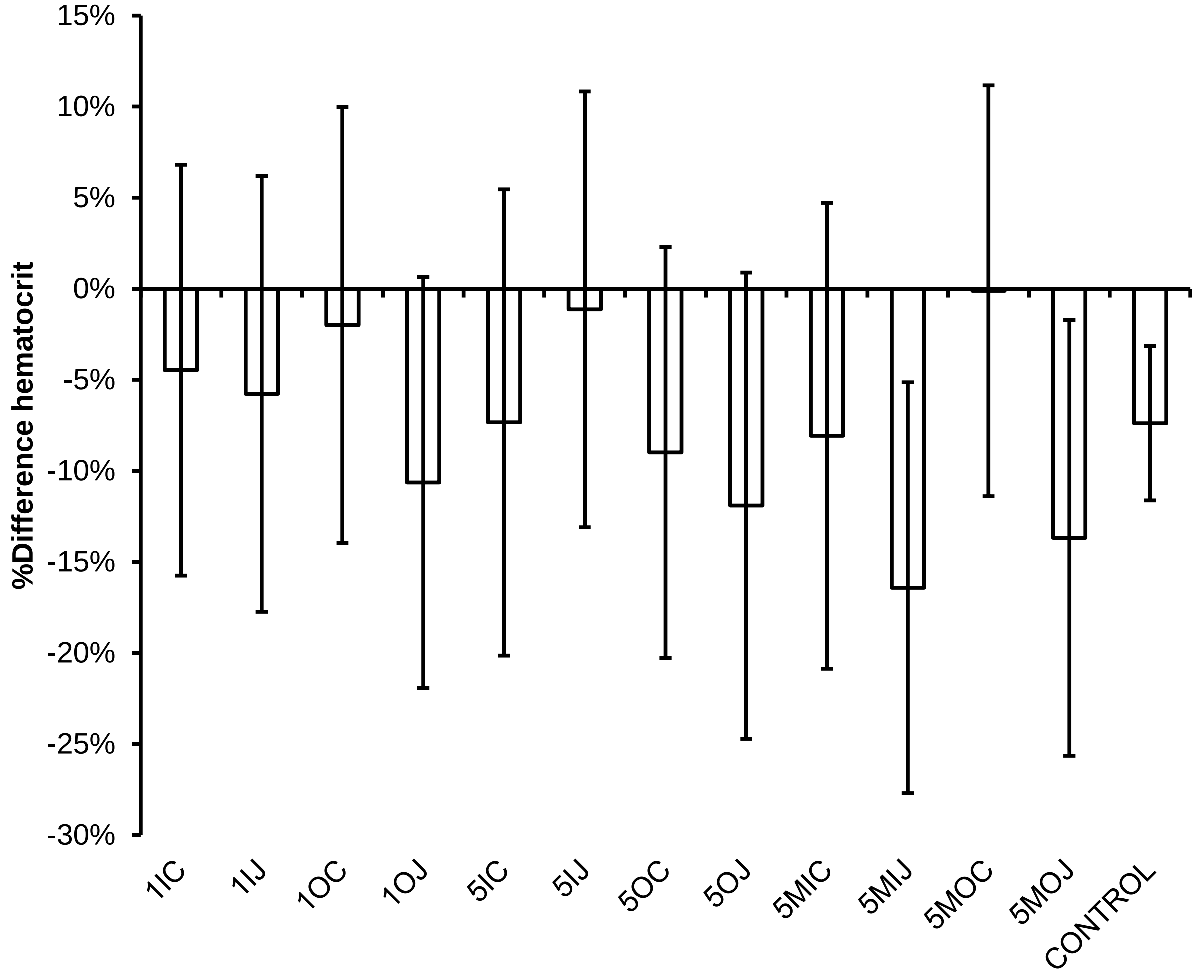

Figure 12. The mean percent difference in White Sturgeon hematocrit levels for the different combinations of hook variables seventeen months after implantation. Error bars are 90% confidence intervals.

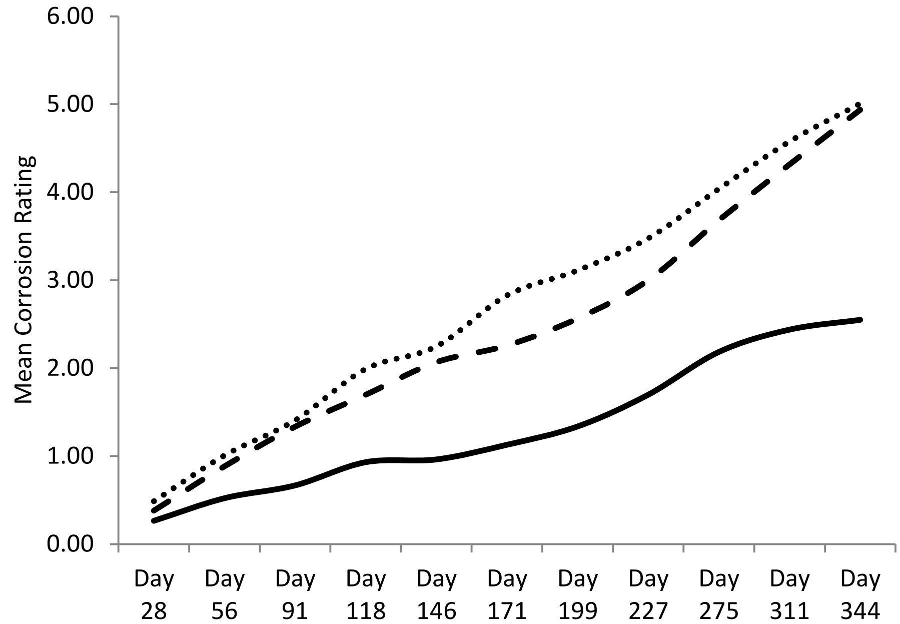

Figure 13. The mean corrosion ratings of White Sturgeon with one hook (solid line), five hooks (dashed line), and five hooks with monofilament and a swivel (dotted line) on sampling days through day 344 of the study.

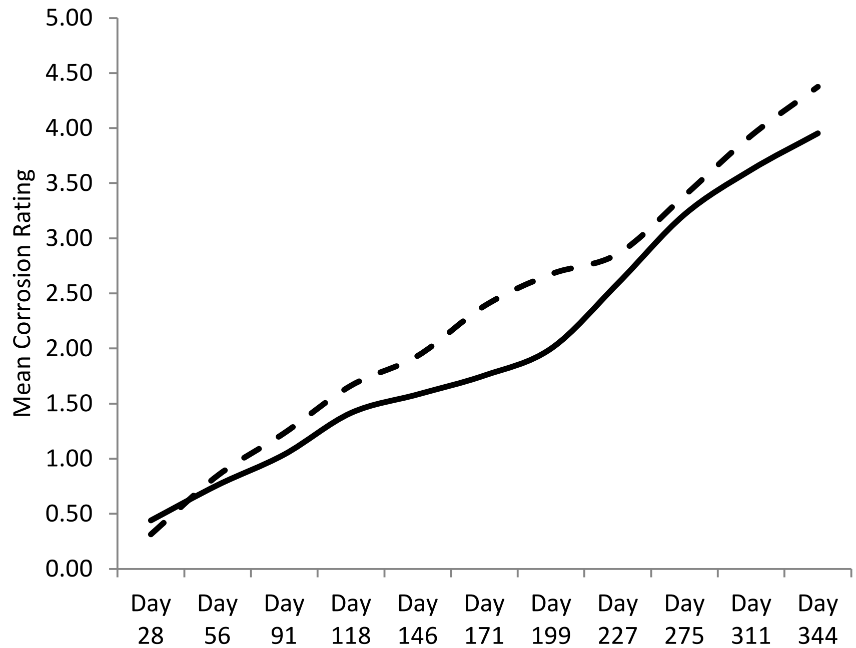

Figure 14. The mean corrosion rating of circle (solid line) and J (dashed line) hooks on sampling days through day 344 of the study.

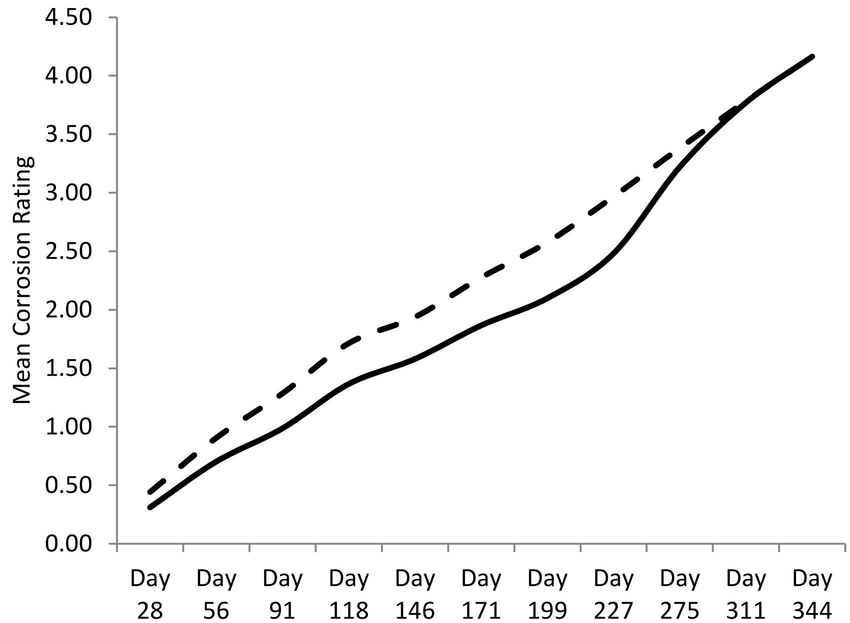

Figure 15. The mean corrosion rating of inline (solid line) and offset (dashed line) hooks on sampling days through day 344 of the study.

ANNUAL PERFORMANCE REPORT
SUBPROJECT 2: HOOK INVESTIGATIONS

State of: Idaho

Grant No.: F-73-R-34 Fishery Research

Project No.: 5

Title: White Sturgeon Research

Subproject #2: Hook Investigations:
Hook Corrosion

Contract Period: July 1, 2012 to June 30, 2013

ABSTRACT

Over the last decade, field reports indicate many White Sturgeon *Acipenser transmontanus* have apparently ingested and retained hooks and other fishing tackle in their digestive systems. The effect of ingested fishing tackle on the health, growth, and reproduction of White Sturgeon is unknown. The length of time fishing tackle persists in the digestive system is also unknown. We conducted a lab study to estimate the length of time sturgeon-sized hooks could persist in the digestive system of White Sturgeon using a simple, buffered acid solution to simulate stomach conditions during digestion. We determined that fishing hooks with different finishes corrode at different rates. Hooks with a bronze finish dissolved completely by day 111. After 555 days, hooks with silver nickel and black nickel finishes lost 84.3% and 58.7%, respectively, of the initial weight, and hooks with a red lacquer finish lost 47.7% of their initial weight. We estimated the silver nickel hooks would dissolve completely in approximately 589 d total, black nickel in 906-911 d, and red lacquered hooks in 1,186-1,188 d. Assuming our simulated stomach conditions mimic actual conditions, our study suggests that the finish on a hook could influence the length of time it would persist inside a White Sturgeon.

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INTRODUCTION

A common piece of advice given to anglers is that if a fish is hooked deeply (i.e., the hook is lodged where removal with fingers or pliers is difficult or impossible) the line should be cut close to the body and the fish released. Many studies suggest that, compared to forcefully removing the hook when a fish is hooked deeply, fish survive better when the line is cut and the fish is released with the hook remaining embedded in the fish (Tsuboi et al. 2006; Fobert et al. 2009). The assumption is that hooks will cause less tissue damage by not removing them, and the hook will deteriorate over time or pass out of the body. However, few studies have empirically estimated the length of time required for hooks to corrode inside a fish (but see Kitano et al. 1990; Edappazham et al. 2010; McGrath et al. 2011). The same is true of studies evaluating how the physical properties of fishing hooks could influence corrosion rates (Varghese et al. 1997; Edappazham et al. 2007). Furthermore, the studies conducted on hook corrosion use a salt spray test approved by the American Society for Testing and Materials (ASTM E 352-93 2000) as a standard test. The salt spray test evaluates corrosion resistance as a measure of longevity and functionality of hooks in a marine environment, not how hooks react in a biologically digestive environment. Likewise, few studies evaluated the time hooks persist when left in bodies of fish, and those that have were of short duration and not the primary focus of the studies (e.g., Mason and Hunt 1967; Hulbert and Engstrom-Heg 1980; Schill 1996; Broadhurst et al. 2007; Butcher et al. 2007). Little information exists concerning the length of time hooks will persist inside a fish's body, and we could find no studies that examined how long hooks are present in the digestive system of fishes when hooks are ingested accidently or voluntarily.

Throughout human history, different materials have been used to catch and hook fish, from simple carved wooden or stone hooks to highly engineered metals and coatings (Edappazham 2010). Manufacturers today offer hooks with high strength and durability that resist corrosion in many conditions from freshwater to marine environments. Most hooks today are made using high carbon steel wire for strength, protected by metallic plating or lacquers to prevent the steel core from corroding. Some hooks are made from metals that are naturally resistant to corrosion including stainless steel or brass (Edappazham 2010). Manufacturers have developed hooks that are strong and resist corrosion under normal use. However, hooks with those properties will probably resist breaking down as quickly inside a fish.

In Idaho, reports of hooks and other fishing tackle ingested by White Sturgeon *Acipenser transmontanus* have increased over the last decade. However, preliminary studies demonstrated that deep hooking of White Sturgeon and line break-off rates of hooked fish are low (<5%; J. DuPont, IDFG, personal communication) suggesting this is not the mechanism for ingesting tackle. The likely cause is that White Sturgeon ingest fishing tackle left in rivers after terminal tackle becomes snagged on the river bottom and anglers break their line, losing the gear. Gear lost includes hooks, sinkers, swivels, jigs, and lures. Idaho fishing regulations require that anglers use a sliding leader/weight combination with a leader of lower test strength than the main line when fishing for White Sturgeon (IDFG 2012). The purpose of the regulation is to reduce the number of hooks lost because the sinker should break off first or prevent the sinker from remaining attached to the hook if the main line is broken. Nevertheless, when hooks break off, the bait oftentimes remains on the hook and can subsequently be eaten by White Sturgeon. Approximately 55% of the White Sturgeon sampled in the reach of the Snake River below C.J. Strike Reservoir have metal of some type in their bodies (K. Lepla, Idaho Power Company, personal communication), and 35% of the White Sturgeon sampled in the Snake River below Hells Canyon Dam contain fishing gear (J. DuPont, IDFG, personal communication). The effect of ingested fishing tackle on White Sturgeon health, growth, and reproduction is unknown, as is the length of time fishing tackle persists in the digestion systems of White Sturgeon.

Because of the difficulty of using live sturgeon, we conducted a lab study to estimate the length of time for hooks to corrode and deteriorate using a simple, buffered acid solution to simulate stomach conditions during digestion. During digestion in a stomach, hydrochloric acid (HCl) is secreted along with enzymes to hydrolyze food for absorption (Bond 1979). After food enters the stomach, the pH decreases (becomes acidic) as HCl is secreted, then returns to a neutral state (approximate pH 7) after the food passes into the intestines (Bond 1979; Moyle and Cech 1988). The pH in a sturgeon stomach can range between 1-4 (Bond 1979; Moyle and Cech 1988), and can vary considerably depending on the food consumed. We created an HCl solution buffered with potassium chloride (KCl) at pH 2 to simulate stomach conditions. Our objective was to measure the time necessary for hooks with different finishes to dissolve in simulated stomach conditions and estimate the time required for hooks to corrode or break up to a point where a fish could possibly pass the hook material through the digestive tract.

OBJECTIVES

1. To determine the time required for fishing hooks to dissolve in simulated stomach conditions of a fish.

METHODS

We selected hooks to conduct our experiment in sizes and finishes commonly used for White Sturgeon angling in Idaho, and that were most widely available in local stores. We chose Gamakatsu Octopus hooks in size 7/0 (model # 02149) finished with black nickel, silver nickel, and red lacquer, and Mustad 4/0 hooks (model # 92671) with a bronze finish. We prepared 20 total hooks of each finish, divided into two treatments. For the first treatment, the finish on 10 hooks was left intact (whole), and for the second treatment, we abraded (scratched) a 10 mm section along the bottom of the shank. The finish was compromised by twice dragging the hook across a file. We scratched the hooks to simulate the abrasive action of rocks contacting hooks on the stream bottom that could potentially hasten the dissolving of a hook by removing the protective barrier. We also placed 10 brass snap swivels (size 1) into the acid solution to determine the time required for those to dissolve.

We prepared a solution of HCl buffered with KCl to simulate the conditions inside a stomach during digestion. The solution was buffered to keep the pH consistent throughout the experiment. We began by dissolving 149.1 g KCl in 1000 ml of deionized water to make a 2 M KCl solution. We then mixed 324 ml of 2 M HCl and deionized water to a volume of 3000 ml. Finally, we combined the 1000 ml KCl solution with 3000 ml of HCl solution to achieve a 4000 ml, 2 M HCl/KCl stock solution. Before use, we mixed 275 ml of the stock solution with 750 ml of deionized water (1:3 ratio) to achieve a 0.5 M HCl/KCl solution with a pH 2. We confirmed the pH with litmus strips to ensure the correct pH was achieved. Individual hooks were placed in 100 ml glass beakers and covered with 50-60 ml of the buffered acid solution. Beakers were sealed with Parafilm® to prevent evaporation and protect against spills.

Hooks were weighed periodically to quantify the amount of metal lost to the reaction in the acid solution. Hooks were initially weighed before placing in the acid solution then were removed weekly, rinsed, dried, and weighed using a jewelers scale (±0.002 mg). We followed a strict protocol during weighing to prevent spills and ensure proper drying of the hooks. Using four 1 L flasks, we filled one with a solution of tap water and approximately 250 g of baking soda. The second was filled with tap water. The third was filled with deionized water, and the fourth with raw baking soda for neutralizing used solution and emergency spills. We removed the hooks from the acid solution with non-reactive forceps and dipped the hook into the first beaker with the baking soda and water solution for up to 30 s or until the visible reaction ceased. The hook was then dipped into the plain tap water, and finally in the deionized water. After rinsing, the hooks were placed on absorbent paper towels to air dry thoroughly. After several minutes, the dry hooks were weighed and placed back into their original acid solution beakers. The pH of the acid solution in each beaker was checked with litmus paper and replaced if the pH was above 3. Replacement of the acid solution was required approximately every three weeks. We measured the corrosion of the hooks by dividing the weight of a hook by the previous weight and subtracting from one to calculate the percent of weight lost during weekly intervals. We also calculated the total amount of weight lost as a percent by dividing the final weight by the initial weight and subtracting from one. We analyzed the effect of finish and treatment (whole and scratched) on the total percent weight lost over the entire period with analysis of variance ($\alpha = 0.05$) and Tukey pairwise comparisons to determine where differences existed. The weekly intervals were analyzed with linear regression to forecast the time required for the hooks to disappear entirely.

RESULTS

Fishing hooks with different finishes corroded at different rates. After 555 days in the acid solution, the effect of finish was highly significant ($F = 98.9$, $P < 0.0001$) and explained 78% of the variation in hook corrosion. The effect of treatment was not significant ($F = 0.3$, $P = 0.58$). Tukey comparisons suggested that hooks with each finish were significantly different from each other (Figure 16). Hooks with the whole bronze finish were completely dissolved after 104 days whereas hooks with the scratched bronze finish disappeared after 111 days (Table 3). Of the scratched and unscratched hooks remaining after 555 days, those with the silver nickel finish lost the most weight (84.3%), hooks with black nickel (58.7%) lost less weight, and hooks with the red lacquer finish lost 47.7% of their weight (Figure 16). Regressing the weekly interval for lost weight, the silver nickel hooks should disappear in approximately another 34 days (589 days total). Hooks with the black nickel finish should last 351-436 d (906-911 days total). We estimate the red lacquer finished hooks should last another 629-631 d (1,186-1,188 days total; Table 2).

The brass swivels lost 27% of their weight over the 555 days of the experiment (Figure 16). We estimate the swivels would take 2,421 days total to completely dissolve.

DISCUSSION

The general advice given to anglers that hooks will corrode away quickly if left inside a fish may or may not be correct in the case of sturgeon-size hooks. The bronze finished hooks took almost four months to completely dissolve, whereas the next quickest to dissolve were the silver nickel finish hooks at almost 20 months. We estimate the red lacquer finish hooks to take the longest time for the hooks to dissolve at over 3 years. To some, 4 months is relatively fast for a hook to disappear, but clearly over three years is a long time. Broadhurst et al. (2007)

reported that, at the completion of their study (105 d), hooks inside yellow bream retained over 95% of their original weight.

A surprising result was the length of time required for the swivels to dissolve. Most of the weight the swivels lost was because the snap part on several of the swivels dissolved quickly (approximately 30 d), however, the snap part is supposed to be stainless steel and thereby not susceptible to acid. The brass part of swivels and those with the correct snap material lost practically no weight over the study period.

Importantly, our lab experiment does not account for other factors that could affect the length of time a hook could persist in the digestive system of a fish. Factors such as abrasion of the hook from other tackle (swivels or sinkers), from other hard food items (crayfish or clams) probably accelerate the breakdown of hook material. Regardless, a hook ingested by a fish would not likely dissolve completely, but would break into pieces after the material weakened sufficiently from digestion; subsequently, the pieces would be able to pass through the intestine and out of the body. However, we designed the study to be on the severe end of digestive environments by keeping a relatively constant pH of 2 for 24 h/d at ambient room temperature (18-21°C). When a fish ingests food, the pH inside the stomach becomes acidic only when food is present, probably only several hours/d, and water temperatures are oftentimes cooler depending on environmental conditions, which would slow digestion rates. Increased temperatures accelerate the rates that chemical reactions occur (Pauling 1970). Therefore, our estimates for the length of time a hook would take to dissolve inside a fish stomach are likely underestimated. However, hooks probably do not need to completely dissolve inside the digestive tract because, in the case of White Sturgeon, the peristaltic action of the gizzard likely breaks the hook apart after the metal is weakened, allowing passage of the smaller pieces. Further research should evaluate the tensile or compression strength required to break hooks after exposure to stomach conditions.

In summary, results suggest that, in the absence of abrasive materials, hooks commonly used for sturgeon fishing may require up to a year or more, depending on the finish, to dissolve adequately to pass through the digestive system of a White Sturgeon (also see previous chapter). The amount of time hooks persist in the digestive system increases the likelihood that stress or physical injury may lead to increased mortality in populations of White Sturgeon or other fish species that ingest such material.

RECOMMENDATIONS

1. Introduce other fishing gear (i.e., swivels, sinkers, smaller hooks, monofilament, etc.) into the simulated stomach solution to evaluate the time required for those materials to dissolve.

2. Evaluate the tensile strength of hooks at regular intervals during submersion in the simulated stomach conditions to approximate the time required for hooks to break apart inside the digestive system of a White Sturgeon.

ACKNOWLEDGEMENTS

We would like to thank Daniel Madel and Kristy Stevenson for assisting in this study. We also thank Joe DuPont and David Venditti for constructive comments and suggestions on the manuscript. Cheryl Zink formatted the report.

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Table 3. The estimated number of days hooks with different finishes and treatments, and brass swivels will take to dissolve completely in a simulated stomach solution and the R^2 value for the regression line used to make the estimates. Hooks were in the solution for 555 d.

Hook Finish	**Treatment**	R^2	**# of days**
Bronze	Scratched	0.96	111*
	Whole	0.96	104*
Silver Nickel	Scratched	0.95	589
	Whole	0.92	510
Black Nickel	Scratched	0.97	906
	Whole	0.98	991
Red Lacquer	Scratched	0.95	1184
	Whole	0.97	1186
Brass Swivel		0.96	2421

*- denotes the actual number of days for hooks to completely dissolve

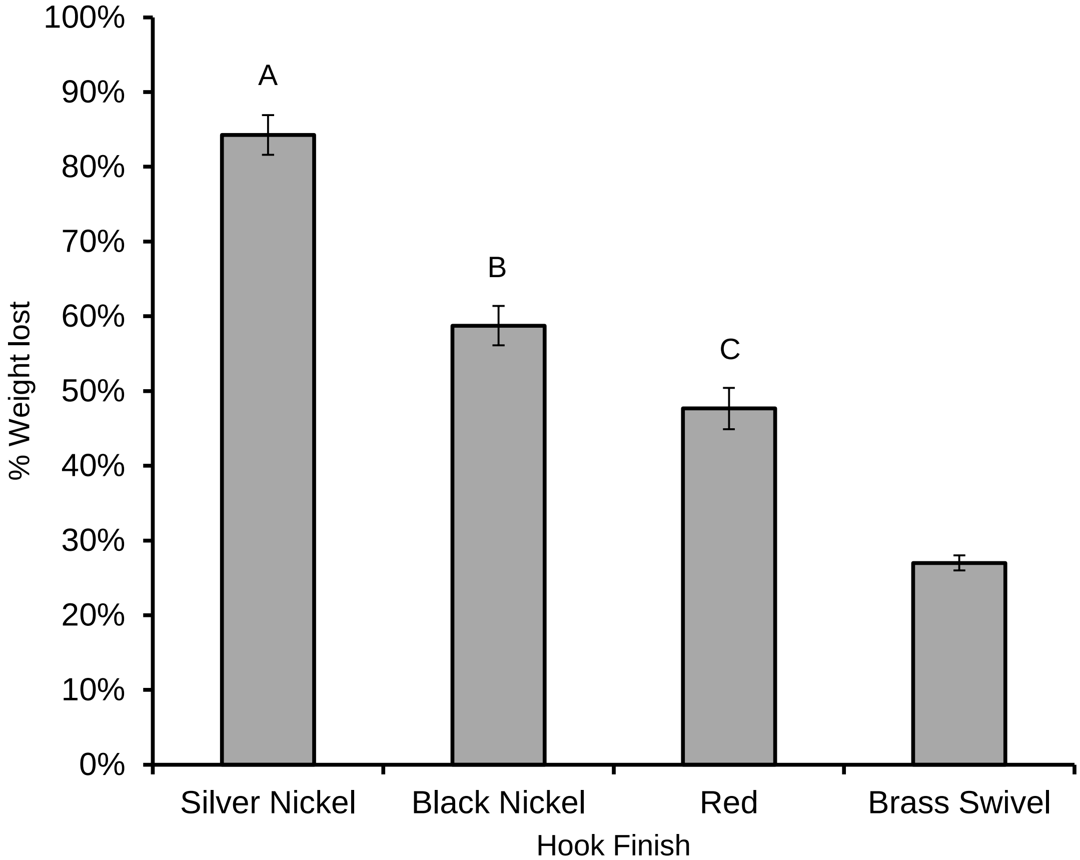

Figure 16. The percent weight lost hooks with three finishes and brass swivels after 555 d in the simulated stomach solution. Bars with different letters are significantly different. Error bars are 95% confidence intervals.

ANNUAL PERFORMANCE REPORT
SUBPROJECT 3: HOOK INVESTIGATIONS

State of: Idaho Grant No.: F-73-R-34 Fishery Research

Project No.: 5 Title: White Sturgeon Research

Subproject #3: Ingested Metal Investigations: Metal ingestion and x-ray comparison

Contract Period: July 1, 2012 to June 30, 2013

ABSTRACT

Over the last decade, field reports indicate many White Sturgeon *Acipenser transmontanus* have ingested and retained hooks and other fishing tackle in their digestive systems. Crews x-rayed White Sturgeon in the Hells Canyon reach of the Snake River to evaluate the percentage that contain metal, the number and type of metal, and the passage or retention time of metal in the digestive system of White Sturgeon. A smaller percentage of White Sturgeon <100 cm (9%) contain metal than White Sturgeon >100 cm (39%). The majority of the metal identified in the digestive system of White Sturgeon is fishing tackle, with hooks being the primary type, followed by jigs, swivels, pieces of broken hooks, sinkers, and spinners. White Sturgeon with metal had a smaller pelvic girth than fish with no metal, indicating a reduced body condition. White Sturgeon x-rayed at least twice in consecutive years appear able to digest or pass metal, but also retain metal for up to 26 months.

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INTRODUCTION

In Idaho, populations of White Sturgeon *Acipenser transmontanus* were in decline due to over harvest and habitat fragmentation from dam construction for at least 100 years (Cochnauer et al. 1985), although populations appear to have stabilized over the past 20 years. Under strict catch-and-release and barbless hook regulations since 1971, sport fisheries for White Sturgeon still exist in Idaho (Idaho Department of Fish and Game 2008). Due to the popularity of sturgeon fisheries, and the potential sensitivity to increased mortality rates, managers are concerned about the effects of angling pressure and ingested fishing tackle on white sturgeon populations. More specifically, the terminal tackle used to catch White Sturgeon may be reducing reproductive success or increasing mortality rates due to chronic stress from deep-hooking injury or the ingestion of lost tackle. Kozfkay and Dillon (2010) documented that individual White Sturgeon were caught an average of 7.7 times in a one-year period for a population that lives below C.J. Strike Dam in southern Idaho. Likewise, fish sampling has identified that approximately 30% of White Sturgeon in the Hell's Canyon reach of the Snake River have metal hooks or other metal fishing tackle in their digestive systems (J. DuPont, IDFG, personal communication; K. Lepla, Idaho Power Company, personal communication).

Considering that White Sturgeon in Idaho are caught almost exclusively using bait, and in some reaches are caught multiple times per year, a reduction in deep hooking rates could benefit populations. Recent studies suggest that using circle hooks reduces deep hooking injury in many fish species (Cooke at al. 2003a, 2003b; Cooke and Suski 2004; Fobert et al. 2009) and reduces the mortality of caught and released fish compared to conventional J hooks (Prince et al. 2002; Aalbers et al. 2004; Graves and Horodysky 2008; Serafy et al. 2008). However, the majority of these studies were conducted on marine fish in commercial long-line fisheries. Several studies also suggest that when a fish is deeply hooked, cutting the line and releasing the fish results in lower post-hooking mortality (Schill 1996; Tsuboi et al. 2006; Fobert et al. 2009). However, few studies have examined long-term effects on mortality rates, reproductive fitness, or body condition when hooks are left in fish, and the studies that did focus on fish that were deep hooked while angling (see Mason and Hunt 1967; Marnell 1969; Hulbert and Engstrom-Heg 1980; Broadhurst et al. 2007; Butcher et al. 2007). To our knowledge, no published studies exist that identify the length of time hooks eaten by fish persist in the digestive system or the effects on mortality, growth rates, or reproductive success of any fish species.

The digestive system of White Sturgeon is similar to other chondrosteans (Buddington and Christofferson 1985). The alimentary canal length (ACL) is short, ranging from 70-100% of fork length. The alimentary canal consists of the esophagus (5% ACL); the stomach, composed of two regions (40-50% ACL); the intestine (20-25% ACL); the spiral valve (20-25% ACL); and a short rectum (2-3% ACL). The two regions of the stomach form a loop, and consist of an anterior fore-stomach and a muscular pyloric region, often referred to as a gizzard. The fore-stomach is capable of distending 3-5 times the empty state when food is present. The muscle wall of the gizzard is hypertrophic and is designed to aid in grinding up hard food items, such as fish bones or shells, for further digestion (Buddington and Christofferson 1985).

The objectives for this study were to x-ray and gather size information of White Sturgeon over time from a wild population in the Hells Canyon reach of the Snake River to evaluate the percentage of White Sturgeon that contain metal, identify the types and amounts of metal ingested, and by recapturing previously x-rayed White Sturgeon, to assess the passage time or retention of metal in their digestive systems.

OBJECTIVES

1. Determine the percentage of White Sturgeon that contain metal in the Hells Canyon reach of the Snake River.

2. Determine if the presence of metal in the digestive systems of White Sturgeon affects growth.

3. Evaluate the passage and retention time of metal in the digestive system of White Sturgeon.

METHODS

Study Area

The study area for our project was the Hells Canyon Reach of the Snake River, extending from Hells Canyon Dam downstream to Lower Granite Dam and included the lower Salmon River from the confluence with the Snake River upstream 51 km. The reach was divided into nine sections to account for differing habitat, river management, and White Sturgeon densities (Figure 17). No x-rays were taken in sections 1 and 2 because they occur in Washington State and are out of IDFG jurisdiction. Upstream of Section 2, access to the river is open with a road extending up the west bank ending at the confluence of the Grande Ronde River in Section 4. No road access exists above the Grande Ronde River except for road and boat ramp access at Pittsburg Landing near the upstream end of Section 6 at Doug Bar and at the upstream end of Section 8 at Hells Canyon Dam.

X-ray and Metal Detection

White Sturgeon in Hells Canyon were sampled with set lines and by angling from 2010 through 2012 by Idaho Fish and Game and Idaho Power personnel to identify the proportion of sturgeon with metal in their digestive systems. All fish captured were scanned with a hand-held metal detector (Garrett Pro-pointer or White's Matrix 100) to identify the presence or absence of metal. When the x-ray equipment (Sound-Eklin tru/DRLX System) was present, all white sturgeon >130 cm (fork length), and all fish that scanned positive for metal, regardless of size, were x-rayed to quantify the number, location, and longevity of ingested metal in the digestive system. To reduce the number of fish x-rayed with no metal, we assumed the metal detector correctly identified the presence or absence of metal 100% of the time in white sturgeon <130 cm (fork length). We calculated the proportion of White Sturgeon that contained metal by river section, counted the total number of pieces present, identified the metal pieces (i.e. hooks, swivels, sinkers, etc.), and identified the location of metal in the digestive tract. Images from individual sturgeon captured and x-rayed multiple times over the course of sampling were compared to evaluate the processing and passage of metal in their digestive systems over time. We also validated the presence/absence of metal using the metal detector with the x-ray.

The x-ray system consisted of an x-ray generator and a plate that receives the x-ray beam, compiles the received information, and sends a digital image to a computer. The protocol settings on the x-ray generator were consistently set at 96 kilovolts (kVp) and 2.00-second exposure (mAs) to produce an acceptable image. A custom, wheeled rack with adjustable brackets was constructed on which to mount the x-ray generator and plate to aid alignment with the study fish in the boat. Using the rack also allowed workers to stay a minimum of 2 m away from the x-ray generator during use, the safe distance required to avoid x-ray scatter. After capture, sturgeon were placed in a sling and suspended across the gunnels of the boat between the x-ray generator and the plate. Sturgeon were kept upside down in the sling and had a constant water supply pumped across the gills. To capture the entire digestive tract of individual fish, the x-ray equipment was aligned with the gill arches for the first x-ray and moved posteriorly the width of the plate after each x-ray until the vent was reached, resulting in 2-8 individual x-ray images for each White Sturgeon. The x-ray equipment was powered with a portable 2000 watt gas generator (Honda 2000ex)

We analyzed x-rays of White Sturgeon to identify and enumerate the metal in their digestive systems. X-ray images for individual fish were stitched together to make counting and identifying metal content simpler and more accurate. First, we counted the total number of individual pieces of metal. We then counted the number of whole hooks and other tackle into different categories including: 1) sturgeon hooks; 2) salmon, steelhead, and trout *Oncorhynchus ssp* hooks*.*; 3) Jigs (hooks with weighted heads typically used for bass *Micropterus ssp.* or other warm-water species); 4) Swivels; and 5) Pieces (pieces of broken hooks, sinkers, and other unidentifiable metal seen in the x-rays not in the previous categories).

We recorded fork length (cm), pectoral girth (cm), and pelvic girth (cm) for all White Sturgeon captured to evaluate differences between fish with and without metal in their digestive systems. Pectoral girth was measured around the body immediately posterior to the pectoral fin insertion point. Pelvic girth was measured around the body immediately anterior to the pelvic fin insertion point. Using linear regression, we assessed the differences in pelvic girth and pectoral girth between White Sturgeon (>130 cm) that contained metal in the digestive system and those that did not ($\alpha = 0.10$) at given fork lengths. Girth and length values were transformed ($\log_{10}$) to meet the assumptions of regression analysis. All analysis was conducted using Minitab (2010).

RESULTS

A total of 1,056 White Sturgeon were scanned for metal in the Hells Canyon Reach of the Snake River from 2010 through 2012. Of those fish, 223 scanned positive for metal (21.1%) and 833 (78.9%) scanned negative for metal (Table 4). During the same period, 200 White Sturgeon were x-rayed, including 108 that contained metal and 92 that did not. Forty-one of the x-rayed fish contained three or more pieces of metal with the balance containing one or two pieces (Figure 18). The greatest number of pieces of metal identified was 14 pieces. The majority of the types of metal identified in x-rays were fishing tackle, including hooks and pieces of hooks, swivels, jigs, spinners, and sinkers (Figure 18).

We compared the accuracy of the metal detector by validating the presence of metal with x-rays. Between 2011 and 2012, 131 White Sturgeon were scanned with both a metal detector and x-ray. The metal detector and x-ray agreed 90% of the time with 76 White Sturgeon scanning positive for metal with the detector, 6 of which contained no metal in the x-ray. Conversely, the metal detector and x-ray agreed 80% of the time with 55 White Sturgeon scanning negative for metal with the detector, 9 of which contained metal in x-rays (Table 5).

The percent of White Sturgeon that contained metal varied widely between length groups from different river sections. Generally, a low percentage (9%) of smaller White Sturgeon (<100 cm) contained metal. In contrast, 39% of White Sturgeon in both 150-199 cm and 200-250 cm length groups contained metal (Figure 18). Twenty-five percent of the White Sturgeon in the 100-149 cm and >250 cm length groups contained metal (Figure 20). The percentage of White Sturgeon from different study sections also contained different amounts of metal (Figure 21). White Sturgeon from sections 3 and 4 contained the most metal (23% and 30%, respectively). Section 5 contained the least metal (10%), whereas the percent of White Sturgeon with metal decreased from 21% in section 6 to 13% in section 9 (Figure 21).

Regression analysis of pelvic girth and fork length, and pectoral girth and fork length suggests that the slope of the lines comparing fish with and without metal are not different ($P > 0.1$). The elevations of those lines, however, were different ($P < 0.001$) and fish with metal present had, on average, a 2.6 cm smaller pelvic girth (Figure 22) and a 0.64 cm smaller pectoral girth (Figure 23) than fish with metal.

We recaptured eleven previously x-rayed White Sturgeon with between 5 and 26 months between x-rays. Eight of those fish contained metal on both occasions, two contained no metal the first time they were x-rayed but did contain metal the second time, and one White Sturgeon contained no metal on both x-ray occasions (Table 6). The eight White Sturgeon that contained metal in both x-ray years retained at least one of the pieces of metal from the first x-ray year, but five of the fish also lost between one and nine pieces of metal over the same period (Table 7). The metal identified were mostly hooks, but also included swivels, bass jigs, and spinner parts.

DISCUSSION

Although our data indicates that White Sturgeon consume metal from fishing tackle lost in the river by anglers, and that the metal remains in their digestive systems for at least two years (Table 6-7), detecting negative effects on the population is difficult. White Sturgeon from the Hells Canyon reach of the Snake River grow slowly, making comparisons of growth of individual fish tenuous over short time scales. However, our data suggests that White Sturgeon with metal in their digestive systems have a smaller pectoral girth than those without metal (Figures 22-23). This indicates that when metal is present, White Sturgeon are not maintaining a similar body condition to those without metal. Reasons may be that White Sturgeon with metal do not eat as much or that the metal or other tackle, such as monofilament, are partially impeding the digestive tract, reducing the uptake of nutrients. Reduced body condition is concerning because it could affect gonad development and possibly reduce reproductive fitness. Currently, we do not understand the effects or whether the observed differences could have population level effects.

The percentage of White Sturgeon that contain metal in the different river sections may reflect the effort of anglers fishing for sturgeon and other species. Sections 3 and 4 are accessible by road and have popular steelhead *O. mykiss* and Chinook Salmon *O. tshawytscha* fisheries. Therefore, angling pressure in sections 3 and 4 are likely higher than upriver sections, resulting in the more frequent loss of fishing tackle and increasing the availability of tackle for White Sturgeon to ingest. One surprise is the low percentage of White Sturgeon from section 5 that contain metal. Section 5 is a narrow reach where pools lack definition and locations to fish for White Sturgeon are less obvious. As such, salmon and steelhead anglers are also likely to expend less effort angling, perhaps decreasing the amount of tackle lost in that section of the river.

White Sturgeon are apparently able to process and pass metal through their digestive system, although they can also retain metal for at least 26 months and continue consuming metal. Of the eleven White Sturgeon we sampled and x-rayed in multiple years, only one did not contain metal on both occasions, but that fish was also resampled in the shortest interval (5 months; Table 6). Our results suggest that White Sturgeon may consume and process unknown amounts of metal, potentially over their entire lifetime and that, although many did not contain metal when we sampled them, White Sturgeon may continually consume and pass metal through their digestive systems. We are continuing the study to increase the sample size of White Sturgeon x-rayed multiple times to further our understanding.

RECOMMENDATIONS

1. Continue x-raying White Sturgeon in Hells Canyon in 2013 and 2014 until 20-30 fish have been x-rayed more than once, to more definitively assess how White Sturgeon retain or process metal over time.

ACKNOWLEDGEMENTS

We would like to express many thanks to Idaho Power Company and their sturgeon crews, especially Ken Lepla, Brandon Bentz, Phil Bates, Chad Reininger, Dave Meyer, Tim Stuart, Gabe Cassel, and the seasonal crews for assistance collecting the x-ray data and providing financial support to purchase the x-ray equipment. I would also like to thank Dennis Daw, Liz Mamer, Daniel Madel, Matt Belnap, and Erin Larson for their assistance operating the x-ray equipment and all the people from Region 2 who assisted with angling. Liz Mamer also produced the study area map. I thank David Venditti and Joe DuPont for constructive comments and suggestions on the manuscript. Cheryl Zink formatted the report.

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Table 4. The total number of White Sturgeon with and without metal as determined with a metal detector and an x-ray from 2010-2012 in the Hells Canyon reach of the Snake River.

	Number of Fish		
Detection Method	Metal Present	No Metal	Total
X-ray	108	92	210
Metal detector	223	833	1,056
Total	332	925	1,266

Table 5. The number of White Sturgeon sampled in the Hells Canyon reach of the Snake River with and without metal according a metal detector compared to the presence of metal observed in x-ray images of the same fish.

	Metal with X-Ray	
Metal with Detector	Yes	No
Yes	70	6
No	9	46

Table 6. The PIT tag number, sample dates, months at large, length measurements, and the presence of metal verified by x-ray of White Sturgeon recaptured and x-rayed on multiple occasions from the Snake River in the Hells Canyon reach.

PIT #	Sample Date	Months at Large	Total Length (cm)	Fork Length (cm)	Pectoral Girth (cm)	Metal Present
1C2D9B9EF3	10/8/2010		197	169	59	Y
	7/14/2011	9	193	173	58	Y
1BF1675772	5/28/2010		133	118	45	N
	7/10/2012	26	141	124	49	Y
1BF25F5838	5/26/2010		152	135	56	Y
	7/10/2012	26	173	151	62	Y
1C2D5CB031	5/28/2010		79	69	26	N
	10/20/2010	5	82.5	74	25	N
1C2D717E02	7/15/2011		251	218	90	Y
	9/18/2012	14	250	218	85	Y
1C2D9B1799	10/6/2010		271	242	97	Y
	10/2/2012	24	273	247	104	Y
1C2D9B82BE	10/19/2011		223	198	75	Y
	8/28/2012	10	226	198	71	Y
1C2D9BA84E	10/18/2011		90	76	26	Y
	8/28/2012	10	89	77	25	Y
1C2D709F06	7/15/2011		185	177	72	Y
	7/31/2012	12	-	-	-	Y
1C2D9C2E74	10/19/2010		199	178	73.5	Y
	7/16/2011	9	195	178	70	Y
1C2D703641	7/15/2011		283	259	110	N
	9/18/2012	14	277	253	109	Y

Table 7. The PIT tag number, months at large, number of pieces of metal identified in individual White Sturgeon during the x-ray year, and the number of pieces of metal lost between x-ray years (Lost), new pieces of metal gained between x-ray years (New), and the number of pieces of metal identified in both x-ray years (Old) in White Sturgeon recaptured and x-rayed on multiple occasions from the Snake River in the Hells Canyon reach.

		Pieces of Metal					
		X-Ray Year					
PIT #	Months at large	2010	2011	2012	Lost	New	Old
1C2D9B9EF3	9	15	8	-	9	6	2
1BF1675772	26	0	-	2	0	2	0
1BF25F5838	26	1	-	2	1	0	2
1C2D5CB031	5	-	0	0	0	0	0
1C2D717E02	14	-	2	1	1	0	1
1C2D9B1799	24	2	1	-	1	0	1
1C2D9B82BE	10	-	6	4	5	3	1
1C2D9BA84E	10	-	1	1	0	0	1
1C2D709F06	12	-	1	1	0	0	1
1C2D9C2E74	9	1	1	-	0	0	1
1C2D703641	14	-	0	1	0	1	0

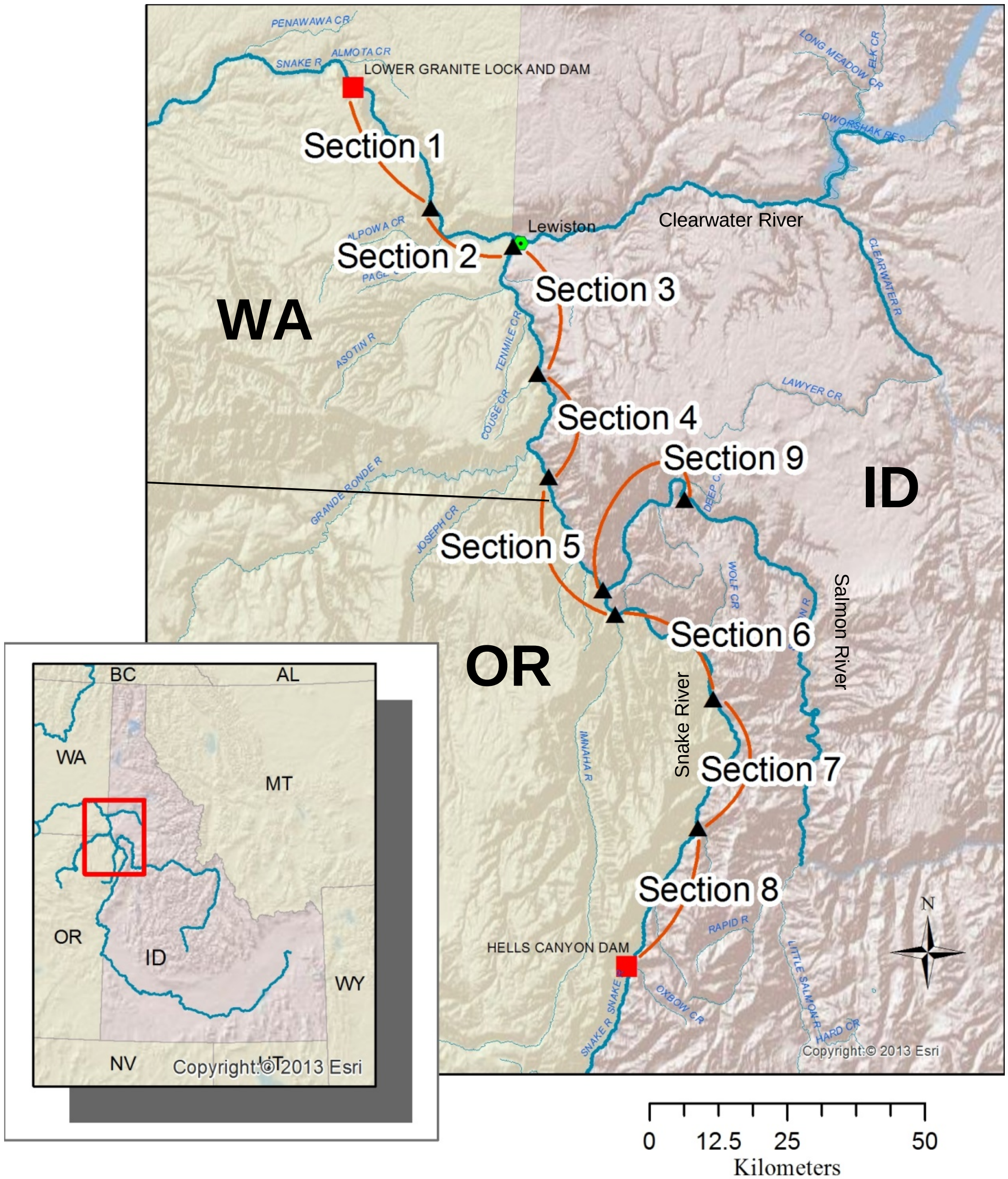

Figure 17. Map of the Hells Canyon reach of the Snake River from Hells Canyon Dam downstream to Lower Granite Dam and locations of the study sections.

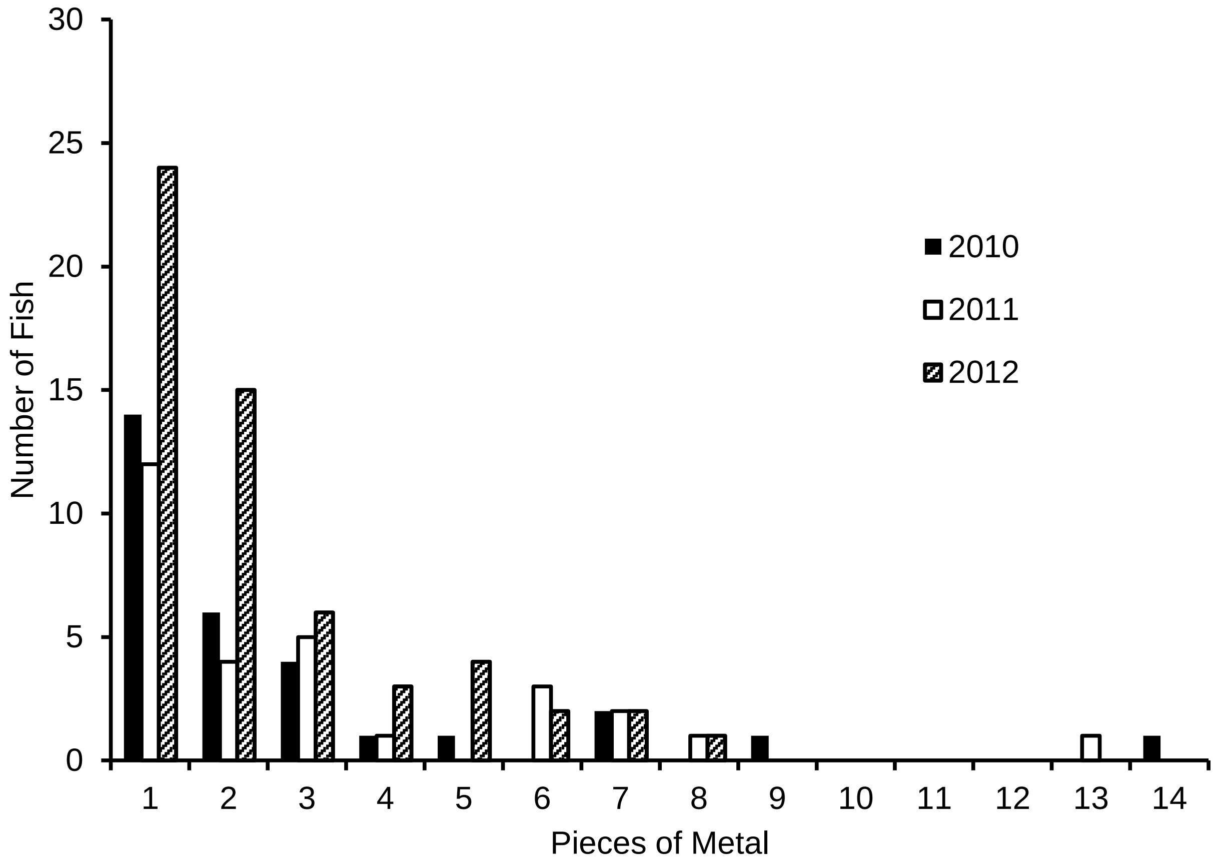

Figure 18. The number of White Sturgeon that contain different numbers of pieces of metal in different years. Counts were made from x-rays of White Sturgeon sampled from the Snake River in the Hells Canyon reach.

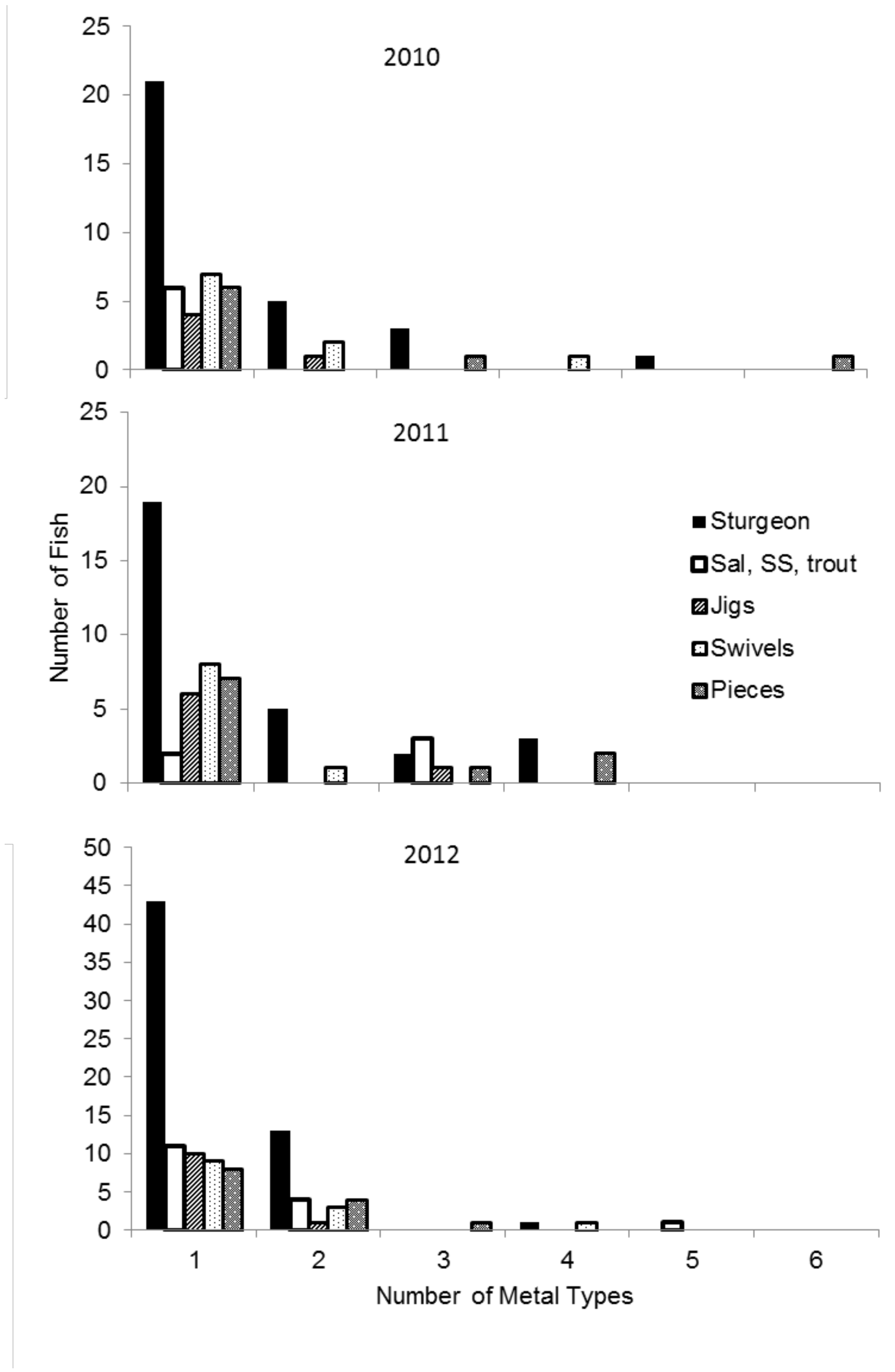

Figure 19. The number of White Sturgeon that contain different numbers of metal types (Sturgeon hooks, Salmon, steelhead and trout hooks, jigs, swivels, and pieces of metal) in different years. Counts were made from x-rays of White Sturgeon sampled from the Snake River in the Hells Canyon reach.

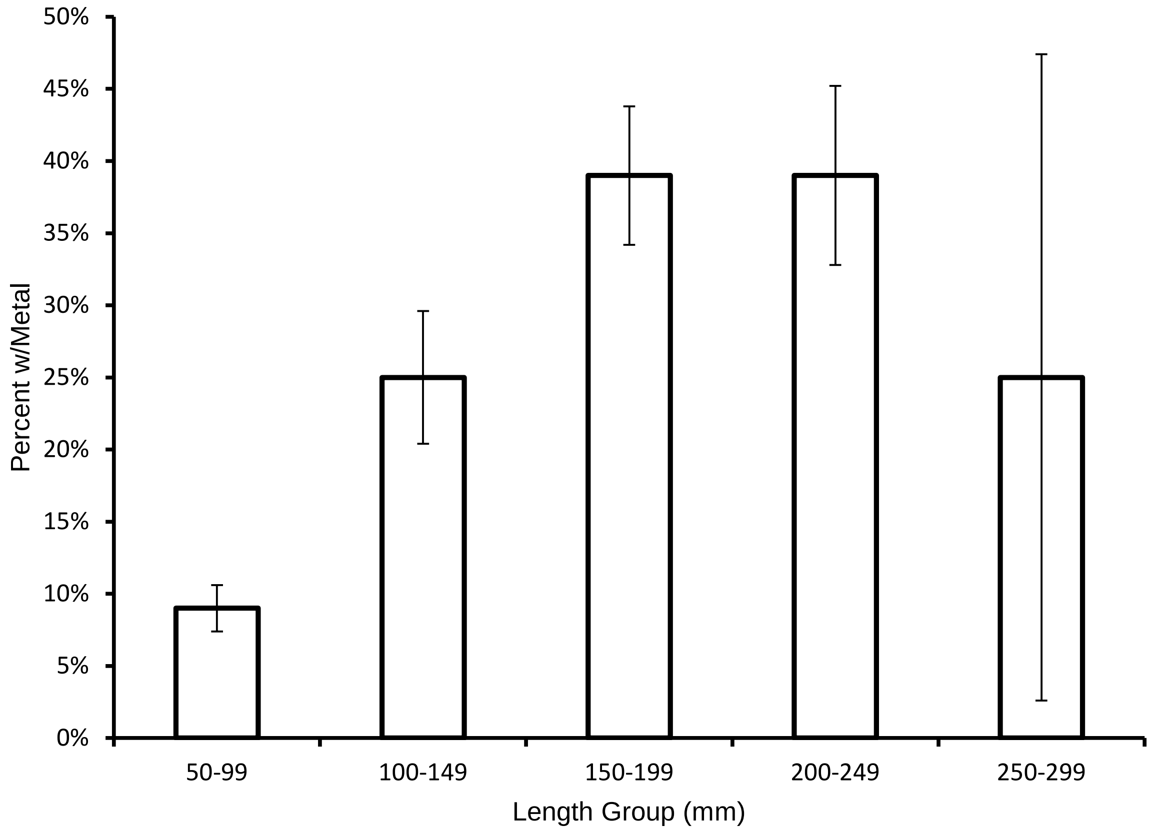

Figure 20. Percentage of White Sturgeon by length group from the Snake River in the Hells Canyon reach that contained metal in 2011 and 2012. Error bars are 90% confidence intervals.

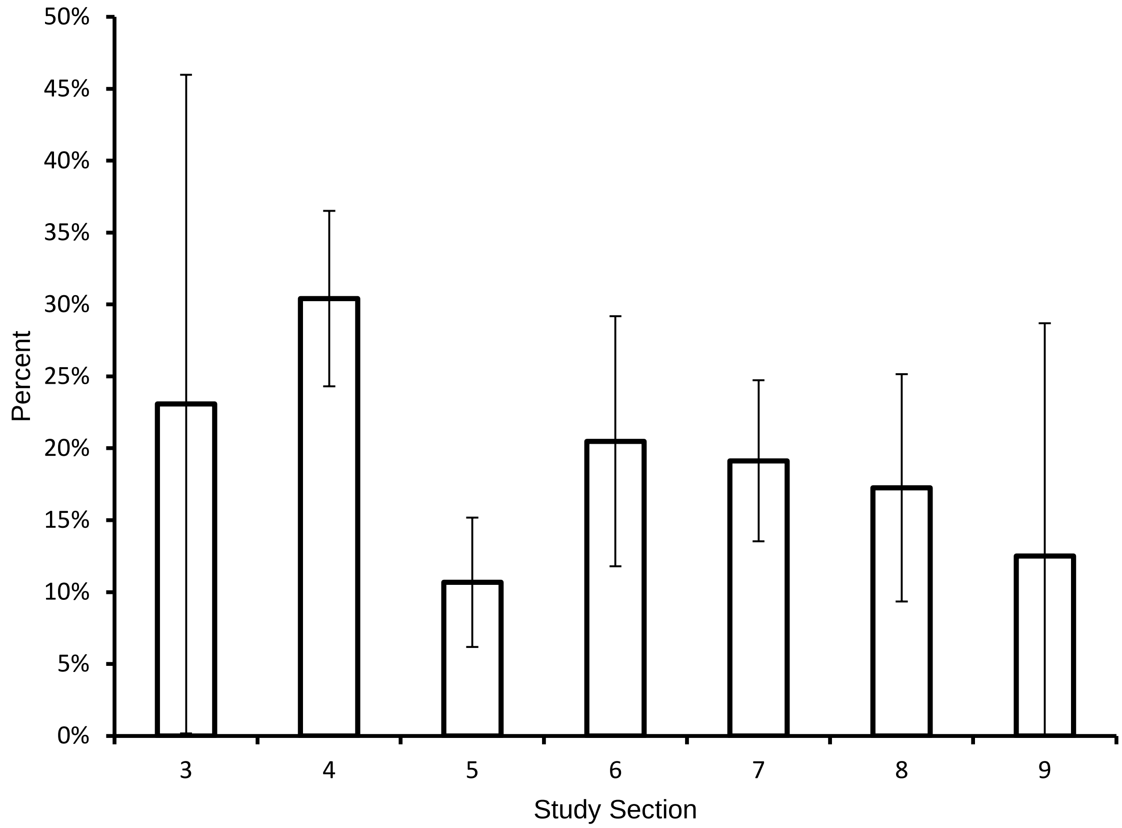

Figure 21. Percentage of White Sturgeon in study sections 3-9 from the Snake River in the Hells Canyon reach that contained metal in 2011 and 2012. Error bars are 90% confidence intervals.

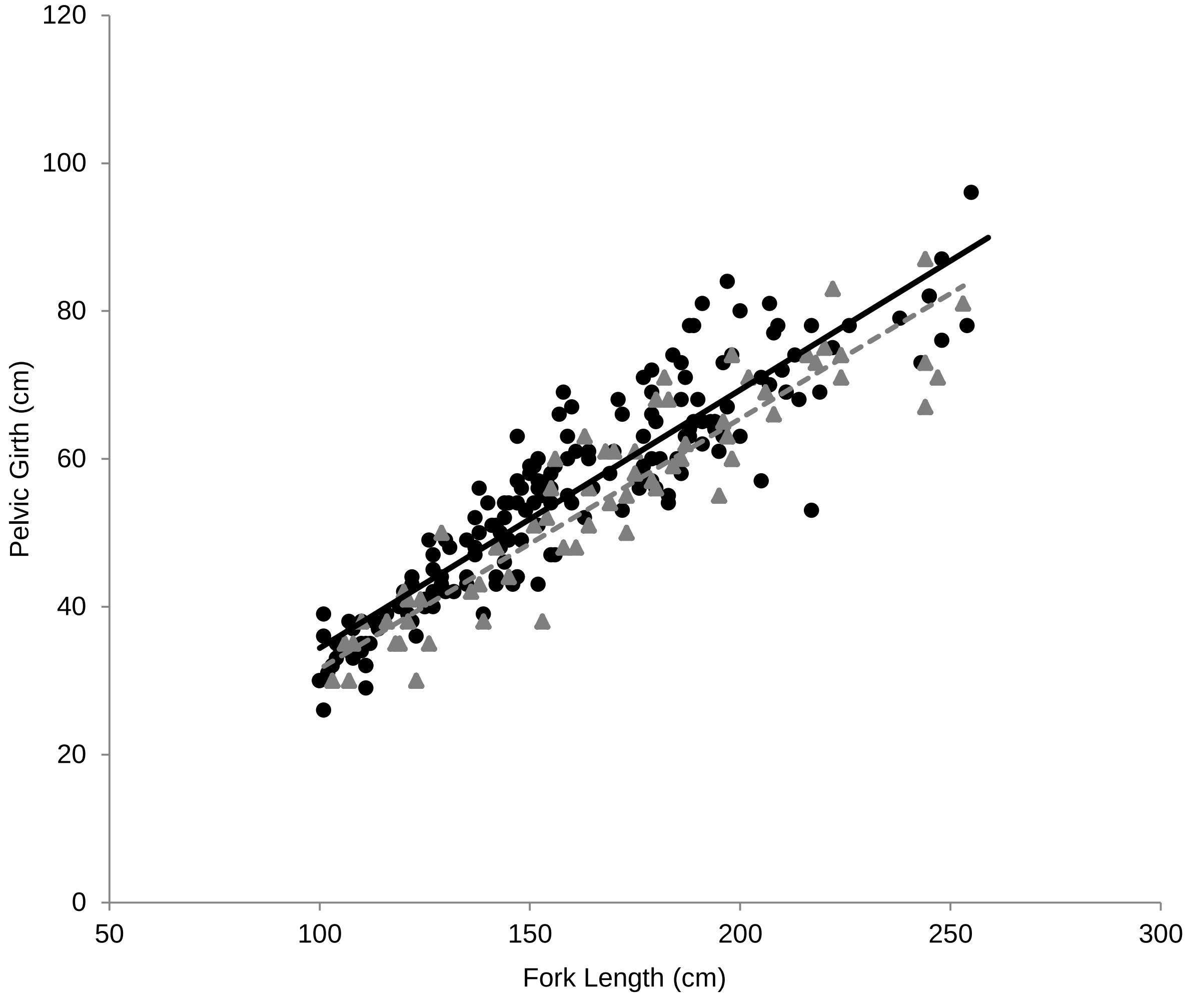

Figure 22. Fork Length/pelvic girth comparison of White Sturgeon that contained metal (grey triangle) and those that did not contain metal (black circles) from the Snake River in the Hells Canyon reach from 2010 through 2012.

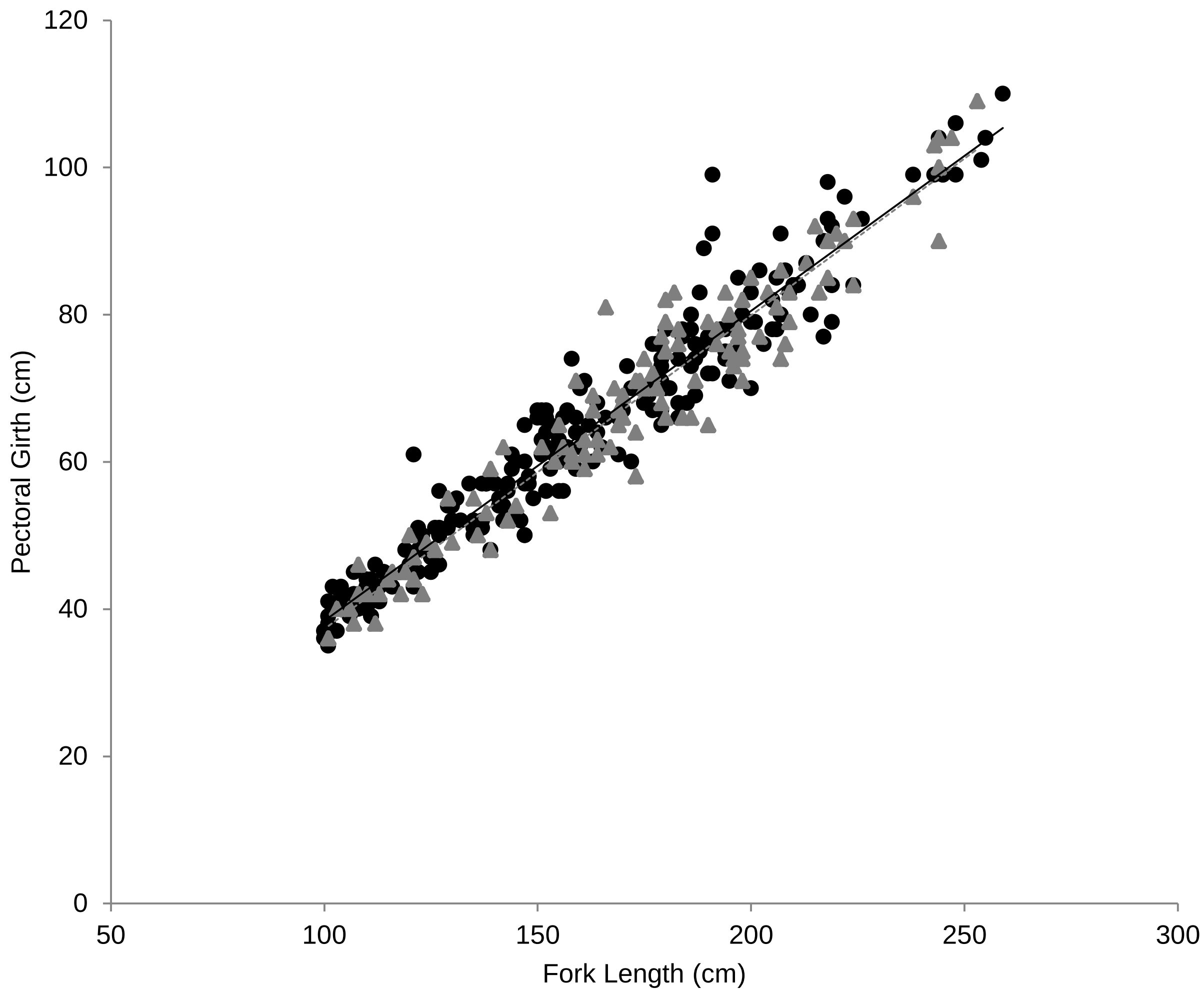

Figure 23. Fork length/pelvic girth comparison of White Sturgeon that contained metal (grey triangle) and those that did not contain metal (black circles) from the Snake River in the Hells Canyon reach from 2010 through 2012.

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