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Subproject 2: Hook Investigations: Hook Corrosion

Subproject 3: Angling Investigations: Comparison of Inline and Offset Circle and J Hooks

Subproject 4: Ingested Metal Investigations: Metal ingestion and X-ray Comparison

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ANNUAL PERFORMANCE REPORT
SUBPROJECT 1: HATCHERY WHITE STURGEON INVESTIGATIONS

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ABSTRACT

Angling for White Sturgeon *Acipenser transmontanus* is popular in Idaho, causing managers to consider the effects that angling pressure or ingested fishing tackle may have on populations. We implanted circle and J hooks in offset and inline alignments at three levels (one hook, five hooks, and five hooks with a monofilament leader and a swivel) into the stomachs of 108 hatchery White Sturgeon with10 control fish to assess the effects of ingesting hooks on the growth and stress response, and to monitor corrosion and passage of hooks. After 782 days of the experiment, x-ray images revealed that only 2.5% of White Sturgeon with implanted hooks expelled all the implanted material from their digestive systems, although all hooks showed signs of corrosion. Hooks in study fish that received multiple hooks corroded faster than when a single hook was present, likely because hooks were abrading each other and scratching the protective finish on the hooks. Fish with implanted hooks grew slightly less compared to control fish with no hooks, suggesting that ingested tackle may hinder growth of White Sturgeon. However, this effect was inconsistent across several growth metrics, which included pelvic girth, pectoral girth, mouth to vent length, and nose-vent length. The presence of hooks in sturgeon digestive systems did not result in higher hematocrit levels, suggesting the ingestion and retention of hook material in the body was not overly stressful. Our results suggest that hook passage occurs slowly in White Sturgeon and that hook ingestion may influence the vital rates of wild populations. Such findings warrant further studies focused on hook passage times and growth effects on wild White Sturgeon that consume fishing tackle.

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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 recreational and commercial fishing for meat plus 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). 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). For example, 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 going 10 years between spawning events (Semakula and Larkin 1968).

In Idaho, populations of White Sturgeon were in decline due to overharvest and habitat fragmentation from dam construction for at least 100 years (Cochnauer et al. 1985), although populations appear to be stable over the past two decades. In 1971, sport fisheries for White Sturgeon in Idaho were placed under strict catch-and-release and barbless hook regulations to both protect populations and provide a fishery [Idaho Department of Fish and Game (IDFG) 2008]. Due to the continuous popularity of White Sturgeon fisheries in Idaho and the potential sensitivity to increased mortality rates, the effects on populations from angling pressure and ingested fishing tackle have come into question, but are not well understood. Specifically, fishery managers are concerned that the terminal tackle (including hooks, swivels, and leader material) used to catch White Sturgeon may be reducing reproductive success or increasing mortality rates due to injury or chronic stress from deep-hooking or the ingestion of lost tackle. Even an increase of 5% mortality can have population implications in fisheries with long-lived, slow growing species such as White Sturgeon (Schroeder and Love 2002). 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, approximately 30% of White Sturgeon contained hooks or other metal fishing tackle in their digestive systems, including monofilament and swivels (J. Dupont, IDFG, personal communication; K. Lepla, Idaho Power Company, personal communication).

Recent studies suggest that using circle hooks often reduces the mortality of caught and released fish compared to conventional J-hooks (e.g., Prince et al. 2002; Aalbers et al. 2004; Graves and Horodysky 2008; Serafy et al. 2008; High and Meyer 2014). The focus of these studies has been to reduce deep hooking rates. However, preliminary studies have demonstrated that when angling for White Sturgeon, deep hooking and line breaks while trying to land the fish are both rare (J. Lamansky, unpublished data). Consequently, a more likely reason that White Sturgeon so frequently have hooks in their digestive systems is that they probably ingest fishing tackle left in rivers after the terminal tackle becomes snagged on the river bottom and anglers break their line, losing their gear. Few studies have examined the long-term effects on mortality rates, reproductive fitness, or body condition when hooks are left in fish; those that have were focused on deep hooked fish that were caught and released by anglers (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 investigators implanted hooks into the digestive systems of fish to identify the length of time hooks persist or whether mortality, growth rates, or stress levels of fish are affected by the presence of hooks.

Factors that may influence persistence time of hooks in White Sturgeon digestive systems include hook shape (circle or J hooks) and hook alignment (inline or offset). 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 hook point from piercing tissue in the esophagus, gills, or inside the mouth until the hook is pulled through the mouth opening, where the hook turns, encircles the mandible, and pierces the lip (Huse and Fernö 1990; ASMFC 2003; Cooke and Suski 2004). Both hook shapes can frequently be purchased in inline or offset alignments, where inline hooks are constructed with the front of the hook in the same plane as the shank (Figure 1C); whereas offset hooks have the front bent at an angle compared to the shank (Figure 1D). The amount of offset generally ranges between 4-18 degrees from the line of the shank, can vary greatly between manufacturers and hook models, and has been shown to influence the likelihood of deep hooking fish (Hand 2001; Prince et al. 2002). Hooks with offset points are designed to penetrate tissue more quickly.

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 survival, growth, and stress response of White Sturgeon after one hook, five hooks, and five hooks with monofilament leader and swivel were implanted into stomachs.

METHODS

To conduct our study, we acquired 118 (108 treatment and 10 control) White Sturgeon from a commercial hatchery operator in Hagerman, Idaho. The 6-9-year-old White Sturgeon 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 were fed volitionally with Rangen 450/sinking, 8-mm pellets throughout the study period. We tagged all study fish with a passive integrated transponder (PIT) tag to allow identification of individual fish during subsequent handling.

We implanted hooks with different shapes (circle/J-hooks) and alignments (inline/offset) at three treatment levels: 1) 1 hook; 2) 5 hooks; and 3) 5 hooks with 480 mm of 60lb test monofilament leader and a size 1 brass barrel snap swivel (Table 1) into the stomachs of study fish on 15 September 2011. We chose the three treatment levels to simulate a spectrum of materials (mild to severe) possibly ingested by White Sturgeon in the wild. The hooks were similar to those commonly available at local tackle shops and regularly used by sturgeon anglers in Idaho. All hooks were of the same brand and were constructed from high-carbon steel with similar wire diameter (about 2 mm), finish (black nickel), and dimensions and only differed in shape and alignment. The model of hooks used were Gamakatsu Octopus circle hooks (size 7/0, model # 208417) and Gamakatsu Octopus J hooks (size 7/0, model # 02149), in both inline and offset configurations. To simulate current Idaho sturgeon fishing regulations, all hooks had barbs removed before implantation by pinching the barb down with pliers. We randomly implanted each combination of hook type and treatment level (Table 1) into nine White Sturgeon. The hook insertion tool was a flexible vinyl tube (32 mm outside diameter, 25 mm inside diameter) with a smaller vinyl tube (1 mm outside diameter, 13 mm inside diameter) placed inside as a plunger . We imbedded hooks into a small piece of fish flesh and placed them into the end of the tube, which was inserted into the mouth and gently pushed down the esophagus (approximately 120 mm) into the fore-stomach. Using the plunger, the hooks were pushed out of the tube into the stomach, and the tube was removed. Ten fish acted as a control group and went through the same insertion process except that no hooks were inserted.

Hooks in the digestive tract were monitored using a portable x-ray system (Sound-Eklin tru/DRLX System). The x-ray system consisted of an x-ray generator and a plate that received the x-ray beam, compiled the received information, and sent a digital image to a laptop computer. The settings on the x-ray generator were consistently set at 96 kilovolts (kVp) and 2.00-second exposure (mAs) to produce a clear 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).

Fish growth metrics were measured at regular intervals over the 782 d 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. We recorded four growth metrics including: 1) pelvic girth (mm), measured directly anterior to the pelvic girdle; 2) pectoral girth (mm), measured directly posterior to the pectoral girdle; 3) mouth-vent length (mm), the distance between the mouth and the anal vent; and 4) nose-vent length (mm), the distance between the tip of the nose and the anal vent. Growth was indexed by changes in these metrics during the course of the experiment and expressed as the average growth/ month (mm). We also measured hematocrit level (the proportion of blood consisting of red blood cells expressed as a percent, by volume), a common indicator of stress possibly caused by internal injury (Wedemeyer et al. 1990; Barton and Iwama 1991). Blood was collected immediately 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 red blood cells stratified (1-2 min), after which the hematocrit was recorded. We analyzed the differences in the hematocrit level between all treatment combinations measured on each sample date with repeated measures analysis of variance (ANOVA; $\alpha = 0.05$) and Tukey pairwise comparisons to determine differences between treatments over time (Minitab 2010).

We compared the effects of hook shape (circle/J hooks), hook alignment (inline/offset), and number of hooks (1 hook, 5 hooks, and 5 hooks with monofilament and a swivel) on growth rates over time. For analysis, the sampling unit was an individual fish with a particular hook type and treatment. We used linear regression to calculate the slopes of the lines relating the growth for the different metrics (pectoral girth, pelvic girth, mouth - vent length, and nose - vent length) over time. The slopes represent the growth (in mm) of study fish per month. For example, a slope of 3.5 for pelvic girth means the pelvic girth of study fish grew 3.5 mm/month, on average, over the study period. The differences in slopes were analyzed with analysis of variance (ANOVA; $\alpha = 0.05$) and Tukey pairwise comparisons to determine differences between treatments (Minitab 2010).

We rated hooks from x-ray images to evaluate corrosion over time. We identified corrosion visually as pitting and the loss of hook material in the x-rays. We rated the hooks on a scale of zero (no corrosion seen) to seven (hook completely gone) with intermediate numbers describing different states of corrosion (see Table 2 for descriptions of ratings). Two people rated x-rays for individual fish from each sampling period. We averaged the corrosion ratings for the number, shape, and alignment of hooks during each sample event and analyzed differences in the average rating over time using repeated measures ANOVA ($\alpha = 0.05$; Minitab 2010).

Forty days after the experiment ended, 62 treatment fish were killed and necropsied to assess the condition of any remaining hook or monofilament material and inspect the tissues surrounding the hook locations for tissue damage or lacerations attributable to the hooks. The hatchery White Sturgeon were killed with a blow to the head and the body cavity was opened with an incision along the ventral surface. The digestive system of White Sturgeon is similar to other chondrosteans and is rather primitive when compared to modern teleosts (Buddington and Christofferson 1985). The alimentary canal consists of the esophagus; the stomach, composed of two regions; the intestine; the spiral valve; and a short rectum. 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). We located the gizzard and scanned for the presence of metal using a handheld metal detector (Garrett Pro-Pointer), to identify the location of remaining metal. We removed the section of the digestive system including the passageway at the posterior end of the fore-stomach leading to the gizzard, the gizzard, and any of the intestine or spiral valve determined to contain metal. We froze the removed sections for later analysis in the lab. After thawing, the tissues were examined for the anatomical locations of hooks, monofilament or swivels, and where hooks had penetrated the surrounding tissues.

RESULTS

The 108 hatchery White Sturgeon that were implanted with fishing hooks in this study passed or digested the hook material slowly. According to x-ray images, the implanted materials appeared to move to the gizzard within one month of insertion, except in one fish. All but four of the hatchery White Sturgeon with inserted hooks still contained at least some hook, monofilament, or swivel material at the conclusion of the 782 day study. Of the four fish that completely eliminated the hooks from their digestive systems on their own, three fish each contained a single hook and had completely eliminated the hooks after 344, 706, and 782 days, respectively. The one fish with the inserted material that did not appear to move to the gizzard in the x-ray images, a fish with five hooks, monofilament and a swivel, had eliminated all the material after 171d, presumably back through the mouth. No mortalities of study fish were attributed to fishing tackle in the digestive systems, although one fish died due to complications from inserting the hooks. Three additional treatment fish were removed from the study due to accidental injuries in the raceway.

Hatchery White Sturgeon with fishing hooks in the digestive systems grew more slowly than control fish. The mean growth of control fish were consistently higher for every growth metric we measured with regard to hook shape, hook alignment, and number of hooks (Figure 2). However, we observed a statistically significant difference in growth only for pelvic girth (F = 3.96, P = 0.02, R^2 = 0.07) and pectoral girth (F = 3.17, P = 0.05, R^2 = 0.06) related to hook shape (Figure 2). Tukey comparisons revealed that the pelvic girths of study fish with circle hooks grew significantly less than those with J-hooks (P = 0.04), but not control fish (P = 0.14); the pelvic girths of study fish with J-hooks were not different from control fish (P = 0.76). For pectoral girths, Tukey comparisons revealed that study fish with circle hooks grew significantly less than control fish (*P* = 0.05), but not fish with J-hooks (*P* = 0.29) and fish with J-hooks did not grow differently from control fish (*P* = 0.29).

Hematocrit levels of treatment fish averaged 0.35 across sample dates and ranged from 0.28 to 0.44. The average hematocrit rate for control fish averaged 0.36 across sample dates and ranged from 0.32 to 0.42. No statistically significant differences in hematocrit levels were attributable to the different hook treatments over time ($F = 0.58$, $P = 1.00$, $R^2 = 0.19$).

The corrosion rating for study fish with five hooks and five hooks with monofilament and a swivel were significantly higher than for fish with a single hook ($F = 8.20$, $P < 0.0001$, $R^2 =$ 71.8%; Figure 3a). No differences in corrosion ratings were apparent due to hook shape (Figure 3b) or hook alignment (Figure 3c). The average corrosion rating of hooks in fish with five hooks was 5.1 on day 344 (approximately half-way through the experiment) and 6.0 on day 782, the last day x-ray images were taken (Figure 3a). In contrast, the average corrosion rating for fish with one hook was 2.5 on day 344 and 3.7 on day 782. By day 344, 11% of fish with one hook had corrosion ratings at or above category 6 (meaning pieces of hooks were missing), whereas for fish with five hooks or five hooks with monofilament and a swivel, 42% and 64% had corrosion ratings at or above category 6, respectively. By day 782, hooks in all but two of the fish that contained either five hooks or five hooks with monofilament and a swivel reached a corrosion rating of 6, compared to only 36% of fish with one hook. None of the fish with five hooks had completely cleared the digestive system of implanted fishing tackle by day 782 (Figure 4). In the x-ray images, the brass portion of the swivels showed no corrosion whatsoever, although the snap portion of some swivels corroded away in several fish.

Of the 62 fish dissected after the end of the study, no hooks or other material were located in 16 fish, meaning that all the material had passed out of the digestive tract or was too small to be located manually. In the other 46 fish, all of the remaining hook material was found in or adjacent to the gizzard (Table 3). In 4 fish, material was found in the passage leading to the gizzard; 26 fish had material in the gizzard; and 1 fish had material in the intestine. In 10 fish, material was found across the sphincter entering the gizzard and 2 fish had material across the sphincter exiting the gizzard. In 3 fish, all with 5 hooks and monofilament, the monofilament was found extending from the passage entering the gizzard, through the gizzard, and ending in the intestine. In 12 fish, hooks had pierced the wall of the digestive tract; 6 along the sphincter between the passage entering the gizzard and the gizzard; 5 in the gizzard, and 1 in the sphincter exiting the gizzard (Table 3). All of the monofilament recovered was intact and appeared to be unaffected by the digestive environment.

DISCUSSION

After 782 days with hooks in the digestive systems of hatchery White Sturgeon, hook material remained in the digestive tracts of all but four fish. One of these fish probably regurgitated all of the material at about day 171 (since no corrosion was apparent in the previous x-ray image) while the other three (all having only one hook) probably passed the material at about day 344, 706, and 782. In the remaining fish, even after many hooks broke into pieces and passed out of the body, fragments of hooks, whole hooks, swivels and monofilament persisted, suggesting that the White Sturgeon had difficulty passing even small hook material through their digestive systems. The fact that most hooks remained in White Sturgeon two years after ingestion, but nearly all remaining hooks showed some sign of corrosion, were not unexpected findings. Broadhurst et al. (2007) reported that some Yellow

Bream *Acanthopagrus australis* in their study appeared to pass hooks (of unreported material or wire diameter) through the vent in 12 d or less; however, other fish retained hooks in their stomach after 105 d, and those hooks had lost only 5% of their weight to corrosion. Numerous studies have been conducted on hook corrosion and passage in trout. Previous studies conducted on hatchery trout have reported hook evacuation rates of 25% in about one month (Schisler and Bergersen 1996), 58% in four months (Mason and Hunt 1967), and 77% in 4.5 months (Hulbert and Engstrom-Heg 1980). For wild trout, hook evacuation rates have been estimated to be 91% in three months (Tsuboi et al. 2006) and essentially 100% in four months (Marnell 1969). As pointed out in Tsuboi et al. (2006), the fact that hook corrosion and passage rates have been higher in wild trout than in hatchery trout suggests that wild fish may have a greater potential to digest and evacuate hook material in natural conditions than hatchery fish under artificial conditions, suggesting our estimates of hook corrosion probably do not accurately reflect expectations of hook passage in wild White Sturgeon. Hook corrosion and associated passage rates in fish are likely related to the hook material and wire diameter of the hook, but clearly there is need for further study investigating how these and other factors affect passage rates in White Sturgeon populations.

Hook ingestion for the hatchery White Sturgeon in our study caused no mortality but did have a negative effect on some (but not all) of the growth metrics we measured. The presence of hooks and other indigestible materials, such as monofilament and swivels, likely interferes with normal food digestion by impeding sphincters between the gizzard and intestine, thereby disrupting the passage of food items into the intestine. The brass portions of the swivels and the monofilament recovered from our necropsied sturgeon appeared to have been completely unaffected after spending 782 days in the digestive system of these fish. The retention of the monofilament is likely the reason that hooks in fish with that treatment were unable to completely eliminate the hooks. If White Sturgeon in the wild are unable to digest or pass such material, it may accumulate and reduce normal food processing in the digestive system. Besides the problem of impeding food passage, ingested hooks may pierce the gut wall at any point along the alimentary canal and possibly lacerate other internal organs (Borucinska et al. 2002). Of the 62 fish we necropsied, hooks had pierced the gut wall in 12 (19%) fish (Table 4), which was surprising considering that we were not angling and setting the hook to cause these lacerations. The presence of monofilament and a swivel could also potentially increase the likelihood of having hooks pierce the stomach wall if they remain connected. The peristaltic action of passing the swivel could orient the hook point so it faces posteriorly, and any subsequent pressure applied to the swivel or line could cause the hook to penetrate surrounding tissue.

Although our results suggest that the presence of fishing tackle may impact White Sturgeon growth, the effect appeared to be small and inconsistent. As such, any population-level impact that hook ingestion may have on the vital rates of White Sturgeon populations, such as on reproductive fitness or survival, may be meaningless biologically. However, considering the long lifespan of White Sturgeon, population-level effects are possible. In one growth metric (pelvic girth), study fish with circle hooks grew less than fish with J hooks, although the fact that there was no difference between circle and J hooks in the other three growth metrics we measured makes it difficult to conclude that circle hooks hindered fish growth relative to J hooks. One explanation for this finding could be that, although hook size differences were minimal, the outside diameter of the circle hooks used in this study was slightly larger (29 mm) than the J hooks (25 mm), making them more difficult to pass the sphincters entering or exiting the gizzard. Another explanation is that the round shape of the circle hook made them more difficult to move through various sphincters in the digestive system. These findings in conjunction with the results from other ongoing studies (Lamansky, unpublished data) could be used in population simulations to help elucidate the importance of any impacts that hook ingestion may have on wild White Sturgeon populations.

Another unexpected finding was that the presence of multiple hooks increased the speed at which hooks corroded. When multiple hooks were present, the hooks likely abraded each other, effectively scratching the surface finish and allowing digestive chemicals greater access to the steel cores of the hooks. X-ray images of study fish with a single hook revealed that many had only slight or no corrosion after more than two years in the digestive tracts of hatchery White Sturgeon. The fish in our study were fed pelletized food that lacked any abrasive material, whereas in wild White Sturgeon, x-ray images have revealed fish skeletons, clams, crayfish, and stones in their digestive tracts (Lamansky, unpublished data). Such hard materials likely increase the abrasion of the hooks in wild White Sturgeon and help increase corrosion and thus passage rates of fishing gear. The gizzards of the hatchery White Sturgeon were also very different from those found in wild fish. Simply stated, the gizzard is a muscular organ designed to grind up solid material. Gizzards in wild White Sturgeon are muscular and thickly walled to aid with hard items included in their diet. The commercial pellets fed to the hatchery fish were soft and easily digestible, likely contributing to their poorly developed and thinly walled gizzards. The comparatively weak gizzards and lack of hard diet items for hatchery sturgeon may partly explain why hooks in our study fish with a single hook lacked much corrosion and those in fish with multiple hooks corroded faster.

In summary, we found that the ingestion of one or several hooks in hatchery White Sturgeon caused no mortality, produced no sign of increased stress, and resulted in minimal but not insignificant reduction in fish growth. Nevertheless, considering the long lifespan of White Sturgeon, the length of time that hooks persisted in the digestive systems of our study fish, and the fact that several hooks pierced the alimentary canal of fish without the aid of any hook setting incident, we cannot rule out the potential that long-term population-level effects may result from sturgeon ingesting hooks and other angling material that is lost by anglers on river bottoms. Because our study included hatchery rather than wild fish, and tested only one brand and size of hook with one type of finish, our results should be considered preliminary. Future research investigating corrosion and hook passage for different hooks with different coatings and sizes, and studying fish in their natural environment, will help elucidate potential impacts that hook ingestion may pose to wild White Sturgeon populations.

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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	Hooks in multiple pieces
6	Pieces are missing/passed
7	Nothing remains

Table 3. The number of hatchery White Sturgeon with hooks and other material found in different locations along the digestive tracts (pre-gizzard, gizzard, intestine, or the sphincters in between, not found). Fish were implanted with a different number of hooks (1hook, 5 hooks, 5 hooks with monofilament and a swivel), alignments (I=Inline, O=Offset), and shapes (C=Circle hooks, J=J hooks). Numbers with a * represent the number of fish found with hooks that penetrated the digestive tract wall in that location.

				Hook locations (anterior to posterior)					
Number of hooks	Hook alignment	Hook shape	N	pre-gizzard	sphincter	gizzard	sphincter	intestine	no metal
1	I	C	4	1	1*	1*			1
1	O	C	7	1		2			4
1	I	J	5			3 1*			1
1	O	J	5			1 2*			2
5	I	C	6		1 2*	1			2
5	O	C	5		1	1	1		2
5	I	J	5			2	1*		1
5	O	J	6			5			1
5 + mono	I	C	4			2		1	1
5 + mono	O	C	5		1 1*	1 1*		1*	
5 + mono	I	J	4		1	2			1
5 + mono	O	J	6	2	1 1*	1		1	

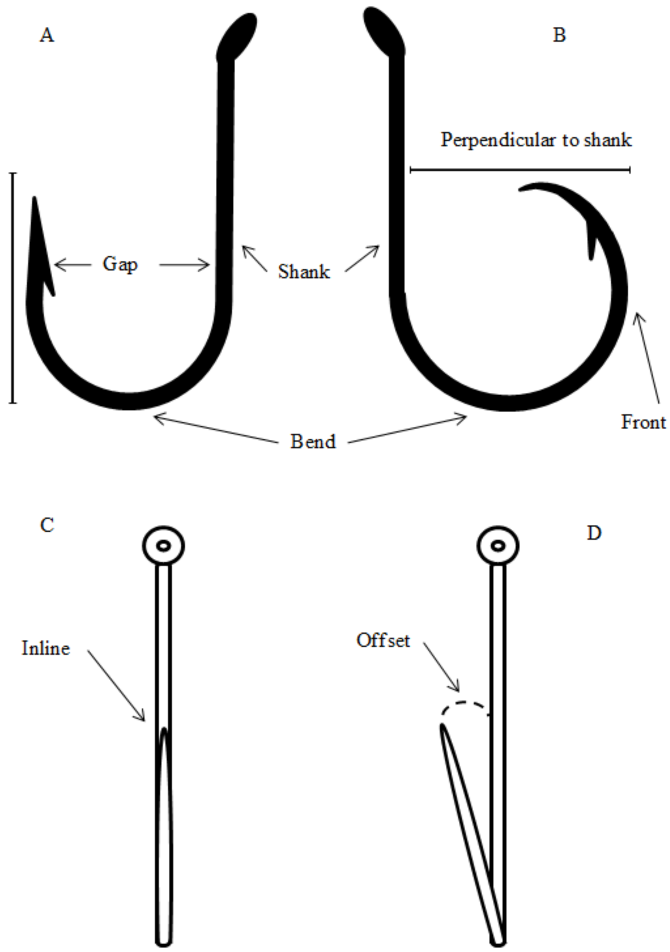

Figure 1. Example of a J (A) and a Circle (B) hook with the different parts labeled and an inline (C) and an offset (D) hook.

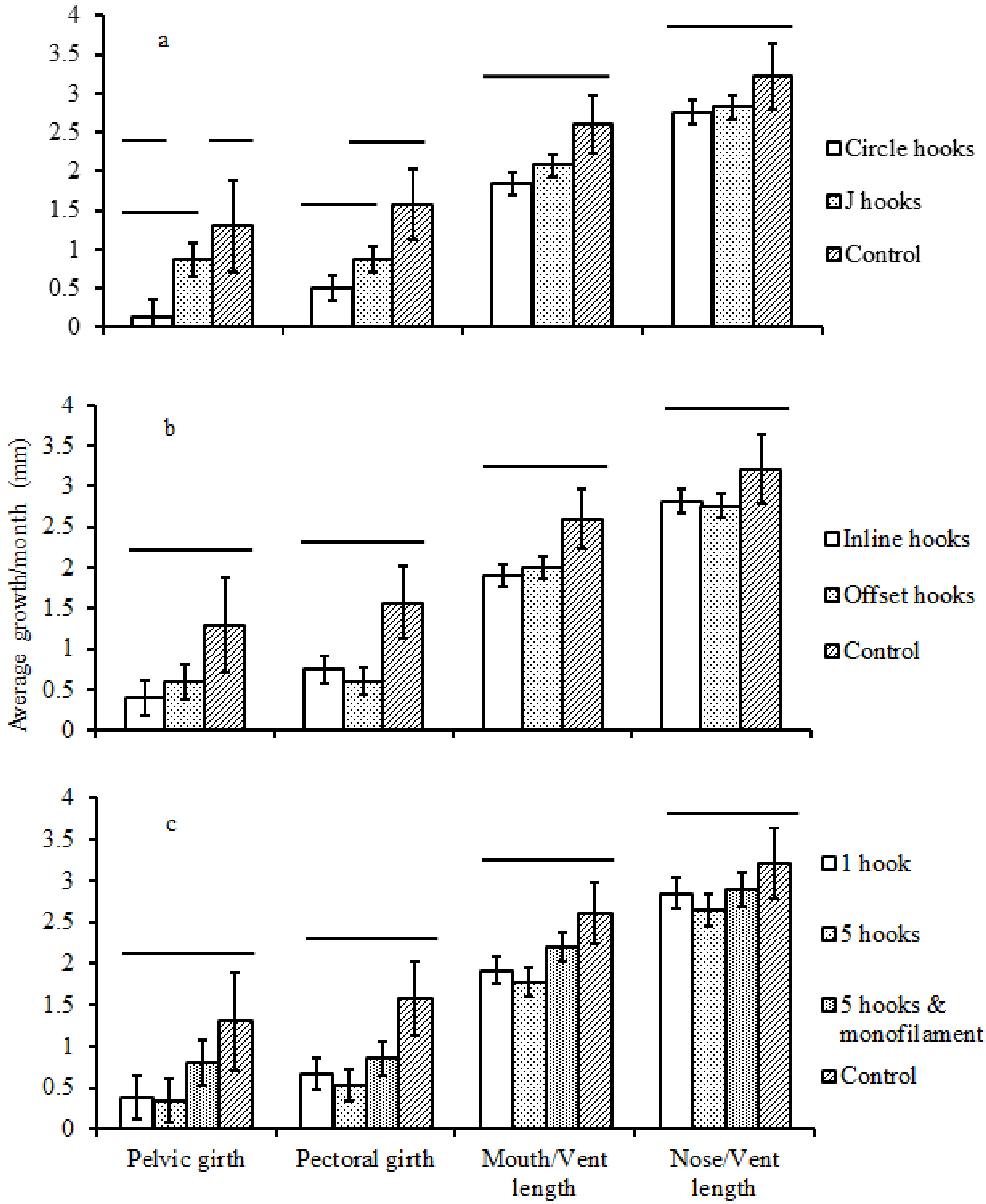

Figure 2. The mean growth/month (mm) of White Sturgeon for the measured growth metrics for the variables hook shape (a), hook alignment (b), and hook number (c) after 782 days. Error bars are one standard error. Bars that do not share a solid line are significantly different.

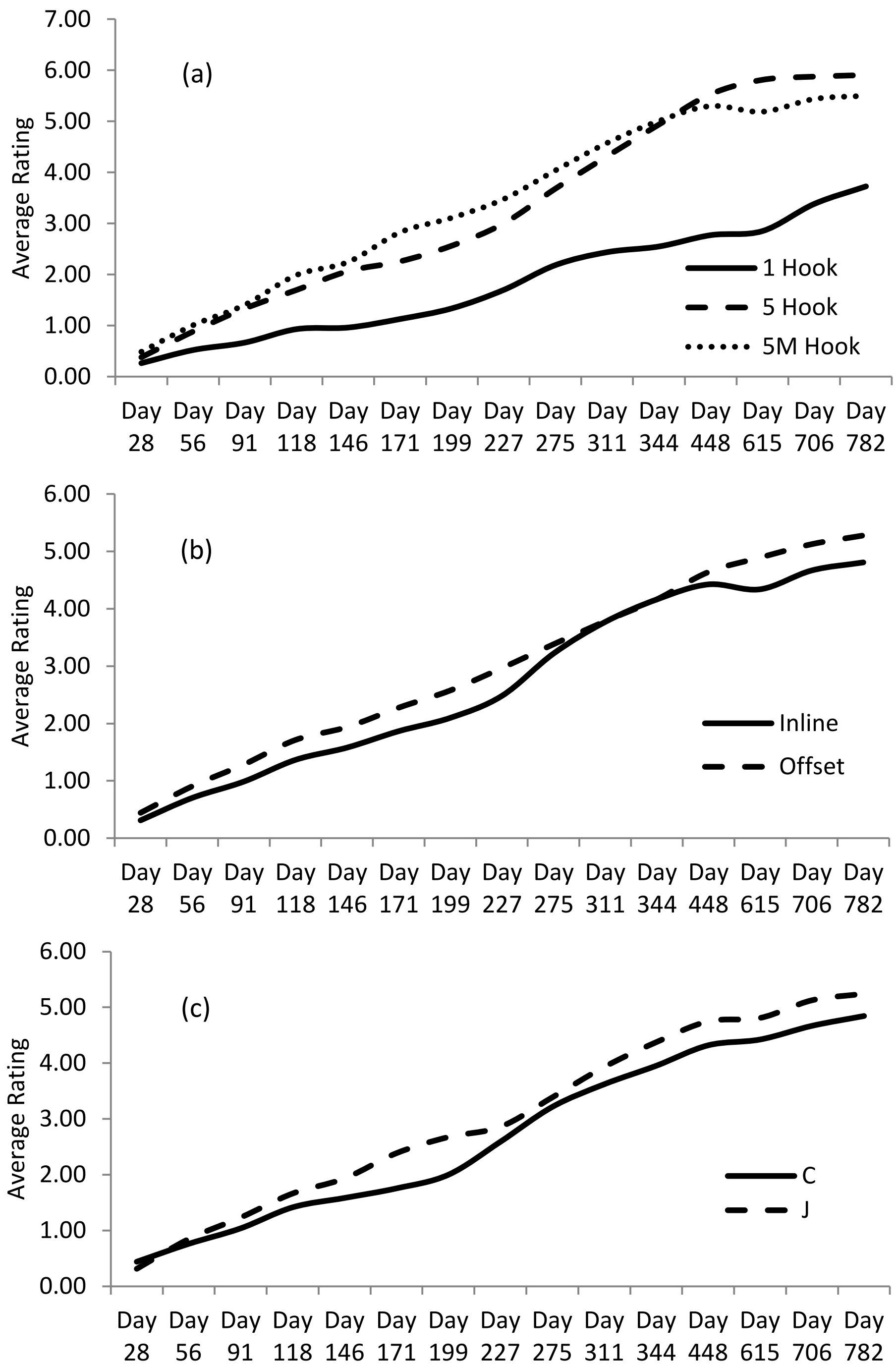

Figure 3. The mean corrosion ratings of White Sturgeon for hook number (a), hook alignment (b), and hook shape (c) on sampling days through 782 days of the study. Error bars are one standard error

ANNUAL PERFORMANCE REPORT
SUBPROJECT 2: HOOK INVESTIGATIONS

State of: Idaho

Grant No.: F-73-R-35 Fishery Research

Project No.: 5

Title: White Sturgeon Research

Subproject #2: Hook Investigations:
Hook Corrosion

Contract Period: July 1, 2013 to June 30, 2014

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, as is the length of time fishing tackle persists in the digestive system. 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 abraded hooks in black nickel and red lacquer finishes corroded more quickly after 174 and 305 days whereas weights of bronze finished hooks were not different between abraded and non-abraded hooks after 174 d, but were different after 305 d. The amount of weight loss of silver nickel finish hooks was not different after either time period. Results suggests that the presence of abrasive food items such as fish bones and clamshells combined with the peristaltic action of the gizzard could potentially decrease the time hooks persist in White Sturgeon digestive systems.

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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 (e.g., Mason and Hunt 1967; Marnell 1969; Schill 1996; Tsuboi et al. 2006; Fobert et al. 2009). The assumption is that less tissue damage will occur if hooks are not removed, and the hook will deteriorate over time or pass out of the body. Studies that have been conducted on hook corrosion, that have not been inside the digestive system of fish, generally use a salt spray test approved by the American Society for Testing and Materials (ASTM E 352-93 2000). However, this 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. The few studies that have evaluated the time hooks persist when left in bodies of fish have generally been of short duration and not the primary focus of the studies (e.g., Mason and Hunt 1967; Marnell 1969; Hulbert and Engstrom-Heg 1980; Schill 1996; Broadhurst et al. 2007; Butcher et al. 2007).

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 these properties could also potentially 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 demonstrate that deep hooking of White Sturgeon and line break-off rates of hooked fish are low (<5%; J. Dupont, IDFG, personal communication) suggesting deep hooking is not the mechanism for ingesting tackle. Rather, White Sturgeon likely consume fishing tackle left in rivers after terminal tackle of sturgeon and other angler types become snagged on the river bottom and breaks off. Lost gear can include hooks, sinkers, swivels, jigs, and lures. Idaho fishing regulations require that anglers use a sliding leader/weight combination when fishing for White Sturgeon (IDFG 2012). The purpose of this regulation is to prevent the sinker from remaining attached to the hook if the line is broken. Nevertheless, the bait oftentimes remains on the hook and could subsequently be found and 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.

The length of time fishing tackle persists in the digestive system may be related to the size of the tackle being ingested, given the large size of hooks commonly used for White Sturgeon angling. The time it takes to physically break the hook into smaller pieces inside the digestive system could influence the time the hook persists. The tensile strength of the hook and amount of abrasion the hook is subject to in the digestive system could also be contributing factors. Tensile strength is the amount of force or pull it takes to cause a material to fail or break. Food sources, such as fish bones and clamshells, that White Sturgeon eat could be a source of abrasion. Abrasion could potentially remove or damage the protective coating of the hook, which in turn could hasten the speed of corrosion. These factors combined with the peristaltic movement of the gizzard could potentially abrade and break hooks into smaller, more easily passed pieces.

Because of the difficulty of using live sturgeon, we conducted a lab study to estimate the length of time needed for sufficient corrosion to occur weakening the tensile strength sufficiently that the hooks could easily break. We created a simple, buffered acid solution to simulate the likely stomach conditions in White Sturgeon 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. Our objective was to measure the time necessary for hooks with different finishes to corrode to a point where hooks could possibly break allowing White Sturgeon to pass the hook material through the digestive tract.

OBJECTIVES

1. To determine the time required for fishing hooks with different coatings and construction to corrode, decreasing tensile strength sufficiently to allow peristaltic movement to physically break the hook.

METHODS

To conduct our experiment, we selected hooks in sizes and finishes commonly used for White Sturgeon angling in Idaho that were most widely available in local stores. We chose size 5/0 Gamakatsu hooks in different finishes: bronze (model #02115), red lacquer (model #02315), silver nickel (model #02015), and black nickel (model #02415). Hooks of each finish were divided into two groups, abraded and non-abraded. Abraded hooks were placed in a small container filled halfway with small stones and shaken three times to simulate the abrasion hooks receive while on the bottom of rivers and the likely abrasion from food sources in the gizzard. Non-abraded hooks did not receive this treatment. A total of 50 hooks for each finish were used, 25 were abraded and 25 were not abraded.

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 correct pH was achieved with a digital pH meter (Eutech Instruments pH spear). Five hooks were placed in each 100 ml glass beaker and covered with 40-50 ml of the buffered acid solution. Beakers were sealed with Parafilm® to prevent evaporation and protect against spills.

All hooks were weighed prior to being placed in the acid solution and each week the hooks were removed, rinsed, dried, and weighed using a jeweler's scale (±0.002 mg). We followed a strict protocol during weighing to prevent spills and ensure proper drying of the hooks. Four 1 L flasks were filled with either: a solution of tap water and approximately 250 g of baking soda, tap water, deionized water, or raw baking soda (for neutralizing used solution and emergency spills). We removed the hooks from the acid solution with non-reactive forceps and dipped them into the 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 and allowed sufficient time to dry. Abraded hooks were treated each time prior to being returned to their respective beakers. The pH of the acid solution in each beaker was checked with a digital pH meter and replaced if the pH was above three, which was required approximately every week.

We calculated the weight loss of the hooks by dividing the weight of hooks after 174 and 305 days by the original weight and subtracting from one to calculate the percent of total weight lost. Mean weight lost and 95% confidence intervals were calculated for abraded and non-abraded hooks in the four finishes. Differences were considered significant if the 95% confidence intervals did not overlap.

RESULTS

Abraded hooks in black nickel and red lacquer finishes lost significantly more weight at both 174 and 305 days than non-abraded hooks. The weight lost for hooks with the bronze finish was not different between abraded and non-abraded hooks after 174 d, but was different after 305 d. The amount of weight loss of the silver nickel finish hooks was not different between abraded and non-abraded after either time period (Figure 16).

DISCUSSION

The advice given to anglers that hooks will corrode away quickly if left inside a fish may or may not be correct, at least in the case of sturgeon-size hooks. Hooks in this study retained >75% of their weight after 305 d in a simulated stomach acid solution. In general, hooks that were abraded corroded faster than hooks that were not, most likely due to the corrosion resistant finish being scratched and nicked which allowed the acid access to the metal. Interestingly, abraded hooks with the silver nickel finish did not lose weight faster than non-abraded silver nickel hooks. This result could affect the length of time a hook could persist in the digestive system of a fish. Abrasion of hooks from other tackle (swivels or sinkers) or 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 would likely be cooler depending on environmental conditions, slowing 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 are most likely not required 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. This is why the hooks in this study will be tested for tensile strength in the near future.

In summary, our results suggest that hooks commonly used for sturgeon fishing may require up to a year or more to dissolve adequately to pass through the digestive system of a White Sturgeon (also see previous chapter), but abrasion does increase the speed of corrosion. The longer hooks take to deteriorate likely increases the probability of stress or physical injury leading to increased mortality in populations of White Sturgeon or other fish species that ingest such material.

RECOMMENDATIONS

1. 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

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ANNUAL PERFORMANCE REPORT
SUBPROJECT 3: HOOK INVESTIGATIONS

State of: Idaho

Grant No.: F-73-R-35 Fishery Research

Project No.: 5

Title: White Sturgeon Research

Subproject #3: Angling Investigations:
Comparison of Inline and Offset Circle and J-hooks

Contract Period: July 1, 2013 to June 30, 2014

ABSTRACT

I conducted a study to compare using different hook types (inline circle, offset circle, inline J, and offset J hooks), fished with two methods (active and passive) on deep hooking rates, the time spent angling to land a fish, and the percent of White Sturgeon landed once hooked (landing success). Anglers hooked 482 White Sturgeon, landed 423, lost 59, and broke gear off in the river 179 times. Only two White Sturgeon were deep hooked during the entire study, suggesting that deep hooking is not an issue regardless of hook type or angling method. Landing rates were similar for all combinations of hook type and angling method, ranging from 2.9 h/fish (offset J, passive) to 4.3 h/fish (inline J, passive) with an overall average of 3.7 h/fish. Likewise, results suggested no differences in landing success between any of the combinations of hook type or angling method (range 84-91 ± 8%; 90% CI). Our results suggest that deep hooking is rare when angling for White Sturgeon using standard bait-fishing gear, and regulations are likely not necessary to minimize deep hooking by anglers.

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INTRODUCTION

In response to declining populations of White Sturgeon *Acipenser transmontanus*, fisheries were closed to harvest by the Idaho Department of Fish and Game (IDFG) in 1971 (IDFG 2008), although catch and release angling is still allowed in several reaches of the Snake River. More recently, regulations stipulate that anglers use barbless hooks, a sliding sinker system (Figure 1), and do not lift or remove fish from the water (IDFG 2014). However, catch and release only benefits the fishery at the rate that released fish survive to reproduce or are caught again by anglers (Cooke and Suski 2005). Fisheries managers have become concerned that other effects from angling, including deep hooking injury and the presence of fishing tackle in the digestive systems of White Sturgeon may be harming populations. The issue of deep hooking is concerning because anglers use bait almost exclusively to catch White Sturgeon, and numerous studies have demonstrated that bait fishing results in higher deep hooking rates than using other types of terminal tackle (Graves and Horodysky 2008; Serafy et al. 2008), and the survival of released fish is typically reduced if deep hooked (Schill et al. 1996; Tsuboi et al. 2006; Fobert et al. 2009). In response, alternative hook types have been designed to reduce deep hooking rates (reviewed in Cooke and Suski 2004). The primary alternative hook design is the circle hook, and 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 mortality rates 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). Considering that White Sturgeon in Idaho are caught almost exclusively using bait, and in some reaches are caught multiple times per year (Kozfkay and Dillon 2010), a reduction in deep hooking rates could benefit populations.

Circle and J-hooks differ in design and function. J-hooks are designed with the point parallel to the shank (Figure 5A), whereas circle hooks are designed with the point perpendicular to the shank (Figure 5B). 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 encircles the mandible and pierces the lip (Huse and Fernö 1990; ASMFC 2003; Cooke and Suski 2004). Hooks may also incorporate an inline or offset point. Inline hooks are constructed with the front of the hook in the same plane as the shank (Figure 6A), whereas offset hooks have the front bent at an angle relative to the shank (Figure 6B). The amount of offset often ranges between 4-18 degrees from the line of the shank and can vary greatly between manufacturers. A hook with an offset point is designed to penetrate more quickly, and when circle hooks are designed with an offset point, the benefits of reduced deep hooking may be reduced (Aalbers et al. 2004; Graves and Horodysky 2008).

In addition to the differences in the design of circle and J hooks, manufacturers recommend a different angling method for circle hooks to perform properly (passive method) than usually used when fishing with J hooks (active method). Anglers bait fishing with J hooks typically raise the rod tip quickly and sharply when a strike is detected; commonly termed setting the hook. As opposed to setting the hook however, manufacturers recommend that anglers using circle hooks should initially apply gentle, steady pressure as the fish are reeled in for greatest effectiveness (e.g., Montrey 1999; also see ASMFC 2003). However, few studies have tested whether angling method (i.e., active or passive) affects circle hook performance (Cooke and Suski 2004). A series of recent studies in Idaho concluded that the use of circle hooks when fishing for stream-dwelling trout reduced deep hooking compared to J hooks, regardless of whether they were fished actively or passively; they also found that circle hooks fished actively reduced deep hooking compared to fishing them passively (Sullivan et al. 2012; High and Meyer 2014; High et al. 2014). These findings contradict conventional wisdom.

Reducing deep hooking rates for White Sturgeon angling may be justification for managers to change the regulations requiring the use of circle hooks. However, for such a regulation to gain the acceptance of anglers, circle hooks also should perform similarly to conventional J hooks in terms of hooking and landing success. Cooke and Suski (2004) suggest that capture efficiency is generally lower for circle hooks than J hooks, although little of the information in their review would be applicable to White Sturgeon angling in flowing water. Likewise, because deep hooking rates for circle hooks relative to J hooks are inconsistent, Cooke and Suski (2004) also suggest that management agencies should not mandate the use of circle hooks as a means of reducing deep hooking in bait fisheries unless compelling data exist to support such a mandate.

OBJECTIVES

1. Estimate the deep hooking rates when bait fishing for White Sturgeon with different combinations of inline and offset circle and J hooks, fished both actively or passively.

2. Estimate catch rates and landing success for anglers bait fishing for White Sturgeon using the same hook and angling combinations as above.

3. Assess the rate of loss of tackle after snagging on the bottom of the river while bait fishing for White Sturgeon.

METHODS

The study area for our project was the Hells Canyon Reach of the Snake River, extending 163 km upstream from the confluence of the Clearwater River to Hells Canyon Dam, including the lower Salmon River from the confluence with the Snake River upstream 51 km (Figure 7). Anglers accessed the river by boat launched from boat ramps at 1) Lewiston, Idaho; 2) Heller Bar at the confluence of the Grande Ronde River in Washington; and 3) Pittsburg Landing near Dug Bar in Idaho. Angling occurred at known and likely White Sturgeon holding areas all along the river.

All anglers that participated in the study used identical terminal tackle attached in the same fashion and followed the current regulations for White Sturgeon angling in Idaho. All anglers used size 8/0 inline circle (IC), and offset circle (OC) hooks and Gamakatsu Octopus size 9/0 inline J (IJ), and offset J (OJ) hooks with a black nickel finish. I used the offset angle manufactured into the hooks without alteration. If inline hooks were unavailable, I gently removed the offset without damaging the hook. I removed the barbs from all hooks before use. Anglers used 60 lb. test monofilament main line on the reel. The terminal tackle consisted of a sliding swivel placed on the main line above a barrel swivel. The hook connected to the barrel swivel with a 460 mm leader section of 80 lb. test monofilament. The sinker connected to the sliding swivel with a 254 mm section of 30 lb. test monofilament (see Figure 8). The knots used to attach the swivels, hooks, and sinkers were left to the discretion of the angler. The amount of weight and design of the sinker was also left up to the angler to fit the river conditions. All anglers that participated were considered seasoned anglers with experience fishing for White Sturgeon.

Along with using the same tackle, anglers applied two different hook setting techniques that I defined as active or passive. The active method was characterized by reeling up any slack line and setting the hook with a sharp, quick lifting of the fishing rod when a strike was detected. On the other hand, the passive method was characterized by lifting the rod gently, without setting the hook, and applying constant rod pressure when reeling in a fish. Once a fish was hooked, the anglers used identical methods to land the fish.

When fishing began, anglers randomly chose the method of fishing (active or passive) along with the hook type (IC, OC, IJ, or OJ). Anglers alternated hook types and fishing methods throughout the day. I attempted to evenly distribute angling effort across all fishing methods and hook types. Anglers fished from boats and either dropped the bait at a location and pulled into shore while letting out line or pulled the boat to shore and cast into sturgeon holding areas. Anglers tended rods by hand or set in rod holders while waiting for a bite. Each angler consistently baited the hook in the same manner so the point of the hooks was exposed (Figure 9). The type of bait used varied, but the most common baits were pickled squid or cut fish.

Each time an angler fished with a particular hook type and angling method at a location, I considered it a session of angling (hereafter opportunity) for data collection and analysis purposes. I considered it a new opportunity when anglers changed locations, angling method, or hook type. Anglers recorded the time angling began, the angling method and hook type, the bait used, the soak time (minutes) for each opportunity, and the number of White Sturgeon hooked, landed, or lost. If a snag occurred and tackle was lost, anglers recorded the tackle lost as follows: 1) both hook and sinker; 2) sinker broke off but hook present; and 3) hook broke off but sinker present. When a White Sturgeon was landed, hook location was recorded as: 1) Lips (around the opening of the mouth); 2) inside the sucker tube; 3) in the gills; 4) deeper than the gills; and 5) foul hooked (i.e., anywhere on the body except in the mouth). I defined deep hooking for this study as a fish hooked in the gills or deeper. I did not record strikes that did not result in a hooked fish, or hooked but non-landed fish not identified to be White Sturgeon. A White Sturgeon was considered lost by the gear if it was hooked, actively fought, and subsequently lost.

We evaluated whether a particular hook type or angling method resulted in differences in the proportion of fish landed, whether a fish came unhooked or broke off, and hooking location. I calculated 90% confidence intervals for proportions according to Fleiss (1981), and considered proportions with non-overlapping confidence intervals as statistically significant. Catch per unit effort (CPUE as h/fish) was calculated for the different angling methods and hook types by dividing the number of sturgeon caught using each combination by the number of hours that hook type or method was used. Fish lost per unit effort (LPUE) was established similarly, by dividing the number of sturgeon hooked and lost using each combination by the number of hours that hook type or method was used.

RESULTS

Through 2013, anglers hooked 482 White Sturgeon and landed 423 fish in Hells Canyon. Hooking location was recorded for 415 landed fish during the study period and only two were considered deeply hooked (0.5%), whereas 13 (3%) were foul hooked and 18 (4%) were hooked inside the tube of the mouth; the remaining 382 (92%) were hooked in the lip (Table 4). Of the 59 fish that were lost during angling, 29 (49%) came unhooked and 30 (51%) broke the line (Table 5). Overall, anglers lost gear due to snagging on the bottom of the river on 179 occasions; 38 times all the gear was lost, 120 times only the sinker was lost; and only one time did the hook break off with the sinker still attached (Table 6).

The number of hours fishing per fish landed was similar for all angling methods and hook types ranging between 2.9 h/fish (OJ Passive) and 4.3 h/fish (IJ Passive) with an overall average of 3.7 h/fish (Table 7). The hour per fish lost and hour per gear lost were also similar for all angling methods and hook types (Table 7). Landing rates for the different hook types and angling methods were not significantly different (all 90% confidence intervals overlapped), ranging between 84% (IJ Passive) to 93% (IC Passive; Figure 10). Comparing the individual variables of fishing method (active vs. passive), hook set (inline vs. offset), and hook shape (circle vs. J hook) for landing rates varied little and were practically identical, also suggesting no differences in landing rates (Table 8).

DISCUSSION

Our results indicate that deep hooking of White Sturgeon is probably not an issue. Indeed, only two fish out of 423 fish landed were considered to be deep hooked, likely because sturgeon fishing is different than fishing for other species as in other studies. The majority of existing studies comparing deep hooking rates of circle and J hooks targeted pelagic species in marine fisheries in the open ocean (Graves and Horodysky 2008; Cooke and Suski 2004; Prince et al. 2002), or species where the fishing process is different than fishing for White Sturgeon (Cooke et al. 2003a, 2003b; Fobert et al. 2009; Horodysky 2008; Serafy et al. 2008). The same is true of most studies that suggest that using circle hooks reduces the mortality of caught and released fish compared to conventional J hooks (Aalbers et al. 2004; Graves and Horodysky 2008; Serafy et al. 2008). The average landing rates only varied by 1-3% (± 5-7% 90% CI) for any of the combinations used (Table 1). Results of two studies comparing landing rates of river dwelling trout using circle and J hooks fished actively or passively (Sullivan et.al. 2012; Meyer and High 2011) suggested differences did exist. However, those studies did not compare all combinations of hook types and angling methods and the process of fishing was different. In those studies, the bait was cast into the water and, as the bait drifted downstream, fish would take the bait. The angler controlled the rod the entire time and the bait did not sit while waiting for a bite. Fishing for White Sturgeon consists of casting the bait into likely areas, reeling in the slack, and letting the bait sit until a bite occurs. The results of our study suggest that using inline or offset circle or J hooks fished either actively or passively have little effect on deep hooking rates, landing rates, or loss rates of White Sturgeon.

Results from this study suggest that the regulation that anglers use a sliding sinker with a leader of lower test line strength is likely reducing the number of hooks lost in the river and when hooks are lost they do not remain attached to the sinker. Only one hook was lost by itself and only 20% of the time that gear was lost was the hook part of the lost gear.

ACKNOWLEDGEMENTS

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Table 4. The number of White Sturgeon hooked in different body locations using the different combinations of angling method and hook type (IC=inline circle, IJ=inline J, OC=offset circle, OJ=offset J) while angling in the Hells Canyon reach of the Snake River, Idaho from 2011-2013.

					Deep hooked	
Angling method	**Hook type**	**Lip**	**Tube**	**Foul**	**Gills**	**Past gills**
Active	IC	41	3			
	IJ	45	2	2		
	OC	64	3	1		
	OJ	76	2	4		1
Passive	IC	38	1			
	IJ	22	2	1	1	
	OC	47	2	1		
	OJ	49	3	4		
Total		382	18	13	1	1

Table 5. The number of White Sturgeon hooked and the number lost because they came unhooked or broke the line during angling using the different combinations of angling method and hook type (IC=inline circle, IJ=inline J, OC=offset circle, OJ=offset J) in the Hells Canyon reach of the Snake River, Idaho from 2011-2013.

		Number	**How fish lost**	
Angling method	**Hook type**	**hooked**	**Unhooked**	**Broke off**
Active	IC	53	3	2
	IJ	57	4	3
	OC	77	4	5
	OJ	100	6	9
Passive	IC	43	3	0
	IJ	31	2	3
	OC	59	4	5
	OJ	62	3	3
Total		482	29	30

Table 6. The number of gear setups that broke off after snagging on the bottom and what was lost.

Angling type	Hook type	Opportunities	Number lost	What gear lost		
				All	Hook	Sinker
Active	IC	326	16	3	0	13
	IJ	342	17	6	0	11
	OC	377	24	2	0	22
	OJ	584	43	9	1	33
Passive	IC	286	20	4	0	16
	IJ	215	10	4	0	6
	OC	303	15	6	0	9
	OJ	310	14	4	0	10
Total		2743	159	38	1	120

Table 7. The number of angling opportunities (Opps) and the number of White Sturgeon hooked, landed and lost while angling using the different combinations of angling method and hook type (IC=inline circle, IJ=inline J, OC=offset circle, OJ=offset J). Soak time is the average number of minutes spent fishing during each opportunity. Hours per fish (h/fish) and hours per gear lost (h/gear lost) are the average number of hours spent angling for fish landed and lost, and breaking off gear in the river in the Hells Canyon reach of the Snake River, Idaho from 2011-2013.

			Number of fish				h/Fish		
Angling method	**Hook Type**	**Opps**	**Hooked**	**Landed**	**Lost**	**Soak time average (min)**	**Landed**	**Lost**	**h/Gear lost**
Active	IC	326	53	48	5	110	4.1	39.1	12.2
	IJ	342	57	50	7	74	4.2	30.1	12.4
	OC	377	77	68	9	78	3.3	24.8	9.3
	OJ	584	100	85	15	75	4.1	23.2	8.3
Passive	IC	286	43	40	3	61	3.8	50.8	7.6
	IJ	215	31	26	5	61	4.3	22.4	11.2
	OC	303	59	50	9	60	3.2	18.0	10.8
	OJ	310	62	56	6	61	2.9	27.1	11.6
Totals		2743	482	423	59	580	3.7	29.4	10.4

Table 8. The average percent of White Sturgeon landed after being hooked for each combination of angling method and hook type (IC=inline circle, IJ=inline J, OC=offset circle, OJ=offset J) while angling in the Hells Canyon reach of the Snake River, Idaho from 2011-2013.

Angling method	**Hook type**	**Percent landed (90% C.I.)**	
Active	Circle	89	(82-94)
	J	86	(79-91)
Passive	Circle	88	(80-94)
	J	88	(79-94)
Active	Inline	89	(81-94)
	Offset	86	(80-91)
Passive	Inline	89	(79-95)
	Offset	88	(80-93)
Active	All	87	(83-91)
Passive	All	88	(83-92)
All	Circle	89	(84-92
All	J	87	(82-91)
All	Inline	89	(85-93)
All	Offset	87	(82-90)

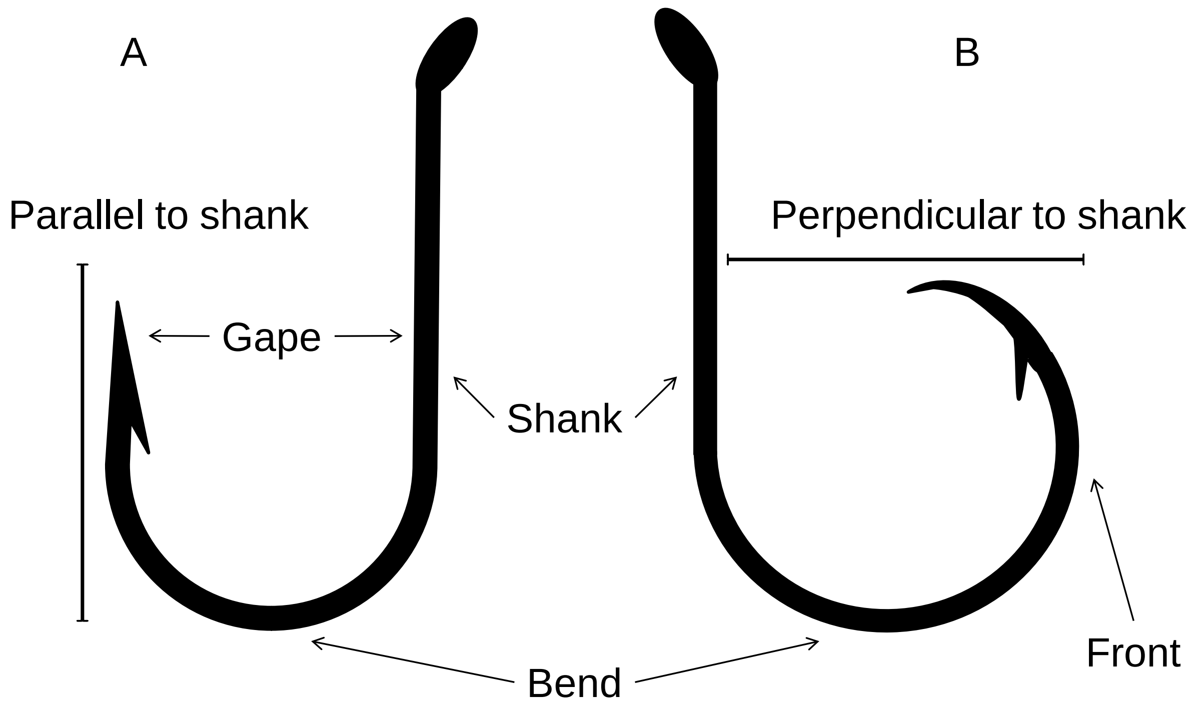

Figure 5. Example of a J hook (A) and a Circle hook (B) with the different parts labeled.

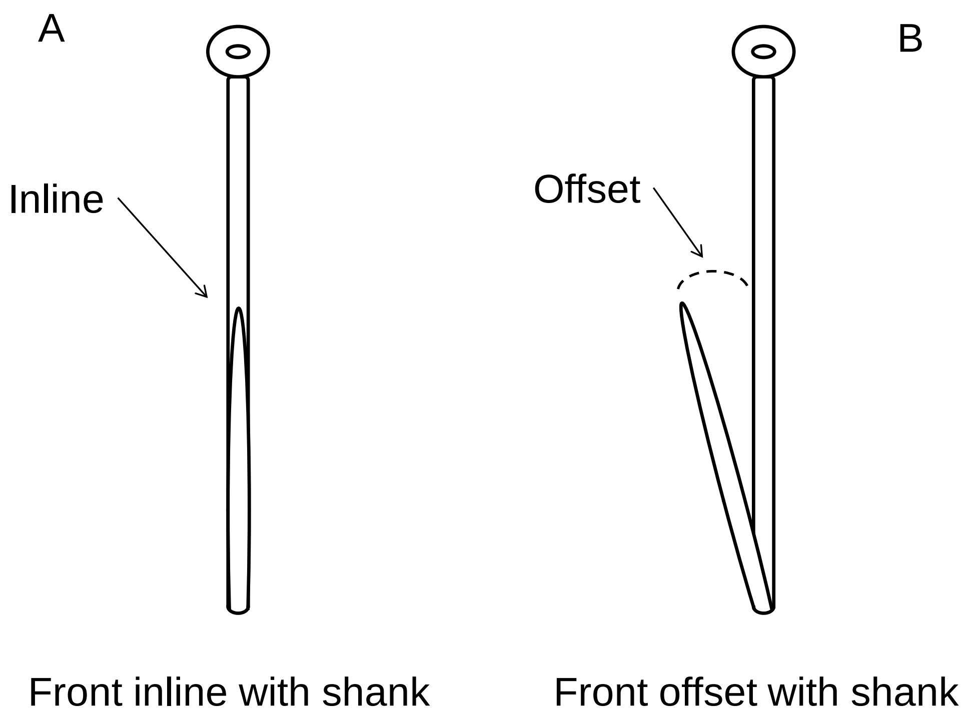

Figure 6. Example of an inline hook (A) and an offset hook (B).

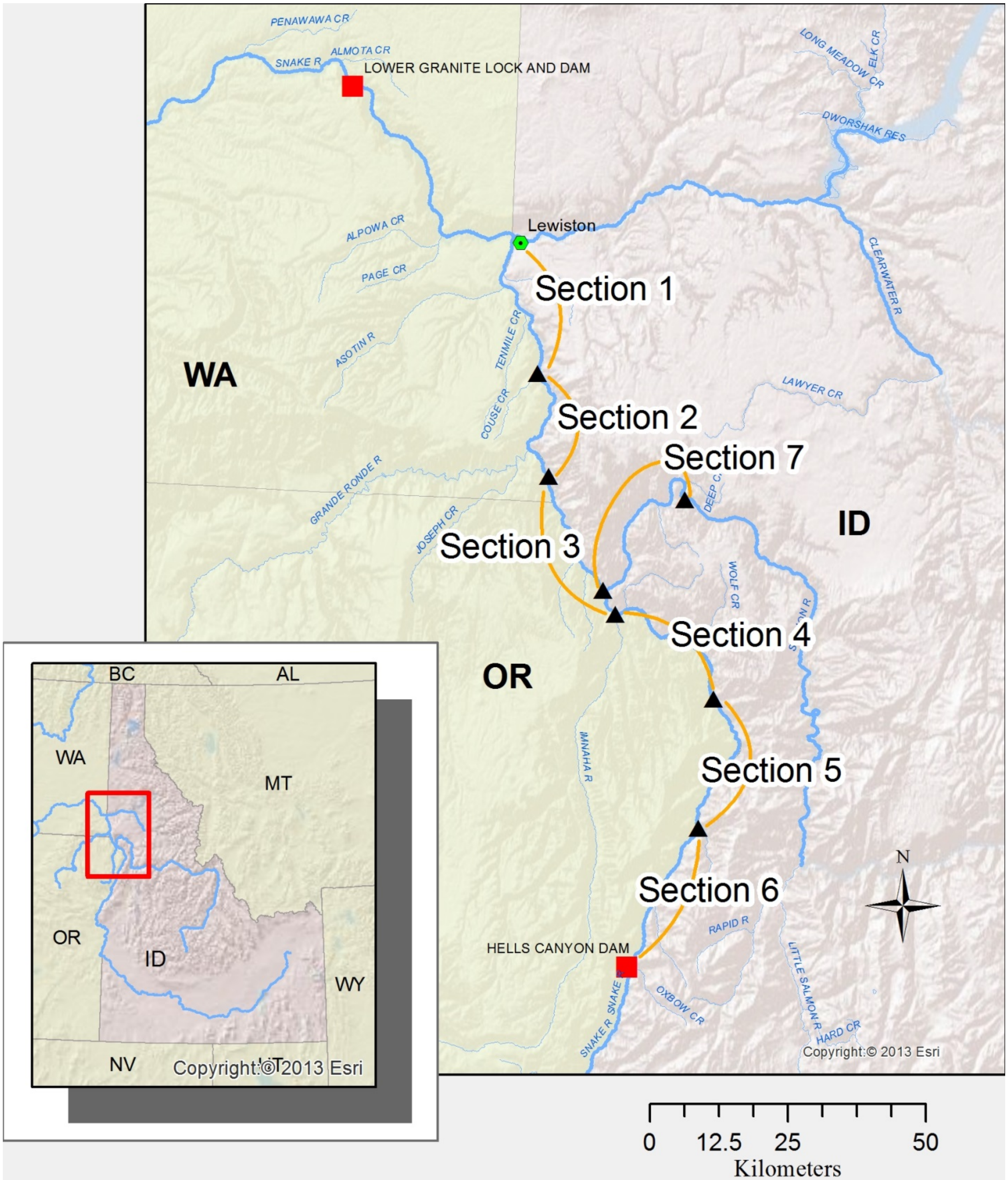

Figure 7. Map of the Hells Canyon reach of the Snake River from Hells Canyon Dam downstream to Lewiston, Idaho and locations of the study sections.

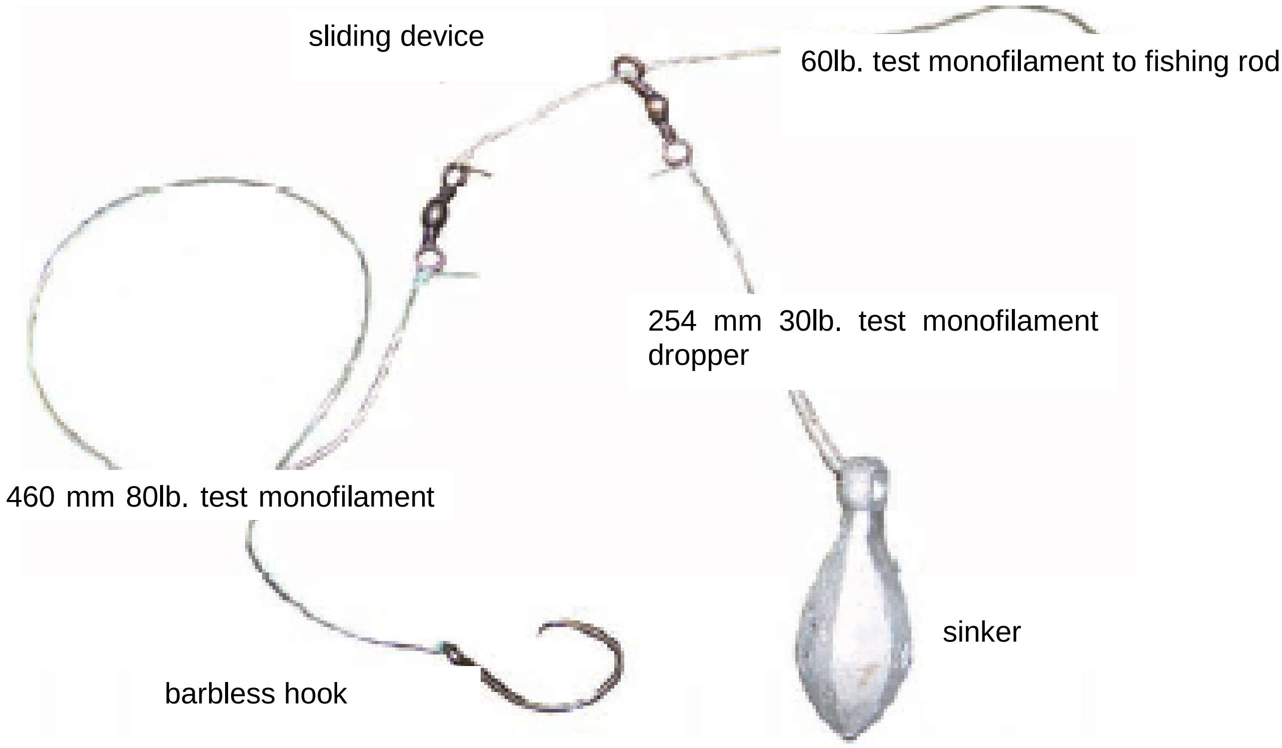

Figure 8. Terminal tackle configuration recommended for White Sturgeon angling.

Figure 9. Examples of the proper hook baiting for J and circle hooks for White Sturgeon angling.

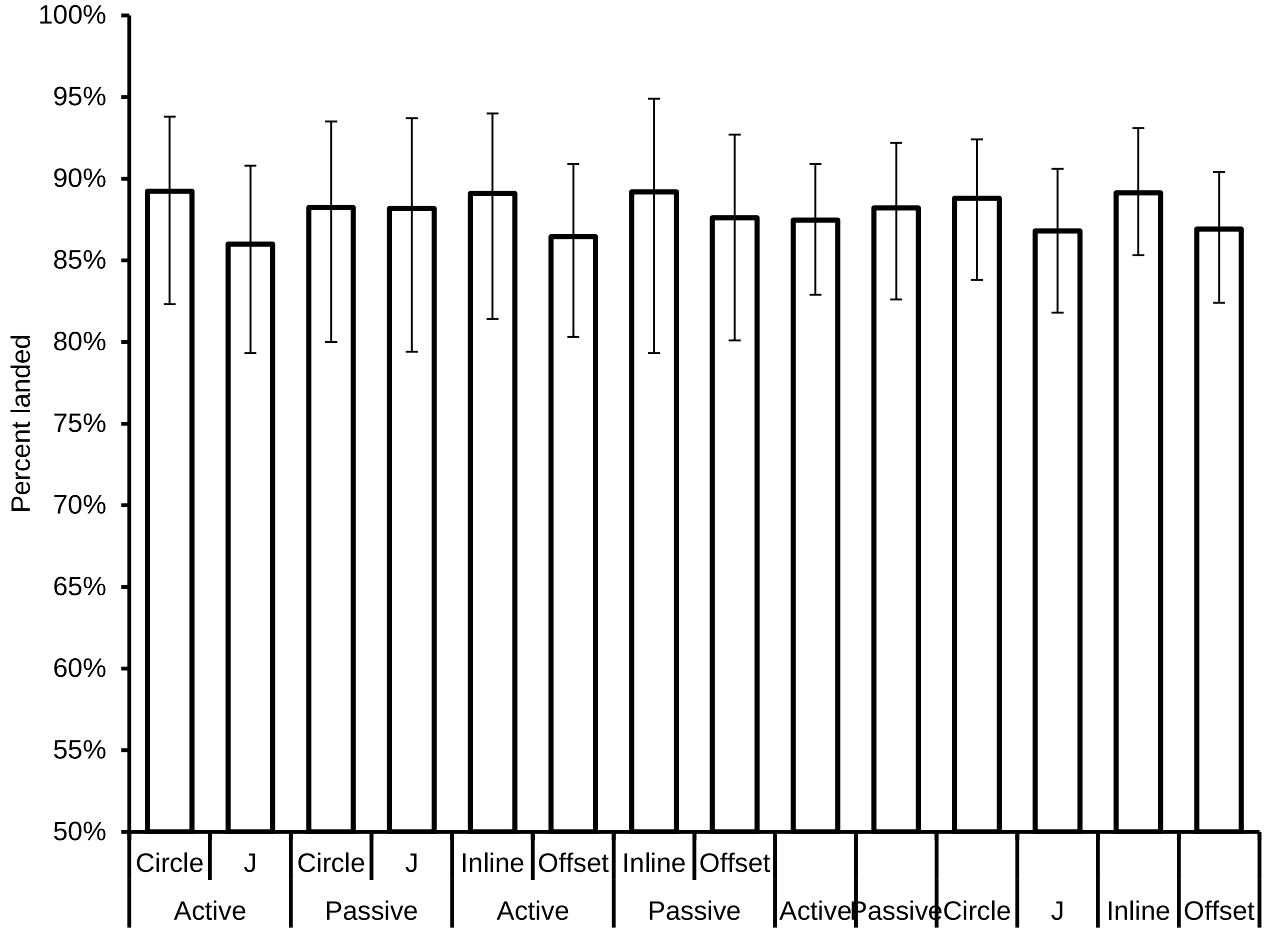

Figure 10. Landing rates of White Sturgeon after hooking for the different hook types and angling methods. Error bars are 90% confidence intervals.

ANNUAL PERFORMANCE REPORT
SUBPROJECT 4: HOOK INVESTIGATIONS

State of: Idaho

Grant No.: F-73-R-35 Fishery Research

Project No.: 5

Title: White Sturgeon Research

Subproject #4: Ingested Metal Investigations:
Metal ingestion and x-ray comparison

Contract Period: July 1, 2013 to June 30, 2014

ABSTRACT

Over the last decade, field reports indicate that 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 percent of fish that contained metal, the number and type of metal, and the retention or passage time of metal in the digestive system. A lower percentage of White Sturgeon <100 cm contain metal (10%) than White Sturgeon >100 cm (23-37%). The majority of the metal identified in the digestive systems of White Sturgeon was fishing tackle, with hooks being the primary type, followed by jigs, swivels, pieces of broken hooks, sinkers, and spinners. White Sturgeon with metal in their digestive system had smaller pectoral and pelvic girths than fish without metal, indicating a reduced body condition. White Sturgeon x-rayed at least twice in consecutive years appeared able to digest or pass metal, but also retained metal for up to 26 months and consumed new metal during the period between x-rays.

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INTRODUCTION

In Idaho, the Snake River population of White Sturgeon *Acipenser transmontanus* is currently stable, however, during most of the 20^{th} century populations declined due to overharvest and habitat fragmentation from dam construction (Cochnauer et al. 1985). Since 1971, sport fisheries for White Sturgeon have been managed under strict catch-and-release and barbless hook regulations (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, 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 angling related injury. 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 White Sturgeon in the Hells Canyon reach of the Snake River have metal fishing tackle in their digestive systems that were either left in fish after deep hooking, or were ingested after anglers lost tackle (J. DuPont, IDFG, personal communication; K. Lepla, Idaho Power Company, personal communication). Although the presence of metal in White Sturgeon in Idaho has been known for several years, until recently, neither the number of fish that contain metal, nor the types or amount of metal has been studied.

Research has been conducted that suggests when a fish is deeply hooked, cutting the line and releasing the fish results in lower post-hooking mortality compared to removing the hook (Schill et al. 1986; Tsuboi et al. 2006; Fobert et al. 2009); however, little research exists regarding the effects of leaving hooks inside fish on long-term health. Being such long-lived fish, the effects of metal in White Sturgeon could be substantial. Several studies have reported the condition of hooks left in fish, but they were relatively short term and focused 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 amount of time hooks persist in the digestive system or the long-term effects on growth rates or mortality of any fish species, especially fish like White Sturgeon that apparently ingest fishing tackle lost by anglers.

A brief description of the digestive system of White Sturgeon is necessary to better understand potential effects of ingested metal. White Sturgeon have an extendable, inferior mouth with soft, fleshy lips, developed to feed on the bottom of rivers. The nature of this design greatly increases the susceptibility of White Sturgeon to ingest fishing tackle lost by anglers. The digestive system of White Sturgeon is similar to other chondrosteans and is rather primitive when compared to modern teleosts (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).

OBJECTIVES

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

2. Evaluate the passage and retention time of metal in the digestive system of White Sturgeon by recapturing previously x-rayed fish.

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

METHODS

Study Area

The study area for our project was the Hells Canyon Reach of the Snake River, extending 163 km upstream from the confluence of the Clearwater River to Hells Canyon Dam, including the lower Salmon River from the confluence with the Snake River upstream 51 km (Figure 11). The reach was divided into seven sections to account for differing habitat, river management, and White Sturgeon densities. From the beginning of Section 1 at the mouth of the Clearwater River at Lewiston, Idaho upstream the river is accessible by road extending up the west bank of the Snake River, to the confluence of the Grande Ronde River in Section 2. The only access points upstream from the Grande Ronde River are by road to a boat ramp at Pittsburg Landing near the upstream end of Section 4 at Dug Bar, and by road to the Hells Canyon Dam at the upstream end of Section 6. Access to the majority of the river is by boat only.

X-ray and Metal Detection

White Sturgeon in Hells Canyon were sampled with set lines and by angling from 2010 through 2013 by Idaho Fish and Game and Idaho Power personnel. All individual fish were tagged with passive integrated transponders (PIT) tags at initial capture to allow comparisons during subsequent recapture. 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. 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). 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. Using fish scanned with the metal detector, we calculated the percentage of White Sturgeon that contained metal by length group (50-99 cm, 100-149 cm, 150-199 cm, 200-249 cm, and >250 cm), and river section (1-7). Using x-ray images of sampled White Sturgeon, we counted the total number of pieces of metal present and identified the metal pieces (i.e. hooks, swivels, sinkers, etc.) in the digestive tract. We compared X-ray images of White Sturgeon captured and x-rayed multiple times over the course of sampling to evaluate the processing and passage of metal in the digestive systems of individual fish over time. We also validated the presence/absence of metal using the metal detector with the x-ray in White Sturgeon >130 cm.

The x-ray system consisted of an x-ray generator and a plate that received the x-ray beam, compiled the received information, and sent 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 the x-ray generator and plate were mounted 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 (D. Dowden, Sound-Eklin, personal communication). To capture images of the entire digestive tract of each 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 using Adobe Photoshop (Adobe Photoshop Elements 10, Adobe Systems Inc. 2001-2011) 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) hooks generally used for salmon, steelhead, or trout *Oncorhynchus spp.*; 3) jigs (hooks with weighted heads typically used for Smallmouth Bass *Micropterus salmoides* 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 represented 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 points. Pelvic girth was measured around the body immediately anterior to the pelvic fin insertion points. Using multiple linear regression, we assessed the differences in fork length-pelvic girth and fork-length pectoral girth relationships for White Sturgeon (>100 cm) that contained metal in the digestive system versus those that did not ($\alpha = 0.05$). Girth and length values were transformed ($\log_{10}$) to meet the assumptions of normality and equal variance. Values were converted to original units (cm) after analysis for presentation in the figures. All analysis was performed using Minitab (2010).

RESULTS

A total of 1,784 White Sturgeon were scanned for metal with a metal detector in the Hells Canyon Reach of the Snake River from 2010 through 2013. Of those fish, 360 scanned positive for metal (18.9%) and 1,388 (81.1%) scanned negative for metal (Table 9). During the same period, 284 White Sturgeon were x-rayed, including 158 that contained metal and 126 that did not. During the four years of x-ray sampling, of the fish that contained metal, 40-60% contained one piece of metal, 11-25% contained two pieces, 8-10% contained 3 pieces, and <10% contained four or more pieces of metal (Figure 12). The greatest amount of metal identified in a single fish was 14 pieces. The majority of the types of metal identified in x-rays were fishing tackle; only two fish contained metal not identifiable as fishing tackle. Depending on year, 30-43% of fish contained one piece of metal identified as sturgeon type hooks. Between 3-10% of fish contained one piece of metal identified as salmon, steelhead, or trout hooks, 8-12% contained one jig, 5-13% contained one swivel, and 8-11% contained one piece of metal not included in the previous categories (Figure 13). In general, 2-11% of fish contained two sturgeon hooks, and <5% of fish contained two or more pieces of metal from the other categories (Figure 13).

Of the 284 White Sturgeon that were x-rayed, there was strong agreement between x-rays and the metal detector regarding which fish contained metal (Table 10). In fish containing metal according to the metal detector (n = 139), the x-ray image confirmed the presence of metal in 130 fish (94% agreement). Conversely, in fish lacking metal according to the metal detector (n = 117), the x-ray image confirmed the absence of metal in 102 fish (89% agreement).

Regression analysis suggests that the slope of the lines comparing fish >100 cm with and without metal were not different for either the fork length versus pelvic girth (F = 0.45, df = 1, P = 0.50) or the fork length versus pectoral girth (F = 20.4, df = 1, P = 0.15) comparisons. The elevations of those lines, however, were different for both the pelvic girth (F = 38.4, df = 1, P < 0.0001) and pectoral girth (F = 9.55, df = 1, P = 0.002), suggesting that fish with metal present had, on average, a 3.4 cm smaller pelvic girth (Figure 14) and a 1.2 cm smaller pectoral girth (Figure 15) than fish without metal.

A total of 22 White Sturgeon were x-rayed more than once during the four-year sample period, one being x-rayed three times. The time interval between x-rays ranged from 5-41 months. On the first x-ray occasion, 15 fish contained metal and seven did not. Of the fish that contained metal in the first x-ray, 13 contained metal on the second x-ray. However, three of those fish eliminated the original metal and ingested new metal, whereas 10 retained some of the original metal. Of the seven fish that did not contain metal in the first x-ray, four contained new metal in the second x-ray, while the remaining three fish did not contain metal on either x-ray occasion (Table 11). The one White Sturgeon x-rayed on three occasions contained the same piece of metal the first two times and none the third time.

The percent of White Sturgeon that contained metal varied widely between length groups and different river sections. A lower percent (10%) of 50-99 cm White Sturgeon contained metal, whereas 23% of 100-149 cm fish contained metal. A similar percent of White Sturgeon in the other three length groups (150-199 cm, 200-249 cm, and >251 cm) contained metal with 33%, 32%, and 31%, respectively (Figure 16). The percent of White Sturgeon from different study sections also contained different amounts of metal (Figure 17). White Sturgeon from Section 2 contained the most metal (33%) and fish from Section 3 contained the least metal (10%). Moving upstream, the percent of White Sturgeon with metal decreased from 24% in section 4 to 9% in section 7.

DISCUSSION

Our data indicates that White Sturgeon ingest fishing tackle and that the metal remains in their digestive systems for long periods (Table 5), which apparently slows their growth. Our data suggests that once White Sturgeon have ingested metal in their digestive systems, they do not maintain a similar body condition to those without metal. Reasons may be that White Sturgeon with metal present are less likely to feed effectively or that the metal or other tackle, such as monofilament, are obstructing the digestive tract, reducing the uptake of nutrients. Reduced body condition is of concern because it could affect gonad development and possibly reduce reproductive fitness.

One assumption made at the beginning of this study was that the fishing tackle in the digestive systems of White Sturgeon was likely introduced by the deep hooking of fish and the subsequent loss of gear. All previous research that studied fishing tackle left in fish were introduced through the act of angling and deep hooking (Mason and Hunt 1967; Marnell 1969; Hulbert and Engstrom-Heg 1980; Broadhurst et al. 2007; Butcher et al. 2007). However, recent information indicates that deep hooking occurs infrequently while angling for White Sturgeon (see previous chapter). Rather, the loss of gear due to snagging on the bottom of the river occurs considerably more often. Thus, along with the anatomical nature of White Sturgeon to feed directly off the bottom, we believe that the majority of fishing tackle identified in White Sturgeon digestive systems were ingested off the bottom after anglers lost gear with bait still attached.

Approximately 50% of the fishing tackle identified in White Sturgeon were hooks of the size typically used for sturgeon angling; however, many of those hooks could also come from angling for different species. The percentage of White Sturgeon that contain smaller hooks and jigs that are not usually associated with sturgeon angling suggests that White Sturgeon are ingesting tackle in a rather random fashion. In other words, if a hook with any type of bait attached is lost in the river, it could be ingested by White Sturgeon. One concerning issue is the likely presence of monofilament or other line material that is ingested with metal tackle. Monofilament and other material used as line for angling do not appear in x-rays, yet is likely present when a hook is ingested, especially when a hook and swivel are identified together. The effect of line material in the digestive systems of White Sturgeon could be more problematic than metal because line material is not likely to break down (see chapter one), and once ingested it could potentially accumulate over the life of the fish. We are currently unable to evaluate the presence, amount, or longevity of line material in White Sturgeon.

The percent of White Sturgeon containing metal in the different river sections likely reflects the effort of anglers fishing for sturgeon or other species. Sections 1 and 2 are accessible by road and have popular Steelhead Trout and Chinook Salmon fisheries. Therefore, angling pressure in sections 1 and 2 are likely higher on all species 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 was the low percentage of White Sturgeon from section 3 that contained metal. Section 3 is accessible only by boat, does not provide a substantial salmon or steelhead fishery, and is a narrow reach where pools lack definition and locations to fish for White Sturgeon are less obvious. As such, anglers are probably less likely to expend effort angling in that section, decreasing the amount of tackle lost.

Our results suggest that White Sturgeon consume and process metal through their digestive systems; however, one fish contained metal for at least 26 months (Table 5) and White Sturgeon potentially consume and process metal over their entire lifetime. Further research is required to understand the effects of ingested fishing tackle on White Sturgeon populations.

RECOMMENDATIONS

1. Complete x-ray imaging of White Sturgeon in Hells Canyon in 2014, using the increased number of x-rayed fish to more definitively assess how White Sturgeon retain or process metal over time.

2. Consider possible regulations that could reduce the amount of fishing tackle lost in the Hells Canyon reach of the Snake River.

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Table 9. The total number of White Sturgeon with and without metal as determined with a metal detector and an x-ray from 2010-2013 in the Hells Canyon reach of the Snake River.

	Number of White Sturgeon	
Metal Present	**Detected**	**X-Rayed**
Yes	360	158
No	1388	126
Total	1784	274

Table 10. 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**	**Percent agreement**
Yes	139	9	93.9
No	15	117	88.6

Table 11. The PIT tag number, months at large, and number of pieces of metal by year identified in individual White Sturgeon recaptured and x-rayed on multiple occasions from the Hells Canyon reach of the Snake River, Idaho. “Lost” is the number of pieces of metal lost between x-ray years, “New” is the number of new pieces of metal gained between years, and “Old” is the number of pieces of metal present in both years in from the Snake River in the Hells Canyon reach.

		Pieces of metal						
		Year						
PIT tag number	Months at large	2010	2011	2012	2013	Lost	New	Old
3D9.1C2D9B9EF3	9	14	8	-	-	9	2	5
3D9.1C2D9B82BE	10	-	6	4	-	5	3	1
3D9.1BF25F7298	41	3	-	-	5	3	5	0
3D9.1BF25F5838	26	1	-	2	-	1	2	0
3D9.1C2D5CF5E0	21	-	1	-	1	1	1	0
3D9.1C2DEAAF92	12	-	-	2	2	1	1	1
3D9.1C2DEB35B3	12	-	-	1	0	1	0	0
3D9.1C2DEB3675	10	-	-	1	0	1	0	0
3D9.1C2D717E02	14	-	2	1	-	1	0	1
3D9.1C2D9B1799	24	2	1	-	-	1	0	1
3D9.1C2D9C2E74	36	1	1	-	0	0,1*	0	1,0*
3D9.1BF1675772	26	0	-	2	-	0	2	0
3D9.1C2D703641	14	-	0	1	-	0	1	0
3D9.1C2D708288	27	-	0	-	1	0	1	0
3D9.1C2D9B3BFA	23	-	0	-	1	0	1	0
3D9.1C2D5CB031	5	-	0	0	-	0	0	0
3D9.1C2DEAC49E	15	-	-	0	0	0	0	0
3D9.1C2DEB0B96	13	-	-	0	0	0	0	0
3D9.1C2D709F06	12	-	1	1	-	0	0	1
3D9.1C2D9BA84E	10	-	1	1	-	0	0	1
3D9.1C2DEB14F0	11	-	-	1	1	0	0	1
3D9.1C2DEB4A6B	10	-	-	1	1	0	0	1

* the two numbers represent metal status on second and third recaptures, respectively.

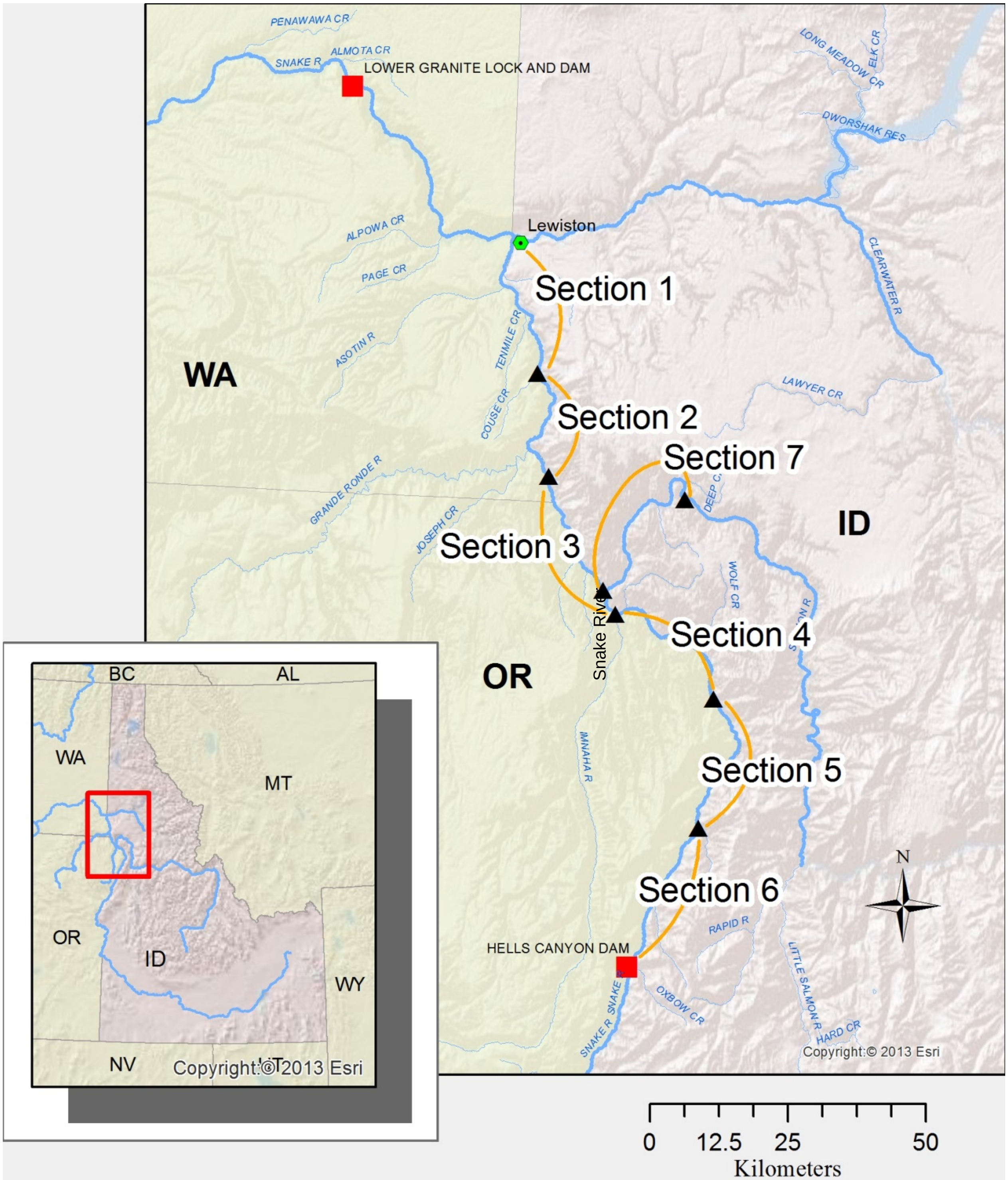

Figure 11. Map of the Hells Canyon reach of the Snake River from Hells Canyon Dam downstream to Lewiston, Idaho and locations of the study sections.

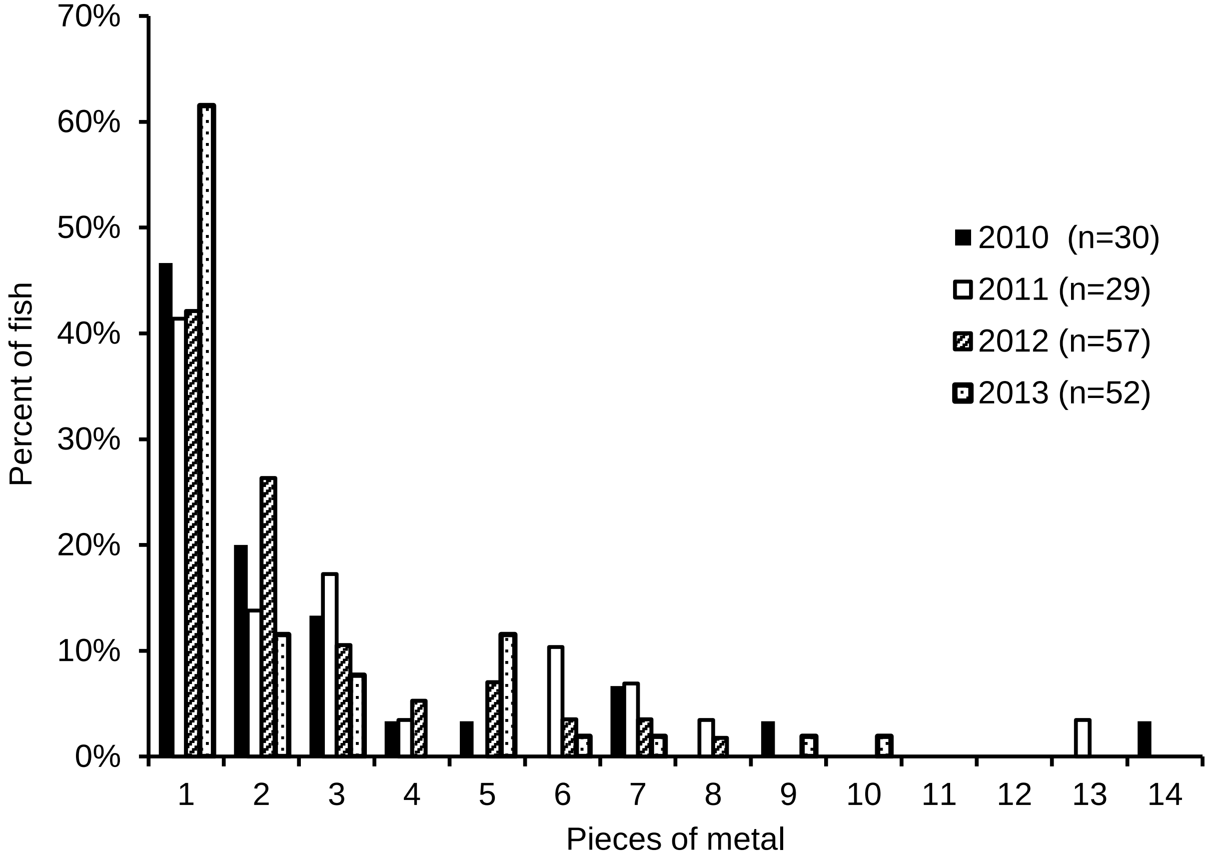

Figure 12. The percent of White Sturgeon that contain 1-14 of pieces of metal in the different sampling years. Counts were made from x-rays of White Sturgeon sampled from the Snake River in the Hells Canyon reach.

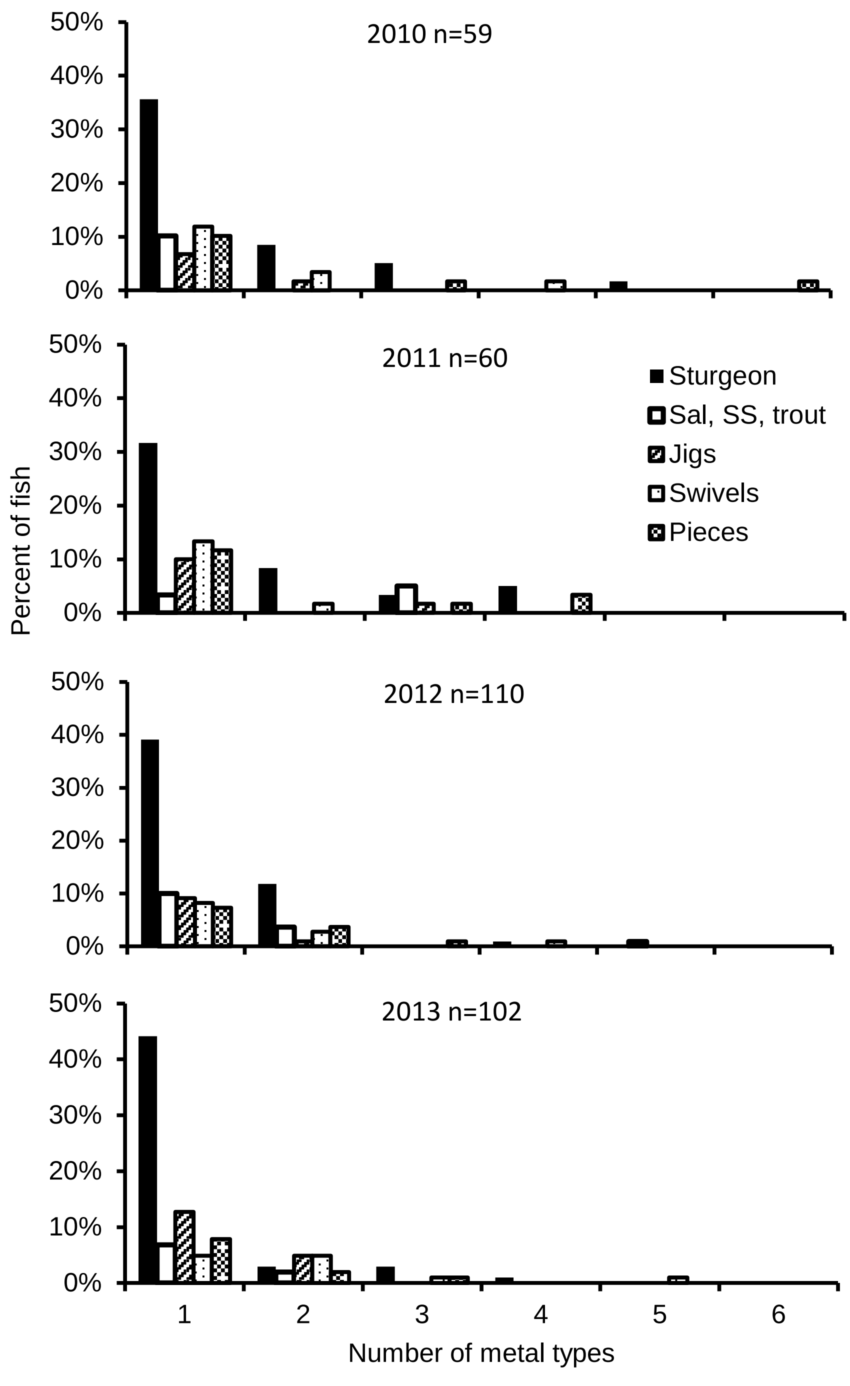

Figure 13. The percent of White Sturgeon that contained 1-6 items of the metal types (Sturgeon hooks; Salmon, steelhead and trout hooks; jigs; swivels; and pieces of metal) in the different sampling years. Counts were made from x-rays of White Sturgeon sampled from the Snake River in the Hells Canyon reach.

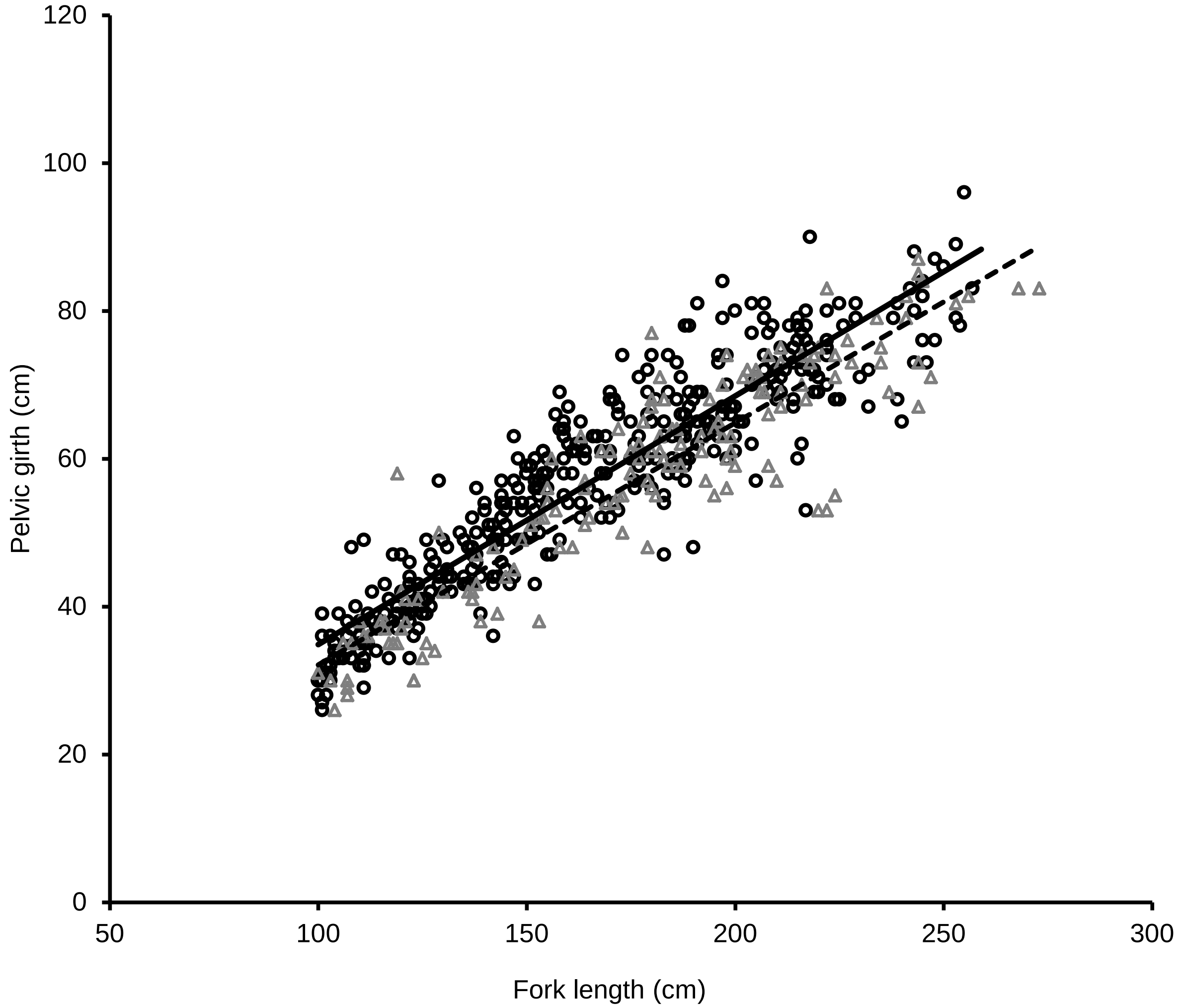

Figure 14. Fork Length/pelvic girth comparison of White Sturgeon that contained metal (grey triangle) and those that did not contain metal (black circles) sampled from the Snake River in the Hells Canyon reach from 2010 through 2013.

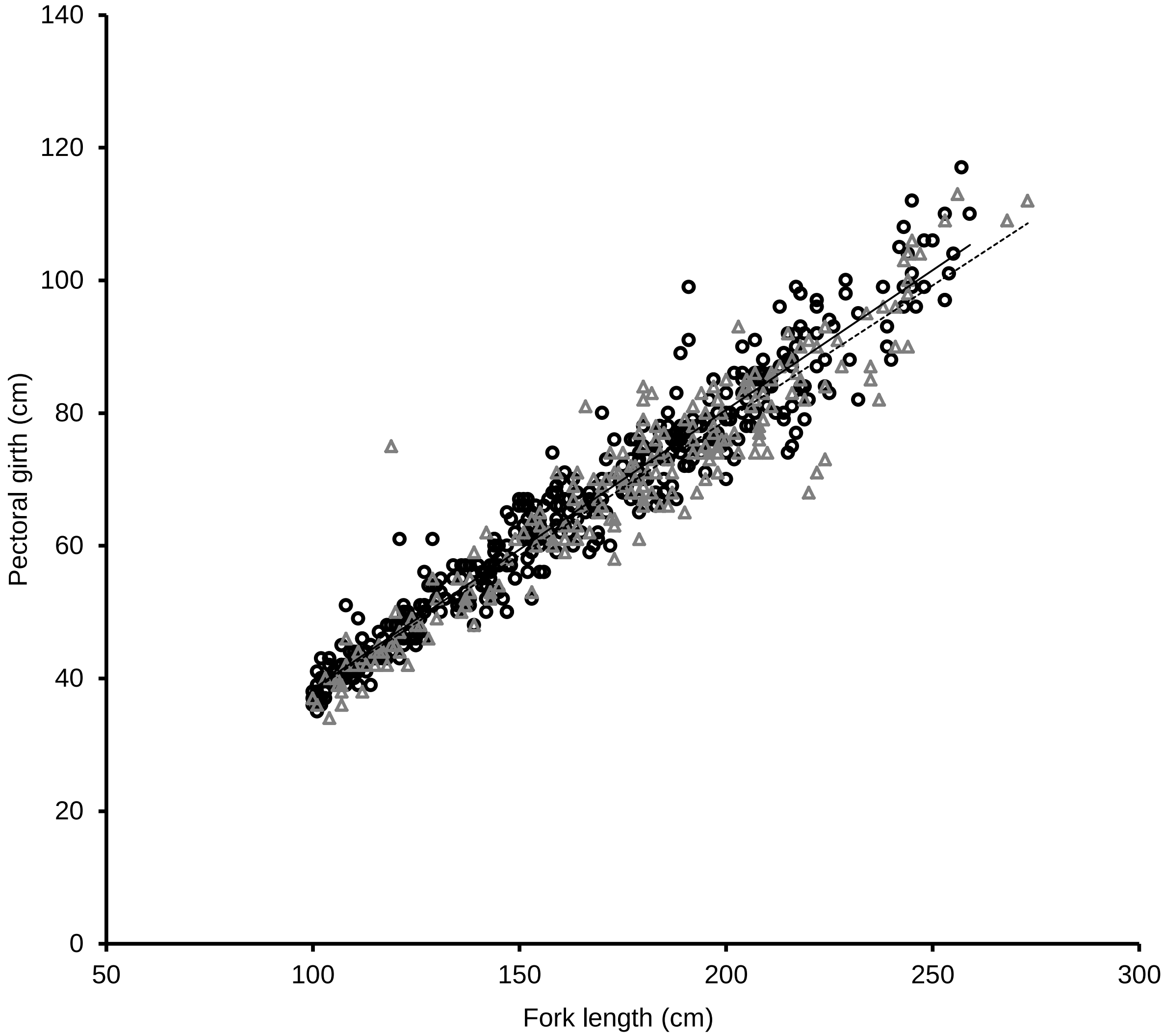

Figure 15. Fork length/pelvic girth comparison of White Sturgeon that contained metal (grey triangle) and those that did not contain metal (black circles) sampled from the Snake River in the Hells Canyon reach from 2010 through 2013.

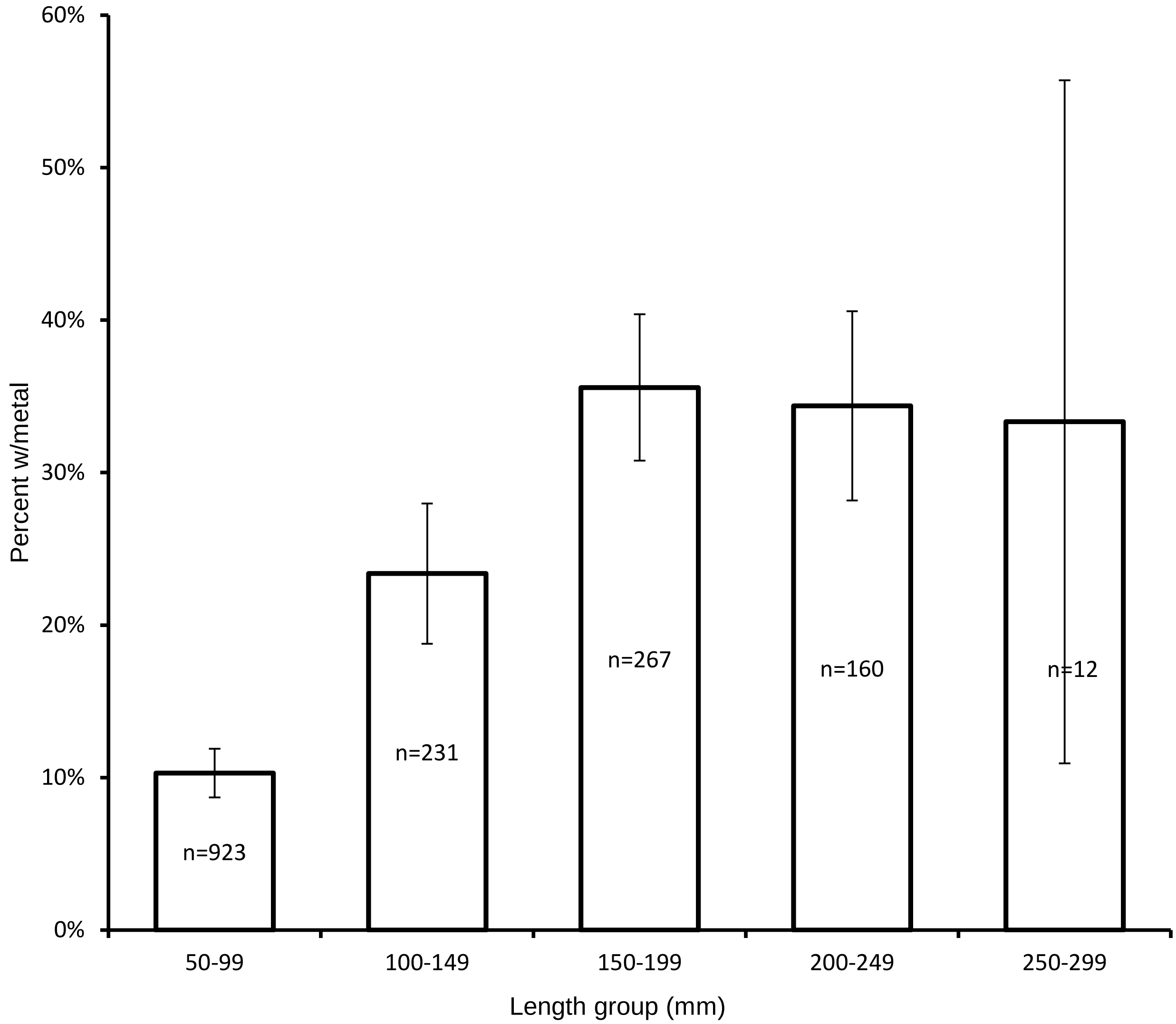

Figure 16. The percent of White Sturgeon by length group sampled from the Snake River in the Hells Canyon reach that contained metal in 2010-2013. Error bars are 90% confidence intervals.

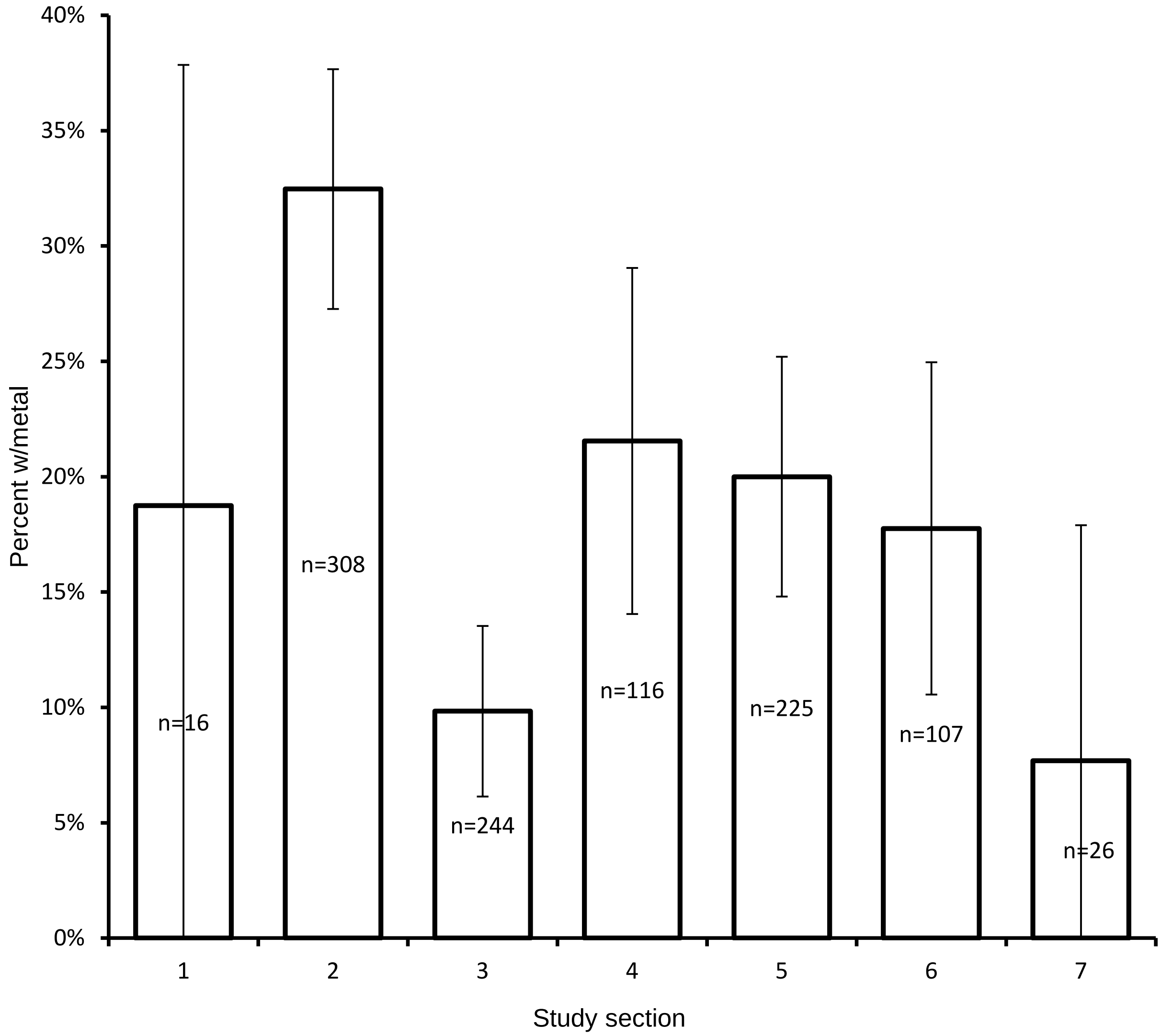

Figure 17. The percent of White Sturgeon in study sections 1-7 sampled from the Snake River in the Hells Canyon reach that contained metal in 2010-2013. Error bars are 90% confidence intervals.

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