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**Article**

# Population dynamics of White Sturgeon in the upper Snake River, Idaho: Evaluation of management options for a harvest fishery

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## ABSTRACT

**Objective:** Understanding how fish populations will respond to management actions is critical for making effective management decisions. This study provides important information regarding population demographics for a nonnative, hatchery-implemented population of White Sturgeon *Acipenser transmontanus*. We investigated the population dynamics of White Sturgeon in the upper Snake River, Idaho, and developed an age-structured population model to evaluate potential stocking and harvest scenarios (e.g., length limits and annual quotas).

**Methods:** White Sturgeon were sampled from June to October 2022 and from June to August 2023 using angling (i.e., rod and reel) and setlines from a 260-km-long section of the Snake River. Capture histories from 261 known-age White Sturgeon informed age and growth analysis and an evaluation of movement trends. A closed-population capture–recapture model and an estimate of setline-specific catchability were used to estimate the total abundance of White Sturgeon in the upper Snake River. Apparent survival for the population was estimated using a Cormack–Jolly–Seber model. Finally, a population model was parameterized using information on the population dynamics of White Sturgeon in the upper Snake River. The model was used to estimate the effects of varying stocking rates and harvest scenarios (i.e., harvest slot of 76–122 cm fork length [FL] and annual quotas of 0–25 White Sturgeon harvested) on the population.

**Results:** In total, 340 individual White Sturgeon were captured throughout the study area, with 181 recapture events. Individuals varied in FL from 54 to 205 cm, and the mean relative weight for captures was 105.2 (SD = 14.4), suggesting relatively high body condition. Age varied from 2 to 25 years, and White Sturgeon moved an average of 8.1 km (SD = 23.5) downstream from stocking locations. Estimated abundance of White Sturgeon in the tailwaters of American Falls Dam was 428 fish (95% CI = 403–463). That abundance estimate was used to inform a total abundance estimate of 887 White Sturgeon (95% CI = 835–960) in the study area. Apparent annual survival was 0.79 (95% CI = 0.64–0.89). A stocking rate of 285 age-2 White Sturgeon/year was necessary to maintain current abundance. For every five fish harvested (harvest slot = 76–122 cm FL) per year, estimated abundance decreased by about 2.2% over 20 years.

**Conclusions:** Our research identified fast growth of White Sturgeon relative to other populations and relatively high mortality for a White Sturgeon population without exploitation. Also, like other studies evaluating harvest, a population model was used to illustrate the effect of varying rate functions on a fishery. The age-structured population model suggested that a harvest fishery is possible while still meeting management goals for the upper Snake River White Sturgeon fishery.

**KEYWORDS:** age and growth, fisheries, management, mark–recapture, population dynamics

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## LAY SUMMARY

The information provided by this research will help resource managers to monitor White Sturgeon population trends and will assist in making informed management decisions. Further, the model provides a framework for assessing potential population-level responses to changing conditions and provides managers with the information necessary to effectively manage White Sturgeon harvest fisheries.

## INTRODUCTION

Sturgeon (Acipenseridae) can be found in a variety of lakes, streams, rivers, and estuaries around the world (Birstein, 1993; Birstein et al., 1997; Jager et al., 2016; Jelks et al., 2008). The combination of overexploitation and habitat degradation has led to population declines and resulted in protections for sturgeons across their distribution. In Eurasia, all 16 native sturgeon species have declined in abundance and 15 are now considered endangered or critically endangered (Haxton et al., 2016). The status of North American sturgeon species is generally better than that of Eurasian sturgeon species (Birstein et al., 1997; Haxton et al., 2016). However, all North American species have some form of designation (or consideration for designation) under the Endangered Species Act in some portion of their distribution. For example, the Alabama Sturgeon *Scaphirhynchus suttkusi* and the Kootenai River population (Montana, Idaho, and British Columbia) of White Sturgeon *Acipenser transmontanus* are federally endangered North American sturgeon species (Campton et al., 2000; Duke et al., 1999; Schreier et al., 2013). Only two of the nine North American species are considered least concern for extinction by the International Union for Conservation of Nature (Haxton et al., 2016). Efforts such as strict harvest regulations, the elimination of fisheries, habitat improvement projects, and conservation aquaculture have been implemented to recover sturgeon populations (Beamesderfer & Farr, 1997). Despite the conservation concerns regarding sturgeon populations, several species are currently exploited for commercial or recreational use, including White Sturgeon (Haxton et al., 2016).

White Sturgeon are native to major river systems of western North America (Hildebrand et al., 2016; Pikitch et al., 2005). Individuals have been encountered from Alaska Bay, Alaska, to Ensenada, Mexico. The largest extant populations are found in the Fraser River (British Columbia), Columbia River (Idaho, Oregon, and Washington), and Sacramento–San Joaquin River (SSJ; California) systems. Populations with access to marine habitats appear to be most abundant (Schreier et al., 2013). For instance, White Sturgeon in the SSJ and lower Columbia River (downstream of Bonneville Dam) have access to estuary habitats and regularly support recreational harvest fisheries (Blackburn et al., 2019; Rieman & Beamesderfer, 1990). However, these harvest fisheries occur at low levels of exploitation and must be closely monitored to prevent overexploitation. White Sturgeon are susceptible to overharvest due to their life history characteristics (i.e., late maturing and periodic spawning). Requiring 12–30 years to reach sexual maturity increases the likelihood for an individual to be harvested prior to reproducing (Hildebrand et al., 2016; Scott & Crossman, 1973). Once mature, a 3–5-year period between potential spawning events further limits the reproductive potential of White Sturgeon in exploited populations (Blackburn et al., 2019; Haxton et al., 2016).

In Idaho, White Sturgeon populations of the Kootenai and Snake rivers are of conservation concern due to population declines in association with anthropogenic disturbances. Declines in the Kootenai River population have been associated with extensive habitat alterations, particularly water development in the form of levees and dams in the basin (Ireland et al., 2002; Paragamian et al., 2005). Studies in the 1980s suggested that recruitment of White Sturgeon was absent in the river; in 1994, Kootenai River White Sturgeon were listed as endangered under the Endangered Species Act (Duke et al., 1999). The other White Sturgeon population in Idaho is in the Snake River drainage. The native distribution of White Sturgeon in the Snake River extended upstream to Shoshone Falls, a 65-m-tall natural barrier to upstream fish migration that is located at river kilometer (rkm) 990 (measured from the mouth of the Snake River). Today, nine impoundments fragment the Snake River population of White Sturgeon. Historical accounts are lacking for commercial White Sturgeon harvest in Idaho, but declines in the Snake River coincide with the time frame of White Sturgeon overexploitation in other portions of its distribution (Dillon & Grunder, 2008). Idaho Department of Fish and Game (IDFG) eliminated commercial harvest throughout the state in the 1940s, and recreational harvest was prohibited statewide in 1971 (IDFG, 2024).

White Sturgeon in the lower Snake River occupy approximately 172 km of free-flowing Snake River downstream of Hells Canyon Dam and 33.5 km of Lower Granite Reservoir (Bowersox et al., 2016). This segment of the Snake River forms the border between Idaho and both Washington and Oregon; therefore, management of White Sturgeon is shared between states in border waters. The Nez Perce Tribe co-manages White Sturgeon in Hells Canyon, as the tribe retains treaty rights for harvest of White Sturgeon (Nez Perce Tribe Fisheries Resources Management Staff, 2005). Idaho Power Company (IPC), as a part of the relicensing agreement for its hydroelectric dams (e.g., Hells Canyon complex of dams), performs much of the monitoring of the White Sturgeon population in the Snake River (IPC, 2021b). Sampling by IPC has indicated high abundance of juvenile White Sturgeon, slow growth, and highly variable recruitment in the lower Snake River.

White Sturgeon in the middle Snake River are distributed from Brownlee Dam upstream to Shoshone Falls (Coutant, 2004; Dillon & Grunder, 2008). Water development, including five dams for irrigation, hydropower, and flood control, has deteriorated river habitat and fragmented the White Sturgeon population in the middle Snake River (Dillon & Grunder, 2008; IDFG, 2024; IPC, 2021b). Currently, natural recruitment is absent from all but one segment of the middle Snake River between C. J. Strike Reservoir and Bliss Dam. In response, IDFG and IPC initiated an aquaculture program to supplement recruitment throughout the middle Snake River (IDFG, 2024; Patterson et al., 1992). Beginning in 1988, sexually mature adult White Sturgeon were collected from the middle Snake River and transported to a hatchery for use as broodstock. After spawning, the broodstock were released back into the Snake River and offspring were cultured. Juveniles were raised for 12–18 months before being stocked into segments of the middle Snake River. Genetic testing suggested that the broodstock program was limiting the genetic diversity of hatchery-reared White Sturgeon (IPC, 2021a). A repatriation program was developed that involved the collection and rearing of naturally spawned eggs downstream of Bliss Dam. Collecting spawned eggs from the Bliss Reach allowed for natural mate pairing and provided the opportunity to collect eggs from more White Sturgeon breeding pairs than space allowed for in a hatchery setting (Thorstensen et al., 2019). The broodstock program was replaced by repatriation in 2020 (IPC, 2021a). As a part of the management plan for White Sturgeon, IDFG established the number of fish stocked in each river segment (IDFG, 2024). Since most targets were being met and “surplus” sturgeon were available, a novel population upstream of Shoshone Falls was established.

Many recreational fishing opportunities were present in the upper Snake River prior to the addition of White Sturgeon. These fisheries included coolwater and warmwater species (i.e., Smallmouth Bass *Micropterus dolomieu* and crappie *Pomoxis* spp.) in reservoirs and trophy trout fisheries (i.e., Rocky Mountain Cutthroat Trout *Oncorhynchus virginalis* and Rainbow Trout *O. mykiss*) in the Snake River. Idaho Department of Fish and Game first stocked White Sturgeon upstream of Shoshone Falls in 1990 (Dillon & Grunder, 2008; Table 1). White Sturgeon have been stocked from Lake Walcott to the Upper Idaho Falls Dams (a complex of two dams in Idaho Falls, Idaho; Figure 1). The goal of the stocking program upstream of Shoshone Falls is to provide Idaho anglers with a unique angling opportunity. Interest in the fishery has grown over the past decade, leading IDFG to explore management options for the White Sturgeon fishery. A hatchery-facilitated population could provide anglers the first opportunity in more than 50 years to harvest White Sturgeon in Idaho.

Before changes to management of the fishery, a thorough understanding of the population dynamics of White Sturgeon in the upper Snake River is necessary. Growth, mortality, and recruitment are the population functions that describe the dynamics of fish populations (Allen & Hightower, 2010; Ricker, 1975). Information on growth and mortality provides insight on biotic and abiotic factors influencing fish populations. Recruitment is of particular interest for White Sturgeon populations (Beamesderfer et al., 2012; Jager et al., 2001). However, recruitment in the upper Snake River appears to be solely a function of stocking because natural recruitment has not been documented. Incorporating information on growth, recruitment, and mortality rates into an age-structured population model allows managers to evaluate different options for the fishery. For example, Blackburn et al. (2019) used an age-structured population model to simulate a variety of harvest scenarios for White Sturgeon in the SSJ. Similarly, Koch et al. (2009) used age-structured population models to evaluate the response of Shovelnose Sturgeon *Scaphirhynchus platorynchus* populations to various levels of exploitation. Thus, the objectives of this study were to (1) investigate the population dynamics of White Sturgeon in the upper Snake River and (2) develop an age-structured population model to evaluate potential stocking and harvest scenarios (e.g., length limits and annual quotas).

## METHODS

### Study area

The Snake River is a 1,735-km-long tributary of the Columbia River. The Snake River originates in western Wyoming before flowing through the Snake River Plain of southern Idaho. In western Idaho, the river turns north, enters Hells Canyon, and forms the Idaho–Oregon and Idaho–Washington borders before its confluence with the Columbia River in eastern Washington. Large-scale water development on the Snake River began in 1901 with Swan Falls Dam (Dillon & Grunder, 2008). Additional impoundments were constructed to meet demands for irrigation, hydroelectric power, and flood control. As one of the most altered rivers in North America, the Snake River has 27 main-stem dams and diversions that irrigate over 1 million ha of agricultural land (Palmer, 1991). The first natural barrier to upstream fish movement on the Snake River is Shoshone Falls, which prevents migratory fish species (e.g., White Sturgeon, Pacific Lamprey *Entosphenus tridentatus*, and Rainbow Trout) from populating the upper Snake River.

The study area extended from Milner Dam (rkm 1,028, measured from the mouth of the Snake River) to the Upper Idaho Falls Dams (rkm 1,288; Figure 1). The study area encompassed four reservoirs: Milner Lake (1,760 ha) impounded by Milner Dam, Lake Walcott (3,338 ha) impounded by Minidoka Dam (rkm 1,086), American Falls Reservoir (22,375 ha) impounded by American Falls Dam (rkm 1,149), and Gem Lake (161 ha) impounded by Gem Lake Dam (rkm 1,271). The Snake River from Milner Dam to Minidoka Dam is considered Milner Lake. Upstream of Lake Walcott to American Falls Dam are 29 km of river with relatively low complexity. The river is mostly confined to a single channel except for a few small islands. Upstream of American Falls Reservoir is a 92-km segment of river with relatively high channel complexity (e.g., braided channel and floodplain connectivity). Lastly, upstream of Gem Lake are 12 km of pools created by multiple diversions and hydroelectric power facilities as the river flows through Idaho Falls, Idaho.

The stocking program for White Sturgeon in the upper Snake River was initiated in 1990 (IDFG, 2024). From 1990 until 2006, fish were only stocked from Minidoka Dam to American Falls Dam. Starting in 2007, the river segment from American Falls Dam to Gem Lake Dam was included in the stocking effort. Eight years later, in 2015, White Sturgeon were stocked in the segment from Gem Lake Dam to the Upper Idaho Falls Dams. In total, about 7,650 White Sturgeon have been stocked from Minidoka Dam to the Upper Idaho Falls Dams: The river segment from Minidoka Dam to American Falls Dam has been stocked with 2,595 White Sturgeon, the segment from American Falls Dam to Gem Lake Dam has been stocked with 3,161 fish, and the segment from Gem Lake Dam to the Upper Idaho Falls Dams has received 1,894 individuals. With few exceptions, most of the stocked White Sturgeon were age-2 fish. The segment from Milner Dam to Minidoka Dam was not stocked but is included in the study area because

**Table 1.** History of White Sturgeon stocking in each segment of the upper Snake River. Segments are organized from downstream to upstream in the study area. No White Sturgeon were stocked in the river segment from Milner Dam to Minidoka Dam.

| River segment | Year | Number stocked |
|---|---|---|
| **Minidoka Dam to American Falls Dam** | 1990 | 100 |
| | 1991 | 206 |
| | 1995 | 114 |
| | 1997 | 100 |
| | 1998 | 100 |
| | 2005 | 356 |
| | 2010 | 98 |
| | 2014 | 105 |
| | 2015 | 666 |
| | 2017 | 239 |
| | 2018 | 150 |
| | 2020 | 100 |
| | 2021 | 45 |
| | 2022 | 216 |
| **American Falls Dam to Gem Lake Dam** | 2007 | 74 |
| | 2010 | 436 |
| | 2013 | 251 |
| | 2014 | 381 |
| | 2015 | 821 |
| | 2016 | 331 |
| | 2017 | 309 |
| | 2018 | 300 |
| | 2019 | 8 |
| | 2020 | 237 |
| | 2022 | 13 |
| **Gem Lake Dam to Upper Idaho Falls Dams** | 2015 | 433 |
| | 2016 | 100 |
| | 2017 | 607 |
| | 2018 | 87 |
| | 2019 | 339 |
| | 2020 | 100 |
| | 2021 | 62 |
| | 2022 | 166 |

White Sturgeon have moved into that reach via passage through Minidoka Dam. The study area also contains popular recreational fisheries for Largemouth Bass *Micropterus nigricans*, Smallmouth Bass, Rainbow Trout, Brown Trout *Salmo trutta*, crappie, Bluegill *Lepomis macrochirus*, and Yellow Perch *Perca flavescens*.

### Field sampling and laboratory processing

The study area was subdivided into four segments delineated by dams (Figure 1). The most downstream segment was from Milner Dam upstream to Minidoka Dam (rkm 58). Sampling effort in this segment was primarily in the tailwaters of Minidoka Dam. The next segment began at Lake Walcott and continued upstream to American Falls Dam (rkm 68). Sampling in Lake Walcott was limited to the upper 12 km of the reservoir. Preliminary sampling by IDFG personnel during the year prior to this study suggested that the 4.2-ha pool immediately downstream of American Falls Dam (i.e., American Falls tailwater [AFTW]) had the highest density of White Sturgeon in the study area (N. Tillotson, IDFG, unpublished report). Not surprisingly, AFTW is also the most popular location for recreational angling. Sampling at AFTW took place within 0.6 km of American Falls Dam at an average depth of 8.8 m. The pool was nearly uniform in depth to within about 25 m of either shoreline but shallowed to less than 2 m for the next 1 km downstream. The third segment began at the upstream end of American Falls Reservoir and ended at Gem Lake Dam (rkm 94). American Falls Reservoir was not sampled during the study given sampling logistics. The uppermost segment was from Gem Lake Dam to the Upper Idaho Falls Dams and was the shortest of the four segments (rkm 17.5).

White Sturgeon were sampled in all four segments (Figure 1). In 2022, sampling took place from June to August, with 1 week of supplemental sampling in October. In 2023, sampling occurred during June–August. Sampling in 2022 was largely focused on identifying the distribution of White Sturgeon in the study area, whereas sampling in 2023 was primarily focused on obtaining recaptures for analyses of abundance, mortality, and movement. Considerable effort (i.e., ~70% of total effort) in 2023 was focused on the segment from Minidoka Dam to American Falls Dam.

Sampling was focused on lotic habitat following protocols developed by IDFG and Idaho Power Company (IPC) (Bowersox et al., 2016; IPC, 2021b; Lamansky et al., 2018). Fish were collected using a combination of setlines and angling. Setlines followed IDFG protocols, consisting of a 30-m main line with six equally spaced 16/0 circle hooks. Hooks were tied on roughly 50-cm leaders baited with kokanee *O. nerka* and connected to the main line by longline spring clips. Weights were attached to each end of the main line and marked with a buoy. The gear was deployed in short-duration sets (2–8 h) or overnight (12–16 h). Angling (i.e., rod and reel) techniques followed IDFG regulations (e.g., single hook, sliding swivel with lower breaking-strength line to connect weight) and sampling protocols (Bowersox et al., 2016). Medium-heavy 2.4-m and heavy 2.7-m rods with large-capacity conventional reels were used. The main line consisted of 27.2-kg breaking-strength monofilament. Attached to the main line was a 36.3-kg breaking-strength monofilament leader and a single 8/0 or 9/0 octopus-style hook baited with kokanee or commercially available baits (i.e., Sturgeon Candy [D&G Bait, Clackamas, Oregon]; Maple Premium Pork Sausage [Jimmy Dean, Springdale, Arkansas]). A weight was attached to a sliding swivel by a lower breaking-strength line to prevent loss of gear. Angling took place for 0.5–6.0 h before moving to a new location.

Fork length (FL; nearest 0.5 cm), total length (nearest 0.5 cm), and weight (nearest 0.1 kg) were measured for all sampled White Sturgeon. Pectoral girth (nearest 0.5 cm; measured just posterior to the pectoral fins) was also measured for each fish sampled. White Sturgeon were examined for a missing scute, as removal of a lateral scute has been used to identify hatchery-origin fish in the Snake River system (IDFG, 2024). Individuals were scanned for a PIT tag, as not all fish had been PIT-tagged when initially stocked. Individuals that were unmarked had their second right lateral scute removed, and fish without a PIT tag had one inserted into the dorsal musculature. The mark and tag combination allowed recaptured fish to be identified for capture–recapture methods, age estimation, and description of movement. To increase the number of encounters for analyses, an angling guide at AFTW was provided with a PIT tag reader during the summer and fall of 2023 and was

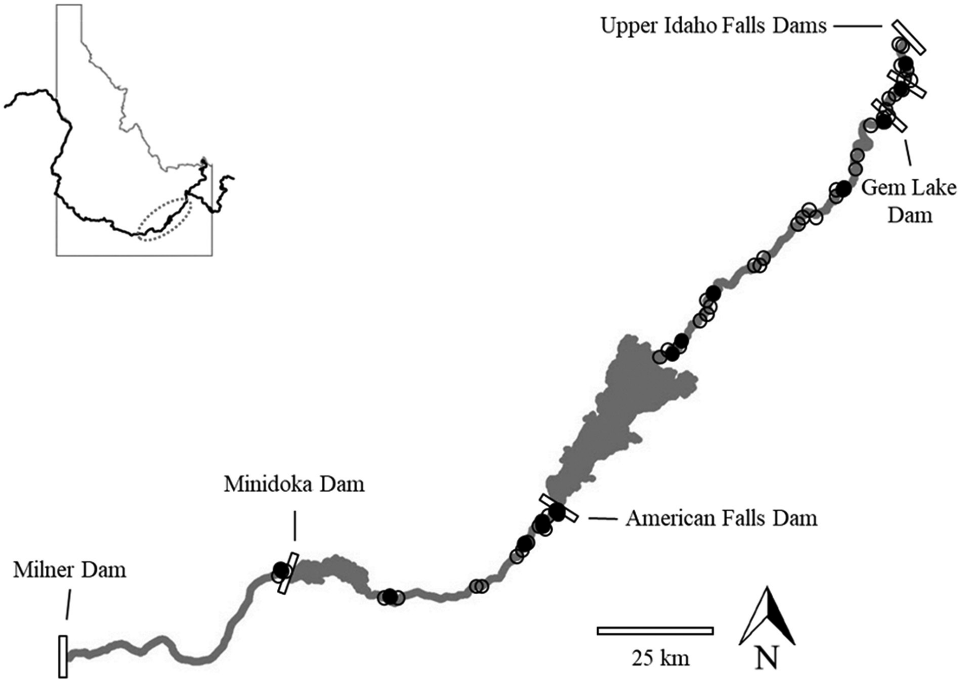

**Figure 1.** The study area for this project, showing Milner Dam, Minidoka Dam, American Falls Dam, Gem Lake Dam, and the Upper Idaho Falls Dams in the state of Idaho. Included is the portion of the upper Snake River that is stocked with White Sturgeon (i.e., from Minidoka Dam upstream to the Upper Idaho Falls Dams). Also included are sampling locations (open circles) and locations where at least one White Sturgeon was captured (closed circles) during 2022 and 2023. River flow is from east to west.

asked to scan all White Sturgeon caught. For age and growth analysis, a 2–3-cm cross section was removed from near the point of articulation on the leading pectoral fin ray (Koch et al., 2008). Fin ray sections were stored in coin envelopes and were allowed to dry until they were processed in the laboratory.

Fin rays were mounted in epoxy following standard protocols (Koch & Quist, 2007). After the epoxy had cured, three cross sections (0.8–1.3 mm) were removed from the proximal end of the ray. Cross sections were aged using a dissecting microscope and transmitted light (Quist et al., 2012). Image analysis software (Image-Pro Plus; Media Cybernetics, Rockville, Maryland) was used to measure increments (i.e., annuli) from sectioned fin rays. Structures from known-age White Sturgeon ($n = 195$) from the upper Snake River were used to gain experience estimating ages and measuring growth increments from fin rays. Age estimates (i.e., without knowledge of known age) for known-age White Sturgeon were highly accurate (>90% accurate; Figure S1 [see online Supplementary Material]), suggesting that age estimates for unknown-age White Sturgeon were also likely accurate.

### Data analysis

Catch per unit effort (CPUE; fish/h) was used to estimate relative abundance. For setlines, effort was recorded as total time (h) for a standard set (see above). For angling, effort was measured as the number of hours that an individual rod and reel was fished. Abundance was estimated for AFTW using capture–recapture methods, and an assumption of closure was made for the 2023 sampling season. Capture–recapture information from 2023 sampling of AFTW (including data from guides) was used to create a capture history (i.e., enumerating presence as “1” or absence as “0” in all sampling occasions) for all individuals sampled. Time intervals between sampling occasions were included as the total number of days between sampling trips. Capture histories and time intervals were then used to estimate abundance using closed-population abundance models (Otis et al., 1978). All capture–recapture analyses were conducted using program R (R Core Team, 2023) with package RMark (Laake, 2013; White & Burnham, 1999). After ensuring that the models had properly converged (e.g., estimated SEs), we used Akaike’s information criterion corrected for small sample size ($\mathrm{AIC}_c$) to aid in selecting the most parsimonious model (Burnham & Anderson, 2004). When the $\mathrm{AIC}_c$ difference ($\Delta\mathrm{AIC}_c$) was less than 2, the top model was then selected based on variability in the estimate. Candidate models for the abundance estimate included $M_o$, representing constant capture probability ($p$); $M_t$, which represented time-varying $p$; $M_b$, representing a constant behavioral response to $p$; $M_T$, which specified time as a regression for effect on $p$; $M_{tb}$, representing individual time-varying $p$ for initial capture and recapture ($c$); and $M_{tb2}$, which represented time-varying $p$, with the effect of $c$ held constant (Otis et al., 1978).

Due to a lack of sufficient recaptures in other portions of the study area, abundance was only estimated using capture–recapture methods for AFTW. However, the abundance estimate from AFTW was used to estimate a setline-specific catchability coefficient ($q$) using the equation

$$C_s / f_s = qN_d,$$

where $C_s$ is the number of White Sturgeon captured from AFTW by setline, $f_s$ is the setline effort (h) at AFTW, and $N_d$ is estimated White Sturgeon abundance per hectare (i.e., density) of the 4.2 ha sampled at AFTW (Hubert & Fabrizio, 2007; Peterman & Steer, 1981). The estimated catchability coefficient was then used with the setline CPUE from each sampling area to estimate White Sturgeon density. Similar methods have been used to estimate Walleye *Sander vitreus* density in northern Wisconsin lakes (Hansen et al., 2004). Density of White Sturgeon was then used to estimate abundance in the study area by multiplying the estimated density by the sampled area. Confidence intervals were estimated by following the same methods stated above with the upper and lower bounds of the abundance estimate from AFTW.

An age-at-length key was used to summarize age structure of the White Sturgeon population and estimate ages for a small number ($n = 31$) of fish that had damaged structures (Paukert & Spurgeon, 2017; Quist et al., 2012). Relative weight ($W_r$) was calculated to evaluate the body condition of White Sturgeon in the upper Snake River as

$$W_r = 100 \times \left(W / W_s\right),$$

where $W$ is the observed weight (kg) and $W_s$ is the length-specific standard weight for White Sturgeon (Beamesderfer, 1993; Neumann et al., 2012). Standard weights for individuals greater than 70 cm FL were estimated using the equation

$$W_s = 2.735 \times 10^{-6} \times \mathrm{FL}^{3.232},$$

where FL is in centimeters.

Mean back-calculated length at age was estimated using the Dahl–Lea method:

$$L_i = \left(L_c / R_c\right) \times R_i,$$

where $L_i$ is the length at age $i$, $L_c$ is the length at the time of capture, $R_c$ is the ray radius at capture, and $R_i$ is the ray radius at annulus $i$ (Quist et al., 2012; Shoup & Michaletz, 2017). A von Bertalanffy growth model was then used to further describe White Sturgeon growth in the population:

$$L_t = L_\infty \left[1 - e^{-K(t - t_0)}\right],$$

where $L_t$ is length at time $t$, $L_\infty$ is the estimated mean maximum length for the population, $K$ is the growth coefficient, and $t_0$ is the time at which length equals zero (Ogle et al., 2017; von Bertalanffy, 1938).

Apparent survival of White Sturgeon in the upper Snake River was estimated from Cormack–Jolly–Seber (CJS) models (Cormack, 1964; Jolly, 1965; Lebreton et al., 1992; Seber, 1965) using capture histories for White Sturgeon sampled from AFTW in 2022 and 2023. Time intervals between sampling occasions were included in the CJS models as proportions of a year. After ensuring that models had properly converged (e.g., estimated SEs), we used AIC$_c$ to select the most parsimonious model (Burnham & Anderson, 2004). Candidate models for CJS were parameterized as follows: constant apparent survival and constant capture probability ($\phi$, $p$); constant apparent survival with time-varying capture probability ($\phi$, $p_t$); constant apparent survival, with capture probability varying in relation to an inclusive harvest slot of 76–122 cm FL ($\phi$, $p_h$; see below for justification); and constant apparent survival, with capture probability varying between two age-classes ($\phi$, $p_s$). The age-classes used for comparison (i.e., age $< 5$; age $\geq 5$) were based on assumed life stage, where juveniles (<95 cm FL) were compared with subadults and adults (≥95 cm FL) following length criteria defined by IDFG (2024).

Estimates of demographics and rate functions were used to parameterize an age-structured population model constructed in program R (R Core Team, 2023). The model was a variation of the population growth model:

$$N_{t+1} = N_t e^{-Zt},$$

where $N_{t+1}$ is the number alive at time $t + 1$, $N_t$ is the number alive initially (at $t$), $Z$ is the instantaneous total mortality rate, and $t$ is time in years (Allen & Hightower, 2010; Ricker, 1975). The apparent annual survival estimate ($\phi$) from the CJS model for AFTW was substituted into the model as

$$N_{t+1} = N_t\left(\phi\right).$$

Harvest was modeled using a quota-based regulation structure; thus, the additive effect of harvest mortality ($H$) was included in the model as

$$N_{t+1} = N_t\left(\phi\right) - H_s,$$

where $H_s$ is the number of fish harvested annually depending on the specific scenario. The simulation model used an initial population $N_t$ of 1,000 White Sturgeon. The observed age structure was scaled to the initial population size by multiplying the proportion of individuals at each age in the population by the total estimated population and mirrored the 2023 population (i.e., only age 3 or older present, as stocking was absent in 2023). The age structure in the modeled population was allowed to vary following a multinomial distribution using the proportion of individuals at each age as the probability of occurrence for that age. Variation in the estimate of $\phi$ was included in the model using the beta distribution, a continuous distribution bounded from 0 to 1 (Bolker, 2008). The shape of the distribution and range of potential values can be adjusted by changing the values for the alpha ($\alpha$) and beta ($\beta$) parameters. Here, the beta distribution was parameterized to reflect the upper and lower bounds of the CIs for $\phi$. Values for $\phi$ were drawn from the beta distribution for all ages present in each year being modeled. A binomial function then used $\phi$ as the probability of an individual remaining in the population and was used to select fish to be removed as mortalities. The model then selected fish that would be harvested, up to $H_s$, based on a two-stage process. First, age-specific vulnerability to harvest was assigned using the proportion of individuals at each age in the observed population that were within a harvest slot (see below). Variation in individual growth—and

Table 2. Summary of White Sturgeon captures during 2022 and 2023 in the upper Snake River. Included are the minimum (Min), maximum (Max), mean, and SD for fork length and weight. Also included is the estimated abundance by segment, with the 95% CI in parentheses.

|  |  |  | Fork length (cm) |  |  |  | Weight (kg) |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| River segment | Individuals captured | Recaptures | Min | Max | Mean | SD | Min | Max | Mean | SD | Abundance |
| **Milner Dam to Minidoka Dam** | 1 | 0 | 142.5 | 142.5 | 142.5 | – | 29.1 | 29.1 | 29.1 | – | 7 (6–8) |
| **Minidoka Dam to American Falls Dam** | 298 | 177 | 57.0 | 205.0 | 109.2 | 33.2 | 1.3 | 82.5 | 15.0 | 14.6 | 795 (760–843) |
| **American Falls Dam to Gem Lake Dam** | 26 | 4 | 54.0 | 150.0 | 105.7 | 24.5 | 1.3 | 32.8 | 12.8 | 7.3 | 81 (77–86) |
| **Gem Lake Dam to Upper Idaho Falls Dams** | 15 | 0 | 60.0 | 130.0 | 84.3 | 22.0 | 1.8 | 23.8 | 6.8 | 6.0 | 84 (81–89) |

therefore vulnerability to harvest at each age—was accounted for using the beta distribution. Parameterization of the beta distribution was based on information from the observed population. Specifically, the number of observed individuals at each age in the harvest slot was used for the $\alpha$ parameter, and total number at that age and not in the slot was used for the $\beta$ parameter. Each age-specific vulnerability was then multiplied by the number of individuals at that age for each year in the model to create a subpopulation of fish available for harvest. A multinomial distribution was used to assign harvest mortality. The probabilities used in the multinomial distribution were the proportions of fish available for harvest at each age. Fish remaining in the population after harvest increased in age by 1, and new individuals were added to the population (i.e., stocking). Growth was assumed to remain constant through time despite any change in abundance, as we did not have enough information to add a density-dependent function to the model. The model simulated 20 years and was repeated for 10,000 iterations for each scenario.

The effect of stocking and harvest on the population was estimated using annual stocking rates of 200, 225, and 550 individuals, and harvest quotas of 0, 5, 10, and 25 individuals/year were modeled. Stocking rates were based on both the White Sturgeon Management Plan (i.e., 200 individuals/year; IDFG, 2024) and historical stocking rates. Historical rates included the mean stocking rates for 1990–2023 (225 individuals/year) and 2013–2023 (550 individuals/year). The specific annual harvest quotas were based on discussions with resource managers. A survey of harvest slots for other White Sturgeon populations and discussions with resource managers led to two potential options for harvest slots: 102–152 and 76–122 cm FL. Ultimately, a 76–122-cm-FL harvest slot was used because (1) testing of mercury concentration in White Sturgeon in the study area showed lower levels of total mercury at smaller sizes (IDFG, unpublished information); (2) yield of White Sturgeon meat by recreational anglers would likely be sufficient to generate interest in harvest; and (3) it is similar to the harvest slots used to manage fisheries in Washington and Oregon. Resource managers suggested that implementing harvest should not detract from the catch-and-release opportunity of recreational anglers currently using the fishery. Therefore, in addition to estimating patterns in abundance through time, the model was used to estimate the number of White Sturgeon that would need to be stocked to maintain a population of 1,000 individuals (i.e., current conditions).

## RESULTS

In total, 521 White Sturgeon captures were recorded across both years, representing 340 individuals and 181 recaptures (Table 2). In 2022, we sampled 102 locations with setlines (763 h of effort) and angling (486 h), and we captured 189 individual White Sturgeon, with 46 recaptures. During 2023, 33 locations were sampled (403 setline hours and 215 angling hours), resulting in the capture of 151 individuals and 135 recaptures. Mean CPUE was highest from Minidoka Dam to American Falls Dam and lowest from Milner Dam to Minidoka Dam for both setline and angling (Figure 2). Sampling at AFTW resulted in the capture of 150 individuals and 43 recaptures during 2022 and the capture of 125 individuals and 132 recaptures during 2023. The angling guide at AFTW added 114 individuals and 254 recaptures to the sample in 2023.

White Sturgeon varied in length from 54 to 205 cm FL (mean ± SD = 107.9 ± 33.2 cm), and 79% of individuals were less than 130 cm FL (Table 2; Figure 3). Fish varied in weight from 1.3 to 82.5 kg (14.5 ± 14.6 kg; Table 2), with a mean $W_r$ of 105.2 ± 14.4 (Figure 4). White Sturgeon varied from age 2 to age 25, with 80% of individuals being younger than age 10. Fish in the upper Snake River were estimated to reach 100 cm FL by age 7 and 150 cm FL by age 14 (Figure 5).

Information on stocking was available for 259 of the White Sturgeon captured in the study. On average, individuals moved 8.1 km downstream from their stocking location and 82.6% were captured within 10 km of their stocking location (Figure 6). The furthest downstream movement was 139.4 km from a location called John's Hole in the town of Idaho Falls to AFTW. This fish had to pass through four dams. The furthest upstream movement was 68.7 km from immediately upstream of American Falls Reservoir to just downstream of the town of Firth, Idaho. No pattern in movement was observed with regard to stocking location or years since stocking (Figure 6).

Only two of the six potential abundance models met selection criteria (i.e., $M_{tb2}$ and $M_t$; Table 3). The estimate from $M_{tb2}$ was 554 White Sturgeon (95% CI = 410–964), and the estimate from $M_t$ was 428 fish (95% CI = 403–463). Ultimately, $M_t$ was selected because it had less variation and provided a more conservative (i.e., lower) estimate of $N$, which was deemed most appropriate for evaluating the potential for a harvest fishery. Using the abundance estimate from AFTW, a setline catchability coefficient $q$ of $2.93 \times 10^{-3}$ was estimated. Total abundance of White Sturgeon in the study area was estimated to be 887 fish (95% CI = 835–960; Table 2).

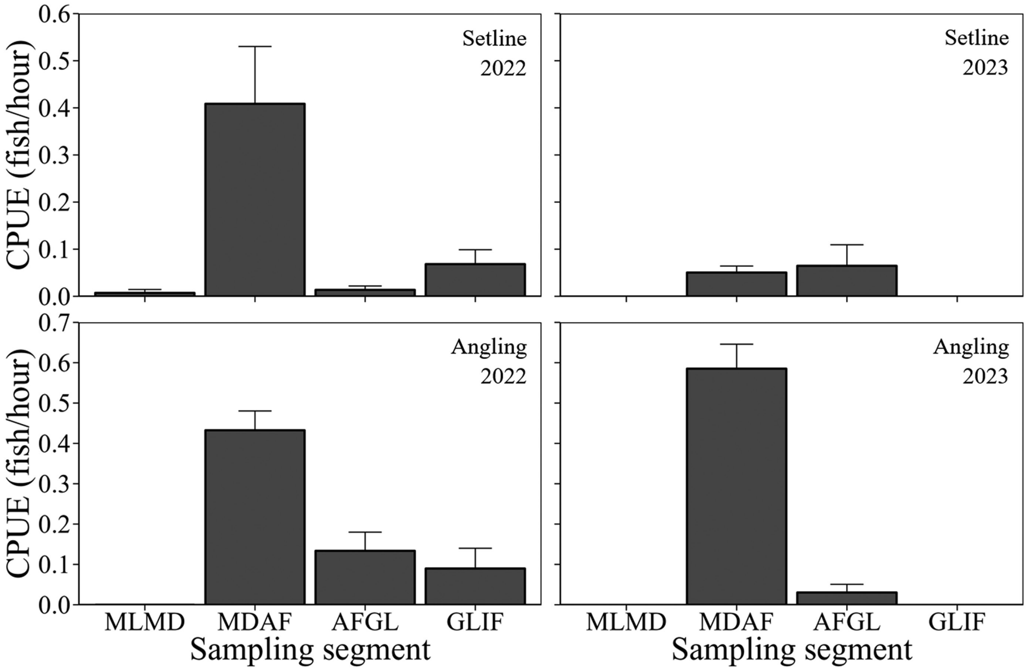

**Figure 2.** Mean CPUE (number of White Sturgeon captured per hour sampled) in the upper Snake River during 2022 and 2023 for each sampling segment. Error bars represent 1 SE. Segments are listed from downstream to upstream and are defined as Milner Dam to Minidoka Dam (MLMD), Minidoka Dam to American Falls Dam (MDAF), American Falls Dam to Gem Lake Dam (AFGL), and Gem Lake Dam to the Upper Idaho Falls Dams (GLIF).

Similar to the abundance modeling, only two models met selection criteria for CJS (Table 4). One of the models held capture probability constant ($\phi$, $p$) and the second allowed $p$ to vary in relation to the harvest slot of 76–122 cm FL ($\phi$, $p_h$). Although the models had similar estimates of $\phi$ (0.78 and 0.79) and the same amount of variation in 95% CIs (0.25), the model with the lowest AIC$_c$ was chosen. Ultimately, the model that allowed $p$ to vary in relation to the harvest slot ($\phi$, $p_h$) was used to estimate an apparent survival of 0.79 (95% CI = 0.64–0.89).

The age-structured population model highlighted the importance of stocking rates for the White Sturgeon population in the upper Snake River. For instance, the first stocking scenario was 200 White Sturgeon stocked per year. With 200 fish stocked annually and no harvest, the estimated population size would decrease by 27.6% in 10 years and 29.8% in 20 years (Figure 7). Depending on the number of White Sturgeon harvested (5–25 individuals/year), the estimated population would decrease by 28.9–36.9% in 10 years and 32.0–40.9% in 20 years (Figure 8). If the stocking rate was increased to 225 individuals/year, the estimated population was predicted to decrease by 18.5% in 10 years and 21.0% in 20 years (Figure 8). An annual harvest of 5–25 White Sturgeon would decrease the estimated population by 21.6–29.8% in 10 years and 23.3–32.3% in 20 years. The number of White Sturgeon was predicted to increase by 85.3% in 10 years and 92.0% in 20 years when 550 fish were stocked annually (Figure 8). With an annual harvest of 5–25 White Sturgeon, the estimated population would still increase by 74.8–82.9% in 10 years and 80.9–89.7% in 20 years (Figure 8). A stocking rate of 285 White Sturgeon/year and no harvest would be necessary to maintain the population near 1,000 individuals (Figure 9). With harvest, the population would decrease by about 2.1% in 10 years and 2.4% in 20 years for every five fish harvested per year (Figure 9).

## DISCUSSION

White Sturgeon were widespread from Minidoka Dam to the Upper Idaho Falls Dams. However, the highest densities of fish were observed in the area immediately downstream of American Falls Dam. Relatively high densities of White Sturgeon were also observed near Massacre Rocks State Park (about 15 km downstream from American Falls Dam) and just downstream of Gem Lake Dam. Similar to what has been observed in the middle Snake River (IPC, 2023), all White Sturgeon were sampled in channels or pools greater than 4 m in depth. As would be expected with an increase in stocking, the population of White Sturgeon has increased substantially over the past decade. The effect of increased stocking was reflected in the length and age structure. White Sturgeon populations in other areas often have maximum lengths that surpass 300 cm (IDFG, 2024) and are thought to exceed 100 years in age (Smith et al., 2002). In our study, the largest fish observed was 208 cm FL and the oldest fish was age 25. Increased stocking over the past 10 years has resulted in most captured fish being from recent stocking events (i.e., about 80% of individuals are less than 130 cm and 79% are younger than age 10).

White Sturgeon in the upper Snake River exhibited several interesting patterns in growth. The leading pectoral fin ray is generally considered the most accurate structure for aging White Sturgeon (Ghere et al., 2024; Phelps et al., 2017). Age estimates for White Sturgeon have been shown to be inaccurate in some systems, especially when growth is slow (Ghere

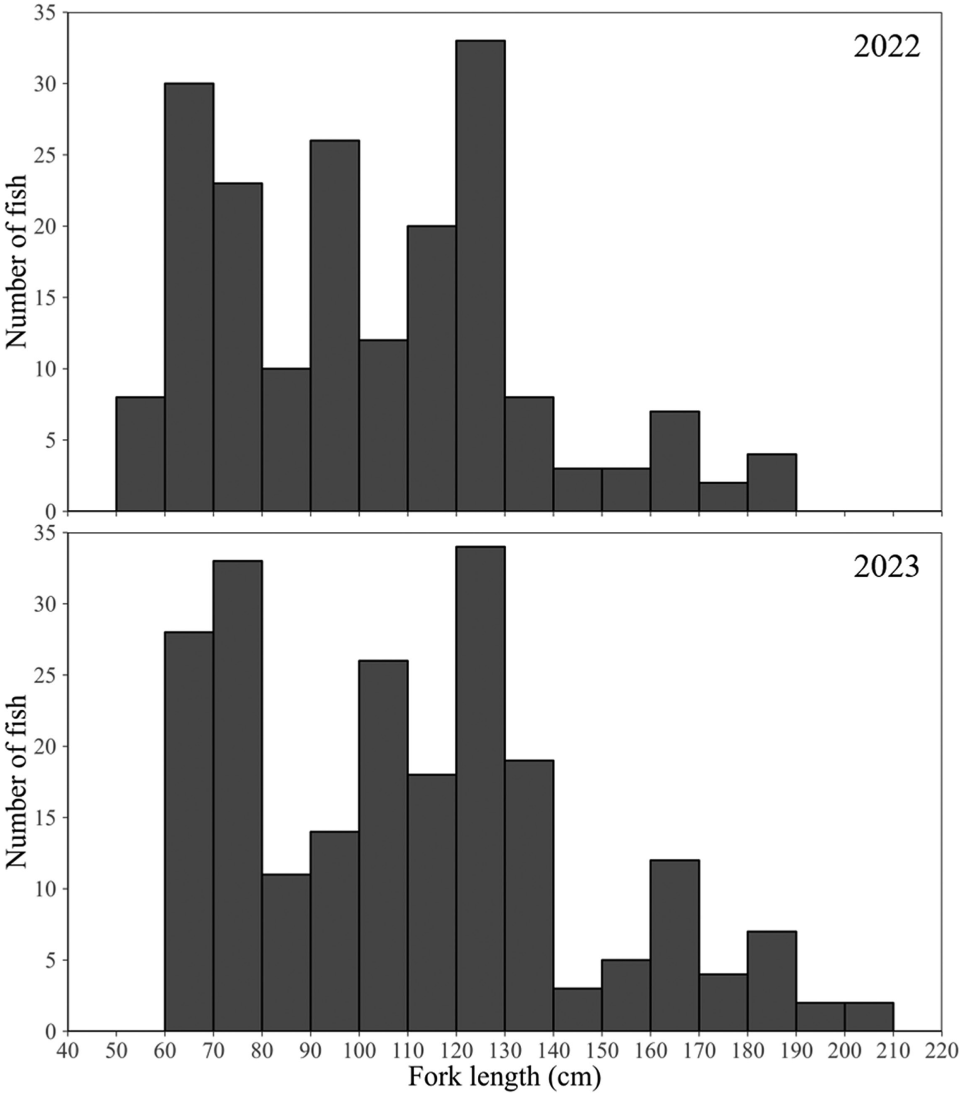

**Figure 3.** Length-frequency distribution of White Sturgeon sampled in the upper Snake River during 2022 and 2023.

et al., 2024). However, other studies have shown good accuracy up to age 20 (Paragamian & Beamesderfer, 2003; Rien & Beamesderfer, 1994). Age estimates for fish in our study were likely quite accurate for several reasons. Not only were most fish less than age 20, but 57% were of known age. When ages were estimated without knowledge of true age, 92% of the known-age fish were accurately aged. The structures from known-age White Sturgeon also provided an opportunity to become familiar with any idiosyncrasies associated with aging fish from the upper Snake River population. The White Sturgeon in the upper Snake River grow fast (confirmed with known-age fish), which results in discernable annuli that are often lacking in other White Sturgeon populations (Ghere et al., 2024; Figure 10). Growth rates of fish younger than age 16 (i.e., <162 cm FL) in the upper Snake River were high compared to those in other White Sturgeon populations. For instance, White Sturgeon downstream of Bliss Dam in the middle Snake River have some of the highest growth rates in Idaho (IPC, 2023). If we consider 122 cm FL (maximum length of the possible harvest slot) as a basis for comparison, White Sturgeon downstream of Bliss Dam reach 122 cm FL at age 19. Conversely, White Sturgeon in the Kootenai River have some of the slowest growth rates in Idaho and are reported to take as many as 37 years to reach the same length (Paragamian & Beamesderfer, 2003). Blackburn et al. (2019) found that growth of White Sturgeon in the SSJ was among the fastest reported for the species. White Sturgeon in the SSJ reached 122 cm FL at age 11. Fish in our study grew even faster, as White Sturgeon reached 122 cm FL at age 9.

Fast growth of White Sturgeon in the upper Snake River suggests that habitat is suitable and that White Sturgeon have adequate prey resources. White Sturgeon is a relatively new species in the upper Snake River and has likely not yet reached its carrying capacity. Density-dependent effects on growth in fish populations at or above carrying capacity are well studied (Hazlerigg et al., 2012; Lorenzen & Enberg, 2002). Crossman et al. (2023) found that density had a more profound effect on growth than habitat or genetics in hatchery-origin White Sturgeon in the upper Columbia River. Because the White Sturgeon population in the upper Snake River is relatively new, fish are likely experiencing low competition for space and

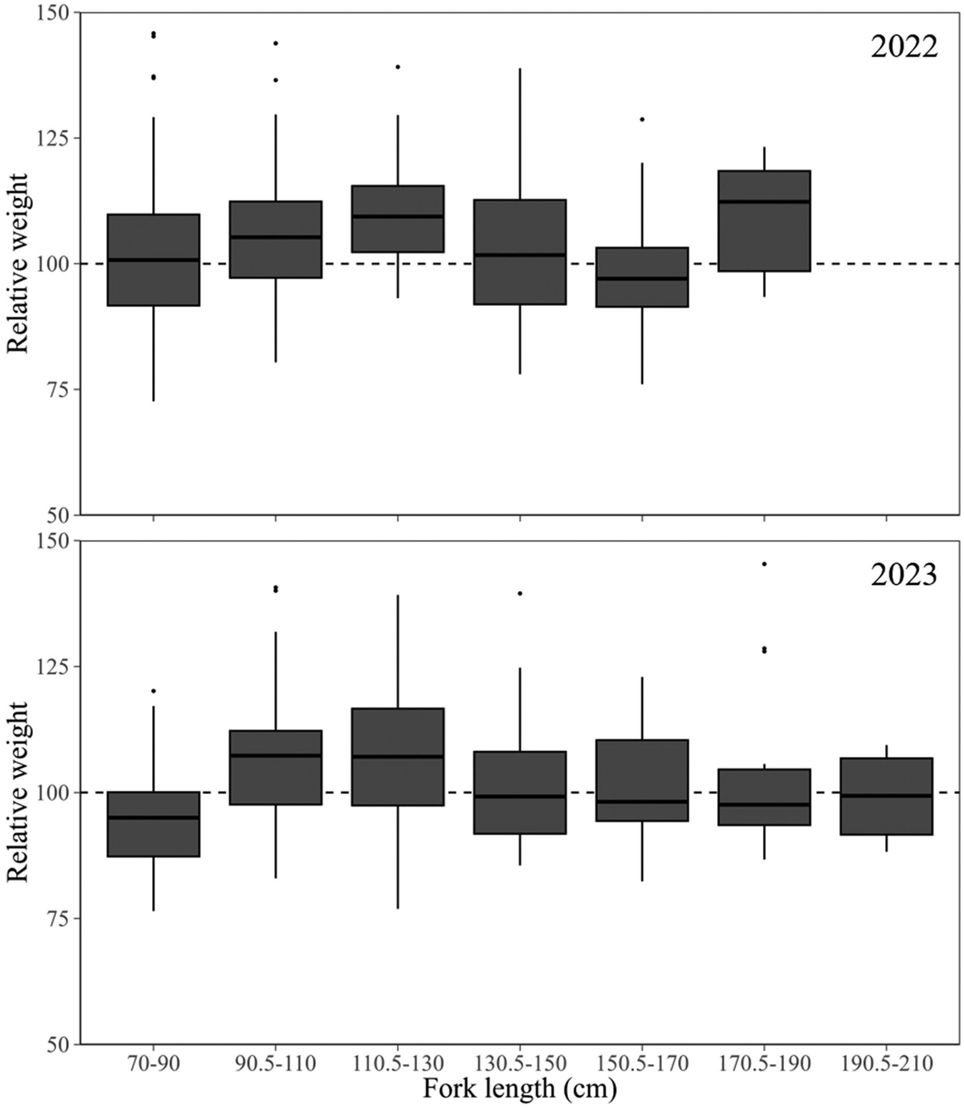

**Figure 4.** Relative weight of sampled White Sturgeon larger than 70 cm fork length in the upper Snake River during 2022 and 2023.

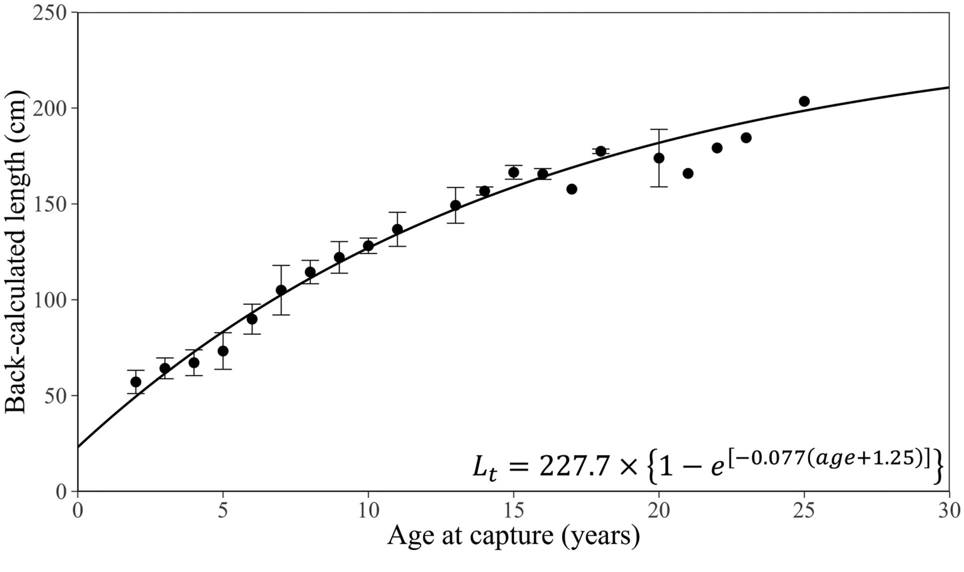

**Figure 5.** Von Bertalanffy growth model for White Sturgeon sampled in the upper Snake River during 2022 and 2023. Circles represent mean back-calculated length at a given age ($L_t$), bars represent 1 SD, and the solid line represents growth model fit.

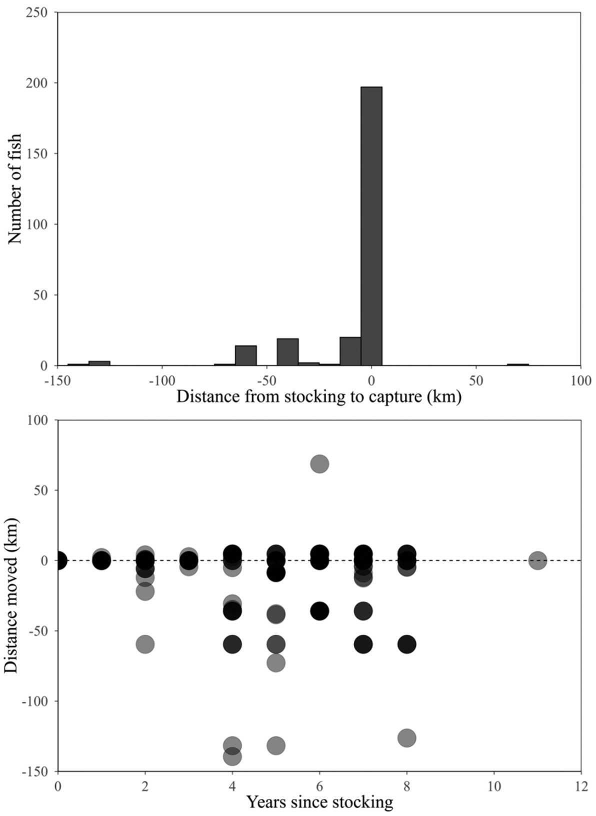

**Figure 6.** Kilometers moved from stocking location to capture location for White Sturgeon sampled in the upper Snake River during 2022 and 2023. Data in the upper panel are total rkm moved from stocking location. Data in the lower panel represent rkm moved relative to time (in years) since stocking, with shading representing the occurrence of repeated values in the sample.

food resources. This contention is further supported by the body condition of White Sturgeon. High $W_r$ has been shown to relate with fast growth in other fish species. For example, Willis and Scalet (1989) found that $W_r$ was correlated with Northern Pike *Esox lucius* growth rates in Midwestern lakes. Specifically, Northern Pike populations exhibiting fast growth had a mean $W_r$ of 106 and populations with slow growth had a mean $W_r$ of 87. In our study, $W_r$ was at or above 100 for 84% of White Sturgeon, suggesting that fish were in good body condition.

Abundance of White Sturgeon in AFTW was estimated using a closed-population capture–recapture model. An assumption of closure was made for the 2023 sampling season. A focus of sampling in 2023 was to specifically assess movement of White Sturgeon downstream of American Falls Dam, largely to help evaluate the assumption of closure. No movement was identified during the sampling, between sampling years, or for fish that had been stocked and at large for less than 2 years. Kendall (1999) investigated the effect of violating the closure assumption on the Otis et al. (1978) models and found that estimates of *N* were robust to random immigration or emigration during the sampling period. Kendall (1999) also suggested that precision would decrease due to lower capture probabilities; however, little movement occurred during the sampling period.

**Table 3.** Closed-population models estimating abundance for White Sturgeon at American Falls tailwater using data from 2022 and 2023. Akaike's information criterion corrected for small sample size (AIC$_c$) was used to rank candidate models. Included are the number of model parameters ($K$), delta AIC$_c$ ($\Delta$AIC$_c$), and model weight ($w_i$). Models were parameterized as follows: $M_o$ = constant capture probability ($p$); $M_t$ = time-varying $p$; $M_b$ = constant behavioral response to $p$; $M_T$ = specifies time as a regression for effect on $p$; $M_{tb}$ = individual time-varying $p$ for initial capture and recapture ($c$); and $M_{tb2}$ = time-varying $p$, with the effect of recapture held constant.

| Model | $K$ | AIC$_c$ | $\Delta$AIC$_c$ | $w_i$ |
|---|---|---|---|---|
| $M_{tb2}$ | 52 | 1,825.9 | 0.0 | 0.6 |
| $M_t$ | 51 | 1,827.0 | 1.1 | 0.4 |
| $M_{tb}$ | 100 | 1,876.3 | 50.4 | 0.0 |
| $M_b$ | 3 | 1,959.6 | 133.7 | 0.0 |
| $M_T$ | 3 | 1,962.5 | 136.6 | 0.0 |
| $M_o$ | 2 | 1,978.6 | 152.7 | 0.0 |

**Table 4.** Cormack–Jolly–Seber models estimating apparent survival for White Sturgeon at American Falls tailwater using data from 2022 and 2023. Akaike's information criterion corrected for small sample size (AIC$_c$) was used to rank candidate models. Included are the number of model parameters ($K$), delta AIC$_c$ ($\Delta$AIC$_c$), and model weight ($w_i$). Models were parameterized as follows: ($\phi$, $p$) = constant apparent survival and constant capture probability; ($\phi$, $p_t$) = constant apparent survival with time-varying capture probability; ($\phi$, $p_h$) = constant apparent survival, with capture probability varying in relation to an inclusive harvest slot of 76–122 cm fork length; and ($\phi$, $p_s$) = constant apparent survival, with capture probability varying between two age-classes.

| Model | $K$ | AIC$_c$ | $\Delta$AIC$_c$ | $w_i$ |
|---|---|---|---|---|
| ($\phi$, $p_h$) | 4 | 3,456.4 | 0.0 | 0.5 |
| ($\phi$, $p$) | 2 | 3,456.5 | 0.1 | 0.4 |
| ($\phi$, $p_s$) | 3 | 3,458.5 | 2.1 | 0.1 |
| ($\phi$, $p_t$) | 76 | 3,460.8 | 4.4 | 0.0 |

The upper Snake River population appears to exhibit high annual mortality relative to other White Sturgeon populations. Throughout Idaho, estimated mortality rates from CJS models (i.e., $1 - \phi$) are reportedly highest in the Kootenai River (mortality = 0.07–0.11; Paragamian et al., 2005), followed by the middle Snake River (0.04–0.10; IPC, 2023) and the Hells Canyon section of the Snake River (0.04–0.09; IDFG, 2024). In exploited populations, such as the White Sturgeon population in the SSJ system, total annual mortality is similar to what we estimated for the upper Snake River population (i.e., $1 - \phi = 0.21$). Specifically, Blackburn et al. (2019) reported that total annual mortality (catch-curve analysis) was 0.19 for age-3 to age-19 White Sturgeon. Cormack–Jolly–Seber models combine mortality with movement from the sampling area, and the models do not distinguish between the two. The estimate of annual mortality for the upper Snake River population could have been an overestimate of true mortality if there was a high rate of movement. However, no movement was identified between captures in 2022 or 2023, suggesting that the estimate largely represents mortality.

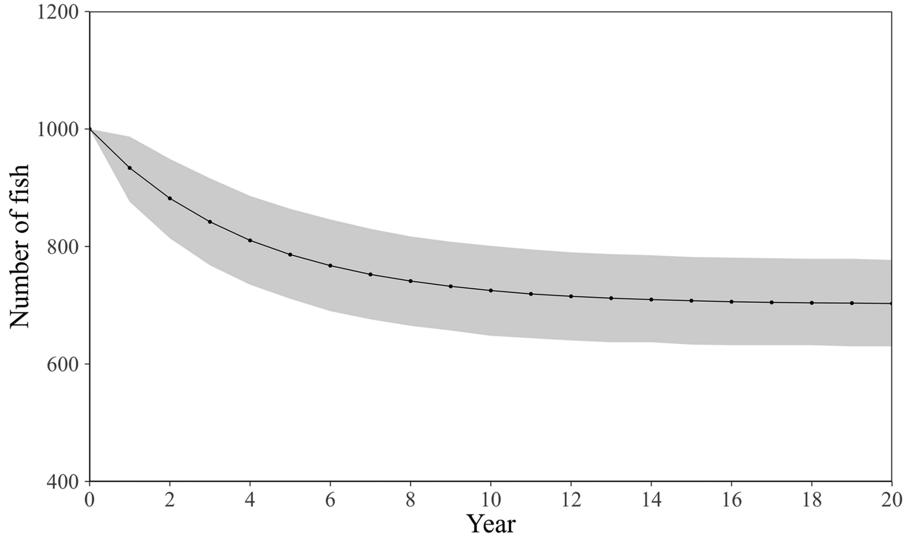

**Figure 7.** Total number of White Sturgeon in the upper Snake River based on an age-structured population model. Included is the effect of a stocking rate of 200 White Sturgeon annually on total abundance in the population. The solid line represents the mean from 10,000 iterations, and the shaded area represents the amount of variability in the estimate.

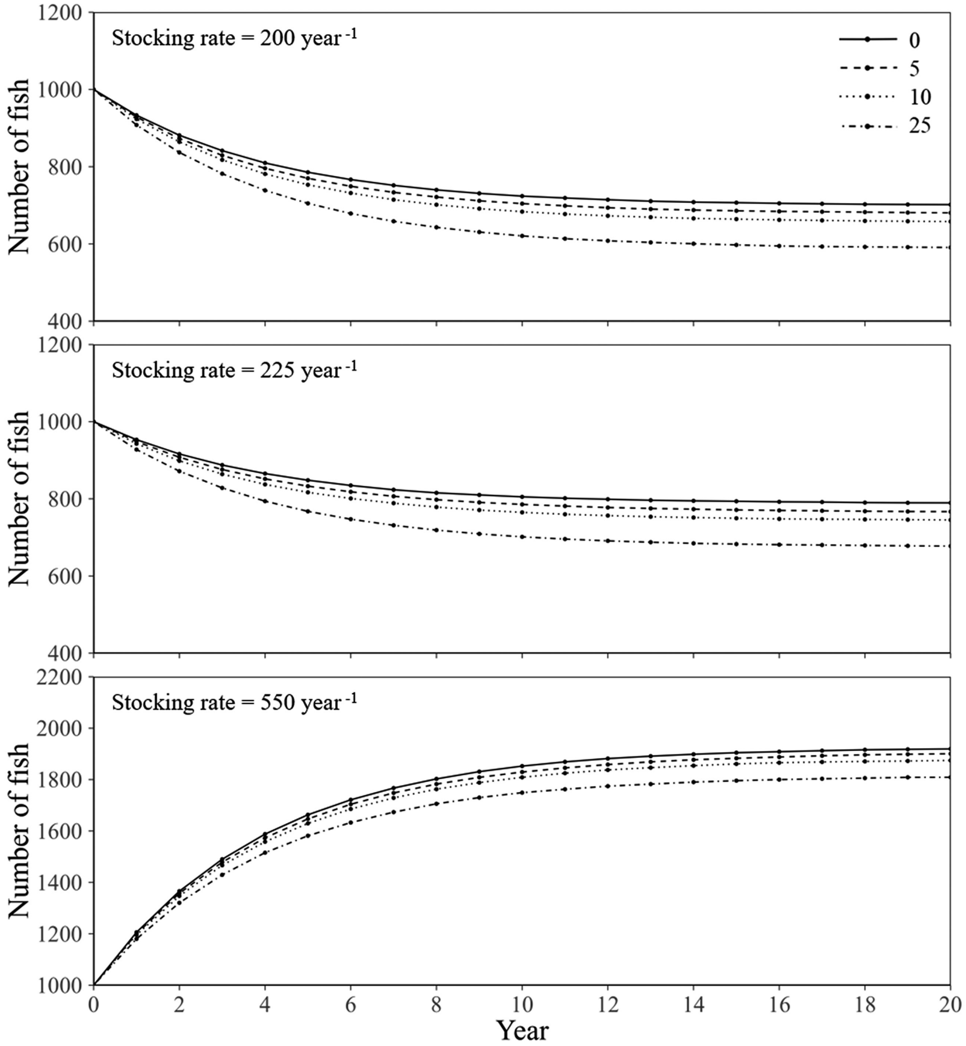

**Figure 8.** Total number of White Sturgeon in the upper Snake River based on an age-structured population model. Included is the effect of harvest on White Sturgeon abundance at varying stocking rates as harvest is increased from 0 to 25 fish/year.

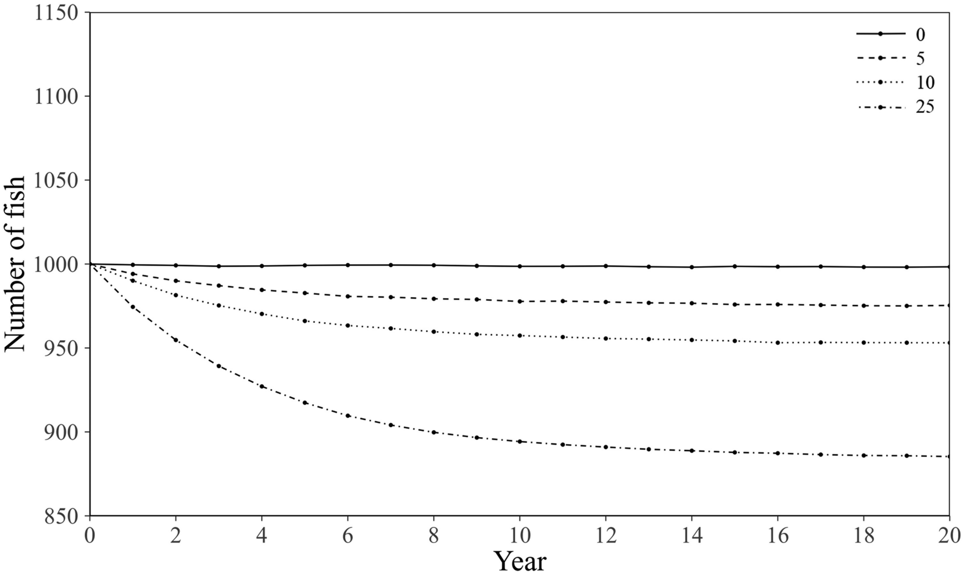

**Figure 9.** Total number of White Sturgeon in the upper Snake River based on an age-structured population model. Included is the effect of harvest on White Sturgeon abundance at a stocking rate of 285 individuals annually as harvest is increased from 0 to 25 fish/year.

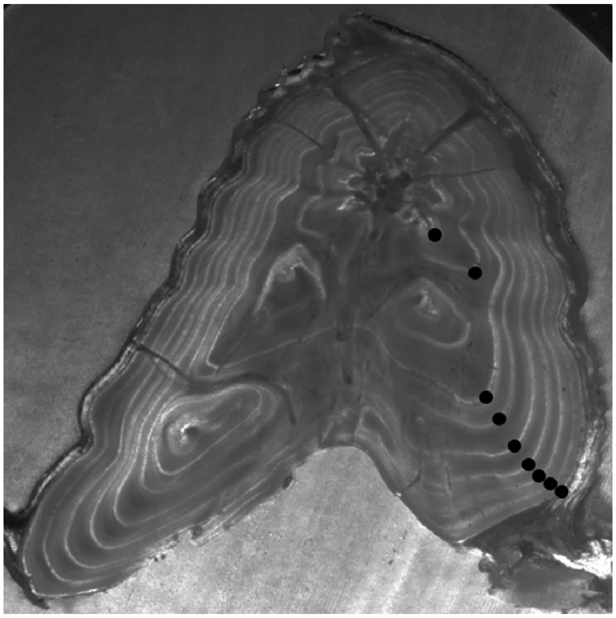

**Figure 10.** Section of a pectoral fin ray from a known-age White Sturgeon (age 9) from the upper Snake River. Black circles denote annuli.

Movement between sampling events was not detected, but poststocking movement of fish stocked at least 2 years prior to sampling was documented in the upper Snake River. Movement tended to be downstream and often included entrainment through dams and hydropower facilities. Of the White Sturgeon with information on stocking location, 18.5% were entrained through at least one such structure following stocking. Entrainment through dams has been documented in other sturgeon populations, but mortality rates associated with entrainment are difficult to estimate (Hegna et al., 2020; IPC, 2023). Another potential source of mortality is entrainment into irrigation canals. From American Falls Dam to the Upper Idaho Falls Dams, at least 12 diversions seasonally remove water from the river channel. Additionally, many of the diversions are not screened; several times per year, there are reports to IDFG of White Sturgeon stranded in irrigation canals. Entrainment at unscreened irrigation diversions is a source of mortality for many fish species. For instance, Carlson and Rahel (2007) estimated that as much as 3.3% of the Bonneville Cutthroat Trout *O. virginalis utah* population in the Smiths Fork River, Wyoming, was entrained during an irrigation season. In a single year, Gale et al. (2008) found that 79% of radio-tagged adult Westslope Cutthroat Trout *O. lewisi* were entrained into canals from Skalkaho Creek, Montana. Another potential source of mortality could be caused by periods of low dissolved oxygen downstream of major impoundments in the system. Several high-mortality events have been reported, but the magnitude of these events, along with the effect of diversions, is unknown and may be an important focus of future research.

Recruitment is an important driver of fish population dynamics, particularly for White Sturgeon. As such, White Sturgeon populations have been shown to be sensitive to even low levels of exploitation. An exploitation rate of 5–10% has been recommended to sustain White Sturgeon populations (Beamesderfer & Farr, 1997; Rieman & Beamesderfer, 1990). However, Blackburn et al. (2019) reported that an annual exploitation rate as low as 5% would result in declines in White Sturgeon abundance within the SSJ. White Sturgeon is not a species of conservation concern in the upper Snake River given that it is nonnative. Nevertheless, maintaining angler satisfaction in the White Sturgeon fishery is of high importance to resource managers. Currently, anglers are happy with the catch rates at AFTW and the "trophy" aspect of the fishery. Maintaining the population at contemporary numbers (i.e., current catch rates) with no harvest would require a stocking rate of 285 White Sturgeon/year. With harvest, the stocking rate would need to be increased relative to the number of fish being harvested. Exploitation would also need to be low enough that fish escape the harvest slot and reach larger size-classes. The population model suggested that with a stocking rate of 285 White Sturgeon/year and a harvest of five fish annually, individuals would be surviving long enough to reach lengths of around 180 cm FL (i.e., age > 20), thereby maintaining angler satisfaction.

The age-structured population model developed in this study had a few important assumptions. The first assumption was that growth would remain consistent despite changes in abundance. If abundance increased through stocking, there could be increased competition for space and prey. Although density-dependent reductions in growth have been shown for White Sturgeon in the upper Columbia River system, we kept growth constant because the presence and magnitude of potential density dependence were unknown. Second, survival was estimated using fish in AFTW and was assumed to be the same across the study area. Sufficient recaptures for a CJS model were not available in other portions of the study area, and variable stocking rates prevented other methods of estimating mortality from being viable options (e.g., catch-curve analysis). Most reports of large mortality events have occurred at AFTW, and high use by recreational anglers relative to other portions of the study area may suggest that survival is lower in AFTW than in other portions of the population. Conversely, irrigation diversions and hydroelectric facilities are more likely to be encountered by White Sturgeon upstream of American Falls Dam. As such, survival in other river segments of the study area may ultimately be comparable to the survival estimate for AFTW. Another assumption of our study was that catchability was constant throughout the study area, as estimated catchability for White Sturgeon in AFTW was applied to other sampling areas. If White Sturgeon were attracted to setlines in AFTW relative to other areas, then the population estimates would be biased high, and vice versa. We lack information to assess whether catchability in AFTW was different from catchability in other areas, but we hypothesize that catchability is likely lower in AFTW than in other areas of the upper Snake River system. Specifically, the prevalence of dead, moribund, and mutilated fishes (e.g., Yellow Perch) resulting from passage through American Falls Dam is quite high in AFTW. High food availability may result in low catchability of sampling gears that rely on bait (e.g., setlines). Finally, all harvest mortality included in the model was additive. Some harvest mortality may be compensatory; if so, annual survival may not decrease by implementing a harvest fishery to the degree suggested in the model.

The modeled 76–122-cm-FL harvest slot for White Sturgeon in the upper Snake River was selected by fishery managers based on several considerations (i.e., mercury concentration, potential angler yield, and similarity to other White Sturgeon harvest fisheries). Analysis of total mercury content in White Sturgeon from the upper Snake River suggests that about 79.2% of the population is in the “good choice” category for consumption of one serving per week by the U.S. Food and Drug Administration (2024; IDFG, unpublished information). Alternatively, 77.8% of White Sturgeon sampled that were larger than 130 cm FL exceeded the recommendation of mercury content for the same consumption. Mercury contamination could be a concern because fish available to harvest would be large enough to yield multiple meals. However, only 20.8% of White Sturgeon in the harvest slot exceeded the U.S. Food and Drug Administration’s mercury content recommendation. The estimated harvest yield for processing a White Sturgeon to skinless fillets is 45% (Price et al., 1989). On the low end of the harvest slot (i.e., 76 cm FL), an angler could expect about 1.5 kg of fillets. On the high end of the harvest slot (i.e., 122 cm FL), the yield would be approximately 7.2 kg per White Sturgeon. Potential yield from harvestable fish in the population would likely be enough to encourage participation in the fishery. Harvest regulations on currently exploited White Sturgeon populations have a structure similar to the harvest scenario modeled in this study. The segments of the Columbia River that currently support harvest are managed using a harvest slot of either 97–137 or 109–137 cm FL (Oregon Department of Fish and Wildlife, 2024; Washington Department of Fish and Wildlife, 2023). Similarly, White Sturgeon harvest in the SSJ is currently managed under an emergency regulation with a harvest slot of 107–122 cm FL and an annual limit of one White Sturgeon per angler (California Department of Fish and Wildlife, 2024). These fisheries appear to be popular with recreational anglers. As such, a similar fishery in the upper Snake River would provide a unique opportunity that would likely be popular with Idaho anglers.

Data on fish population dynamics are necessary for effective management. This study provides important information regarding population demographics for a unique population of White Sturgeon. Our research identified fast growth relative to other White Sturgeon populations and relatively high mortality for a population without exploitation. The information presented here will help managers to monitor population trends and will inform management decisions. Like other studies evaluating harvest, a population model was used to illustrate the effect of varying rate functions on a fishery. The age-structured population model suggested that a harvest fishery is possible while still meeting management goals for the upper Snake River White Sturgeon fishery. Further, the model could continue to be used to assess potential population-level responses to changing conditions and can provide managers with the information necessary to effectively manage a harvest fishery for White Sturgeon in Idaho.

## SUPPLEMENTARY MATERIAL

Supplementary material is available at *North American Journal of Fisheries Management* online.

## DATA AVAILABILITY

Data that support the findings of this study are available from the corresponding author upon reasonable request.

## ETHICS STATEMENT

This project was conducted under Protocol 2021-81 approved by the Institutional Animal Care and Use Committee at the University of Idaho.

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## CONFLICTS OF INTEREST

There is no conflict of interest declared in this article.

## ACKNOWLEDGMENTS

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