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# White Sturgeon Transplants Within the Columbia River

THOMAS A. RIEN AND JOHN A. NORTH
*Oregon Department of Fish and Wildlife,
17330 Southeast Evelyn Street,
Clackamas, Oregon 97015, USA*

*Abstract*.—White sturgeon *Acipenser transmontanus* were captured and transplanted from the free-flowing Columbia River downstream from Bonneville Dam and released into the Dalles Reservoir, during 1994 and 1995, in an attempt to evaluate a means of supplementing natural recruitment. In 1997, we estimated that 99% of the 1994 transplants and 80% of the 1995 transplants had survived. Growth of transplanted fish within the reservoir appeared similar to resident fish, and mean relative weights were greater than resident fish. Distribution of transplanted fish was significantly different from resident fish. The greatest difference occurred in the reservoir section containing the tailrace of the upstream dam in the study area; otherwise distributions appeared similar. Our survival estimate for 1995 transplants may be negatively biased by their smaller size (they had less time to grow), which may have reduced their vulnerability to capture by setlines. Survival and condition of transplanted fish show transplanting is a tenable method for supplementing populations. Relatively limited capital investment and the presence of a robust donor population allowed transplantation to be implemented in a short time frame, with a range of age classes from a naturally diverse parent population. However, the size of the donor population will ultimately limit the magnitude of a transplant program. Ongoing work to describe Columbia River white sturgeon will aid in defining the geographic extent of potential recipient populations by characterizing evolutionary-significant units for the species.

## Introduction

Construction and operation of Columbia River dams has restricted the movements of white sturgeon *Acipenser transmontanus*, among river reaches, and effectively eliminated access to the estuary and the Pacific Ocean for impounded fish (North et al. 1993). Compared with the free-flowing reach downstream from Bonneville Dam, white sturgeon populations in impoundments have reduced harvest potential. While each reservoir has a unique set of habitat conditions, white sturgeon productivity in the Dalles and John Day Reservoirs is ultimately limited by erratic conditions for spawning and recruitment caused by dam operations during low flow years (Beamesderfer et al. 1995). This reduced potential productivity has forced comanagers to severely restrict existing recreational and Treaty Indian fisheries. The objective of our work was to determine the feasibility of using transplanted fish as a means of mitigating for lost recruitment and passage, for providing Treaty Indian harvest opportunities, and to accelerate the recovery of impounded populations.

Dam operations, during drought conditions in the late 1980s, caused low flows and poor conditions for white sturgeon spawning and recruitment in the Dalles Reservoir (Parsley and Beckman 1994). Severe restrictions on existing commercial and recreational fisheries were enacted to counter reduced productivity, caused by hydropower operations, and to allow continued harvest fisheries and long-term recovery.

Transplantation is one of several tools to be considered in restoring white sturgeon productivity in areas impacted by hydropower development (Beamesderfer and Farr 1997). Others include habitat restoration (providing appropriate flows for spawning, modifying the hydropower system, providing passage, and removing dams), harvest management (controlling poaching, optimizing yield, and protecting broodstock), and alternate means of supplementation (hatcheries). Transplantation is unique in its ability to augment poor year classes and differs from typical hatchery supplementation by relying on naturally spawned progeny of genetically diverse parents. This minimizes the risks that may accrue from potentially selective hatchery practices. Hatchery supplementation would likely be founded on releases of one- or two-year old fish and could not supplement several years of lost production with the same age classes that failed to recruit.

During October and November, in 1994 and 1995, we captured juvenile white sturgeon in the Columbia River downstream from Bonneville Dam and released them into the Dalles Reservoir (Figure 1). The intent of this report is to 1) describe transplant methodologies; 2) report growth, condition, and survival of transplanted fish; and 3) to present a range of modeled release numbers necessary to achieve specific density benchmarks in two Columbia River reservoirs.

## Methods

### *Capture and Processing*

Subadult white sturgeon were captured in the Columbia River, in October and November, during 1994 and 1995. Trawling efforts occurred primarily in the navigation channel between river kilometers (rkm) 209 and 212 (Figure 1). This area was selected because it was the nearest site to the Dalles Reservoir, which had previously documented high catch rates of subadult white sturgeon (McCabe and Hinton 1994).

Two different trawl types and boats were used for fish collection: a 7.9-m (headrope length) semiballoon shrimp trawl, fished from a 12.2-m vessel (McCabe 1996), and a 6.2-m high-rise shrimp trawl fished from a 7.3-m vessel (Parsley et al. 1996). Numbers and duration of daily trawl net tows varied with catch rate and transport goals. Tows were made in both upstream and downstream directions.

The net was emptied after completion of each tow. White sturgeon were removed from the trawl and placed into containers with circulating fresh water onboard each trawl vessel. When trawl catches were very large (>250 fish), some white sturgeon were immediately released at the capture site and not counted. If few white sturgeon were captured during a tow, they were held onboard the capture vessel while additional trawls were completed. White sturgeon were transferred between the trawl and transport vessels with dip nets or plastic baskets. Large catches were occasionally unloaded from the trawl directly onto the transport vessel, to reduce handling.

In 1994, we processed fish onboard one of two vessels (9.1-m or 7.6-m long). In 1995, fish were processed on a barge propelled by a tugboat. The barge was equipped with six 520-L plastic totes for holding fish. Each tote received pumped fresh river water. Total water volume of each container was exchanged 7.6 times each hour.

We measured fork length (FL; ± 1 cm) and weighed (±0.1 kg) and tagged each transported fish with a passive integrated transponder (PIT) tag. We selected 35–80 cm white sturgeon for processing and transport, in 1994 (fish outside this length interval were released at the capture site).

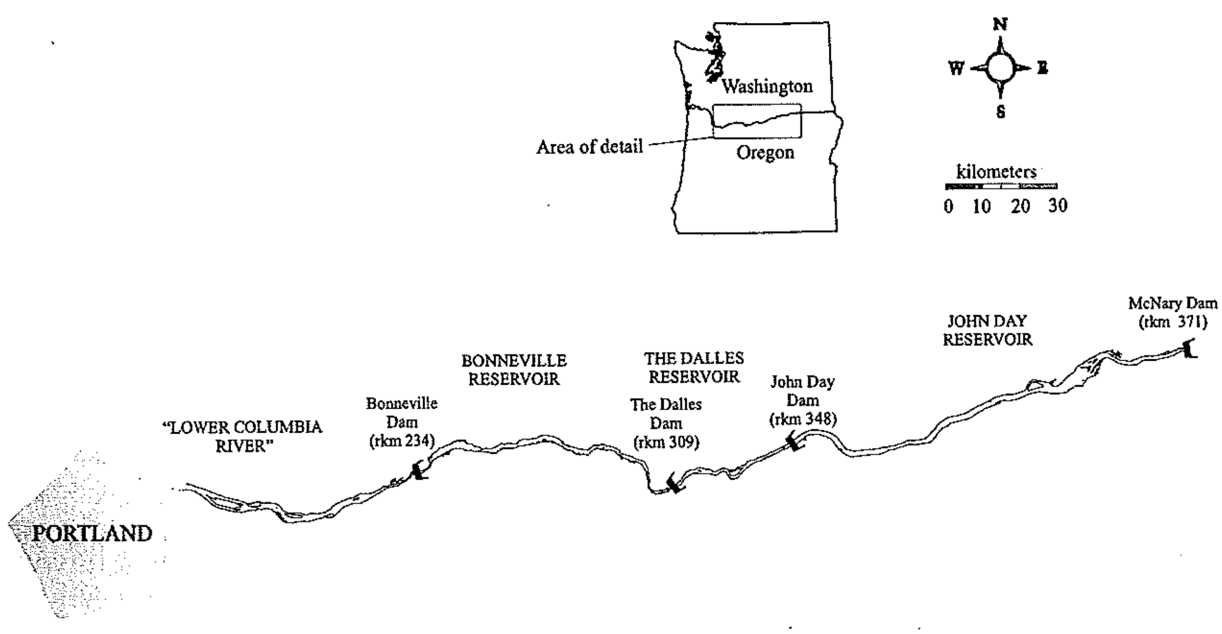


Figure 1. Columbia River from Portland, Oregon, to McNary Dam.

In 1995, we selected 30–92 cm white sturgeon for processing and transport. The PIT tags were injected into the musculature beneath the armor of the head near the dorsal midline. Tags and applicators were disinfected with chlorhexidine before each injection. To assist in identifying PIT-tagged fish at recapture, the second left lateral scute was removed (Rien et al. 1994).

In 1995, we injected white sturgeon with oxytetracycline (OTC) to help validate age determinations from fin-ray sections of recaptured fish. We injected 25 mg OTC/kg body weight into the red muscle under the dorsal scutes immediately posterior to the head (McFarlane and Beamish 1987; Rien and Beamesderfer 1994). A combination of one or two lateral scutes was removed from various positions on the fish to identify the year of marking, OTC-injected fish, and presence of a PIT tag (Rien et al. 1994; Table 1).

### *Transportation*

During 1994, fish were transported by boat from the capture site to the Dalles Reservoir. The boat was outfitted with two 300-L plastic totes and two 267-L live wells; each received pumped river water exchanged at a rate of 6.0 times/h. We monitored temperature (°C) and dissolved oxygen levels (DO; ppm) of the river and tanks throughout transport (Table 2). Supplemental oxygen was added to the transport tanks beginning on the third day to increase DO concentrations. We attempted to maintain loading density of fish in the transport tanks at 0.09 kg/L or less. Most transported fish were released into the navigation channel about 8 km upstream from the Dalles Dam. Due to boat breakdowns, some fish were transported in the totes, by truck, from Covert's Landing to a backwater release site at Celilo Park (rkm 325).

During 1995, all white sturgeon were transported in either a 9,462-L or 13,247-L fish transport truck. The same barge used as the floating platform for fish processing served to ferry the transport vehicles between the fishing area and a boat ramp at rkm 226, where they were driven off the barge. The fish were then transported to Maryhill State Park (rkm 338) for release into the Dalles Reservoir. We attempted to maintain DO levels in the tank similar to those in the river by monitoring and supplementing oxygen as needed. Target loading density of fish in the transport tanker was the same as in 1994 (<0.09 kg/L). Beginning on the third transport day, we added a synthetic fish protectant (Poly Aqua) at a ratio of 1:7570 to water as a precaution to help offset loss of mucus during handling.

### *Recapture*

During December 1996 through January 1997, tribal fishers, working on contract, deployed 771 gill nets and 11 setlines to capture and mark resident white sturgeon in the Dalles Reservoir and to recapture transplanted fish (Table 3). Gill-net dimensions were variable and ranged in length from 61 m to 121 m, with stretched mesh sizes from 10.2 cm to 25.4 cm. Gill nets were fished on the bottom and anchored to remain stationary. Setlines were 122-m to 183-m long, rigged with 40–50 J-style hooks (10/0–12/0) and baited with salmon pieces. Gill nets and setlines were typically fished overnight. However, weather occasionally prevented timely retrieval, and some sets were out for two or three nights. Contracts with fishers were developed to reward maximum catch per effort and number of tagged fish. Fishers were paid for each tagged fish, and they were allowed

Table 1. Number of subadult white sturgeon processed each year by handling procedure during October 1993 and October–November 1994–1995.

| | Year | | |
|---|---|---|---|
| Procedure | 1994 | 1995 | Total |
| Fork length | 3,044 | 5,613 | 8,657 |
| Weight | 3,028 | 5,609 | 8,637 |
| OTC[a] Injection | 0 | 5,609 | 5,609 |
| PIT[b] tag | 2,934 | 5,612 | 8,546 |
| 2nd left scute | 2,948 | 5,612 | 8,560 |
| 2nd right scute | 0 | 5,614 | 5,614 |
| 5th left scute | 2,948 | 0 | 2,948 |
| 6th left scute | 0 | 5,611 | 5,611 |

a. Oxytetracycline.
b. Passive integrated transponder.

Table 2. Hauling conditions of wild white sturgeon transported during October and November, 1993-1995. Missing data indicated with – .

| Year, month/ date | Number of fish transported | Hauling duration[a] (hh:mm) | River Release location[b] | Tank DO(ppm)[c] (min/max) | River DO(ppm) (min/max) | Tank temp.(°C) (min/max) | Total temp.(°C) (min/max) | Water Vessel[d] | Loading fish weight wt.(kg) | Loading fish volume (L) | Loading fish density (kg/L) | Water treatment[e]/ Oxygen added |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1994 | | | | | | | | | | | | |
| 10/18 | 189 | 7:17 | A | 9.1/9.6 | 5.3/11.0 | 15.1/15.6 | 15.1/16.1 | A | 109.9 | 1,579 | 0.07 | No/No |
| 10/19 | 181 | 7:30 | A | 9.1/9.1 | 6.2/8.1 | 15.9/15.9 | 15.9/17.1 | A | 100.5 | 1,579 | 0.06 | No/No |
| 10/20 | 202 | 6:15 | A | 9.0/10.0 | 6.3/26.9 | 15.0/15.7 | 15.1/16.4 | A | 115.2 | 1,579 | 0.07 | No/Yes |
| 10/24 | 206 | 5:20 | A | 9.3/12.2 | 7.0/15.0 | 14.6/15.4 | 14.8/15.9 | A | 122.7 | 1,579 | 0.08 | No/Yes |
| 10/25 | 207 | 8:30 | A | 9.3/13.3 | 6.2/16.1 | 14.4/15.2 | 14.4/15.7 | A | 114.2 | 1,579 | 0.07 | No/Yes |
| 10/26 | 202 | 6:30 | A | 8.6/9.4 | 6.0/10.7 | 14.4/15.6 | 14.5/15.6 | A | 121.2 | 1,579 | 0.08 | No/Yes |
| 10/27 | 206 | 5:25 | A | 8.4/9.0 | 6.2/13.1 | 14.0/14.5 | 14.2/16.1 | A | 112.0 | 1,579 | 0.07 | No/Yes |
| 10/31 | 101 | – | B | –/– | –/– | –/– | –/– | B | 61.0 | 680 | 0.09 | No/Yes |
| 11/01 | 205 | 4:51 | A | 7.8/8.3 | 6.1/7.5 | 12.7/13.8 | 12.9/13.9 | A | 120.6 | 1,579 | 0.08 | No/Yes |
| 11/02 | 215 | 8:31 | A | 10.1/10.5 | 6.9/9.2 | 11.9/12.8 | 11.6/13.1 | A | 122.0 | 1,579 | 0.08 | No/Yes |
| 11/03 | 205[f] | 7:18 | B | 10.3/13.4 | 5.7/21.2 | 9.7/11.9 | 11.0/12.4 | A | 114.2 | 1,579 | 0.07 | No/Yes |
| 11/07 | 208 | 7:04 | A | 10.4/13.4 | 6.7/35.4 | 10.7/12.6 | 10.3/11.8 | A | 120.0 | 1,579 | 0.08 | No/Yes |
| 11/08 | 197 | – | B | –/– | –/– | –/– | –/– | B | 106.5 | 680 | 0.16 | No/Yes |
| 11/09 | 198 | – | B | 10.4/10.4 | 7.8/22.6 | 12.2/12.2 | 10.3/11.8 | B | 112.2 | 680 | 0.16 | No/Yes |
| 11/10 | 213 | – | B | –/– | –/– | –/– | –/– | B | 123.4 | 680 | 0.18 | No/Yes |
| 1995 | | | | | | | | | | | | |
| 10/23 | 560 | 2:15 | C | 10.3/10.4 | 17.5/– | 14.1/14.2 | 13.9/– | C | 296.6 | 13,247 | 0.02 | No/Yes |
| 10/24 | 485 | 2:30 | C | 9.5/– | 15.8/22.0 | 13.9/– | 13.8/13.9 | C | 251.3 | 13,247 | 0.02 | No/Yes |
| 10/25 | 341 | 3:20 | C | 9.9/10.6 | –/– | 13.8/13.8 | –/– | C | 173.2 | 13,247 | 0.01 | Yes/Yes |
| 10/26 | 478 | 3:15 | C | 10.4/– | 20.0/25.0 | 13.9/– | 14.4/14.4 | C | 254.0 | 13,247 | 0.02 | Yes/Yes |
| 10/27 | 475 | 3:45 | C | 10.4/11.0 | 20.0/– | 13.7/13.8 | 14.4/– | C | 267.4 | 13,247 | 0.02 | Yes/Yes |
| 10/31 | 108 | 3:20 | C | 10.8/– | 9.9/10.6 | 11.0/– | 11.8/12.3 | D | 61.8 | 9,462 | 0.01 | Yes/Yes |
| 11/02 | 321 | 3:00 | C | 9.8/10.4 | 9.8/– | 10.1/11.3 | 11.4/– | D | 177.7 | 9,462 | 0.02 | Yes/Yes |
| 11/03 | 347 | 4:15 | C | 11.1/11.9 | 11.2/17.0 | 10.0/10.8 | 9.9/10.6 | D | 176.0 | 9,462 | 0.02 | Yes/Yes |
| 11/06 | 425 | 3:35 | C | 10.7/1.0 | 10.7/10.9 | 10.6/10.9 | 11.1/12.1 | D | 209.8 | 9,462 | 0.02 | Yes/Yes |
| 11/07 | 701 | 3:00 | C | 10.7/10.8 | 11.0/11.7 | 11.1/11.2 | 11.7/12.3 | D | 356.2 | 9,462 | 0.04 | Yes/Yes |
| 11/08 | 701 | 3:00 | C | 10.4/10.6 | 10.3/12.9 | 11.1/11.4 | 11.0/12.5 | D | 359.4 | 9,462 | 0.04 | Yes/Yes |
| 11/09 | 669 | – | C | 10.8/11.2 | 10.3/12.2 | 10.5/10.9 | 10.5/11.3 | D | 353.8 | 9,462 | 0.04 | Yes/Yes |

a. Estimated time of boat transport during 1994 and combined barge and fish liberation truck transport during 1995.
b. Release locations in The Dalles Reseroir were A) river kilometer (rkm) 317.0, B) rkm 325.0, and C) rkm 337.7.
c. Dissolved oxygen levels (parts per million) as measured during daily sampling.
d.Transport vessels were A) plastic totes and live-wells onboard a 9.1-m contracted boat, C) same as A but fish were transferred to plastic totes onboard a truck for a majority of the transfer, C) Oregon Department of Fish and Wildlife fish liberation tanker, and D) U. S. Fish and Wildlife Service Wildlife fish liberation tanker.
e. Water treatment was Poly Aqua in 1995.
f. Only 108 of these fish were released; the others were used in a different experiment.

Table 3. Sampling effort (number of setline or gill net sets) for white sturgeon in The Dalles Reservoir by week and sampling section, December 1996 through August 1997.

| | Sampling section | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Dates | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Total |
| Columbia Inter-Tribal Fish Commission, gill nets. | | | | | | | | |
| 12/01/96–12/07/96 | 2 | 99 | 11 | 35 | 0 | 0 | 0 | 147 |
| 12/08/96–12/14/96 | 18 | 142 | 10 | 15 | 2 | 1 | 0 | 188 |
| 12/15/96–12/21/96 | 0 | 83 | 47 | 25 | 20 | 25 | 1 | 201 |
| 01/19/97–01/25/97 | 0 | 58 | 24 | 15 | 0 | 15 | 1 | 113 |
| 01/26/97–01/31/97 | 3 | 87 | 4 | 3 | 9 | 15 | 1 | 122 |
| Total | 23 | 469 | 96 | 93 | 31 | 56 | 3 | 771 |
| Columbia Inter-Tribal Fish Commission, setlines. | | | | | | | | |
| 01/26/97–01/31/97 | 2 | 1 | 2 | 0 | 0 | 4 | 2 | 11 |
| Oregon Department of Fish and Wildlife, setlines. | | | | | | | | |
| 05/05/97–06/01/97 | 24 | 28 | 21 | 18 | 24 | 18 | 0 | 133 |
| 06/02/97–06/22/97 | 24 | 25 | 23 | 24 | 27 | 18 | 0 | 141 |
| 06/23/97–07/13/97 | 19 | 29 | 20 | 29 | 30 | 22 | 0 | 149 |
| 07/14/97–08/03/97 | 22 | 26 | 15 | 34 | 35 | 18 | 0 | 150 |
| 08/04/97–08/25/97 | 26 | 30 | 18 | 36 | 33 | 15 | 0 | 158 |
| Total | 115 | 138 | 97 | 141 | 149 | 91 | 0 | 731 |
| Oregon Department of Fish and Wildlife, gill nets. | | | | | | | | |
| 07/14/97–08/03/97 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 2 |
| 08/04/97–08/25/97 | 1 | 1 | 0 | 1 | 0 | 2 | 0 | 5 |
| Total | 1 | 1 | 0 | 2 | 0 | 3 | 0 | 7 |

to distribute their effort nonrandomly throughout the reservoir.

The Dalles Reservoir was sampled for recaptures from early May through late August 1997. We deployed 731 setlines and 7 gill nets to capture white sturgeon. Setlines were 183-m long, rigged with 40 circle hooks (10/0–16/0), and baited with pickled squid. Setlines were fished overnight. Gill nets were 45.7-m long by 2.4-m deep. Webbing consisted of alternating monofilament panels with stretched measures of 6.3, 8.9, and 10.2 cm. Gill nets were fished for 1 h, stationary, on the bottom. The reservoir was divided into 6 sections, 5.1 to 7.2 km long. Setline sampling effort was distributed equally among and within these sections. We divided the field season into five, 3-week sampling periods and sampled all sections during each period (Table 3). Gill nets were set in a few widely distributed sites to increase catch of small fish.

All fish were examined for tags at capture and measured (±1 cm FL). Untagged fish were PIT-tagged. During May–August, recaptured fish and a subsample of untagged fish were weighed (0.1 kg). After processing, all fish were released at the capture location.

### *Analyses of Survival, Growth, Condition, and Distribution*

Mark–recapture data from the Dalles Reservoir were used to estimate abundance of white sturgeon in the reservoir, using a modified Schnabel mark–recapture estimator (Ricker 1975). We established six mark–recapture periods. The first mark period was defined by December 1996–January 1997 mark sampling. The remaining five 3-week long mark–recapture periods occurred during April–August 1997. The abundance estimate was restricted to fish 50–109 cm long, to correspond with observed lengths of recaptured, transplanted fish. None of the fish we tagged were found dead, and no fish were recovered outside of the Dalles Reservoir during the mark–recapture period.

Recapture rates between release years were compared using a chi-square frequency test (Proc Freq, SAS 1988). We considered catches significantly different when $P$ was less than 0.05.

We estimated abundance of transplanted white sturgeon as the product of abundance (all 50–109 cm fish) and the proportion of transplanted fish in the catch. Survival was estimated from the ratio of estimated transplanted fish abundance and release number. We used the lower and upper bounds of the 95% confidence interval for abundance to describe a minimum and maximum survival range. The variance, introduced by estimating the proportion of transported fish in the catch, was not incorporated into the range of survival estimates. Annual mortality rate of transplanted fish was estimated from survival data and number of years at large. Because the abundance estimate applies to the first marking period, fish released in 1994 were considered to be at large two years and fish released in 1995 were considered at large one year.

We calculated daily growth increments from lengths, at transplant and recapture, and days at large. Annual growth rates were calculated as the product of daily growth increment and days per year (365.25). We compared mean relative weight of recaptured transplanted fish, less than 70 cm (Beamesderfer 1993), with resident fish of similar size using a *t*-test (Proc *t*-test; SAS 1989).

We described the distribution of transplanted fish using data collected during stratified summer recapture sampling. Upstream and downstream movement was determined from release and recapture data. We compared distribution of resident and transplanted fish using a chi-square frequency test to evaluate catch among six reservoir sections.

### *Supplementation Levels*

As an exercise to determine relative transplant numbers that might be considered in the future, we estimated the number of one- and five-year old fish that would be needed to achieve three benchmark densities in two Columbia River reservoirs that have experienced low recruitment (The Dalles and John Day reservoirs; Parsley and Beckman 1994). Benchmarks were based on reported densities of ten-year old fish in two Columbia River reaches with relatively stable recruitment–Bonneville Reservoir and the free-flowing Columbia River downstream from Bonneville Dam (Beamesderfer et al. 1995; DeVore et al. 1995). Reservoir surface area and reported natural mortality rates were used to back-calculate stocking rates needed to achieve density benchmarks.

## Results

### *1994 and 1995 Fish Collection and Processing*

During 1994 and 1995, we captured 9,767 white sturgeon in 183 trawl tows (Table 4). White sturgeon were the most common fish species captured. Fish in the catch ranged from 18 cm to 92 cm, but those less than 30 cm or larger than 90 cm were generally released on site. The following fish species were also observed in the catch: American shad *Alosa sapidissima*, peamouth *Mylocheilus caurinus*, northern pikeminnow *Ptychocheilus oregonensis*, leopard dace *Rhinichthys falcatus*, redside shiner *Richardsonius balteatus*, largescale sucker *Catostomus macrocheilus*, chinook salmon *Oncorhynchus tshawytscha* (two juveniles), sand roller *Percopsis transmontana*, prickly sculpin *Cottus asper*, walleye *Stizostedion vitreum*, and starry flounder *Platichthys stellatus*. Numbers of white sturgeon measured, weighed, tagged, marked, and injected with OTC each year are presented (Table 1).

### ***1994–1995 Transportation***

We released 2,838 white sturgeon into the Dalles Reservoir, during 1994, and 5,611, during 1995. Mean length of transplanted fish was 48.2 cm, in 1994, and 50.7 cm, in 1995 (Figure 2). Mean weight

Table 4. Summary of effort and catch by year and agency for subadult white sturgeon transported during October and November 1993–1995.

| Year, Agency | Sampling days | Trawl efforts | Total catch | Mean catch/trawl | Mean trawl time (minutes) | Mean depth (m) |
|---|---|---|---|---|---|---|
| 1994 | | | | | | |
| NMFS[b] | 15 | 59 | 3,428 | 58.1 | 9.9 | 19.5 |
| USGS[c] | 5 | 22 | 365 | 34.8 | 10.0 | – |
| 1995 | | | | | | |
| NMFS | 12 | 102 | 5,974 | 58.6 | 10.4 | 20.3 |
| Total | 32 | 183 | 9,767 | 53.4 | 10.2 | 20.0 |

a. Approximate number since some estimated catches are included.
b. National Marine Fisheries Service.
c. U. S. Geological Survey.

of transplanted fish was 0.57 kg, in 1994, and 0.52 kg, in 1995.

Transportation conditions varied daily and annually (Table 2). Dissolved oxygen levels in the transport tank averaged 114% of river DO levels in 1994. In 1995, transport tank DO averaged 133% of river levels, and the variance was reduced. Differences between mean river and transport tank temperatures, in 1994 and 1995, did not exceed 0.3°C. Mean duration of hauling was 6.8 h/trip, in 1994, and 3.2 h/trip, in 1995.

### *1996–1997 Mark-Recapture*

During six mark–recapture periods, 6,387 white sturgeon (50–109 cm) were captured. We applied tags, or recorded and accounted for past tags, on 5,899 of these fish (this included 774 transplanted white sturgeon). We recaptured 236 fish that were marked in a prior period. The estimated abundance of white sturgeon in this size-class was 60,183 (95% confidence interval 53,005–68,239; Table 5).

Chi-square test results showed recapture frequencies, in 1997, were significantly different between the 1994 and 1995 transplant groups ($c^2$=8.0271; df = 1; $P$ = 0.0046). Survival estimates for fish released in 1994 and 1995 differed considerably. For fish at large two years, we estimated 99% survival (range 87–113%), while 80% of those at large one year survived (range 70–90%). These survival rates translated into annual mortality rates of 1% and 20% for 1994 and 1995 releases, respectively (Table 6).

Transplanted fish grew as much as 51 cm, after being at large up to 1,031 d. However, growth was highly variable, and many fish did not increase in length at all (Figure 3). The mean annual growth rate for fish transplanted in 1994 was

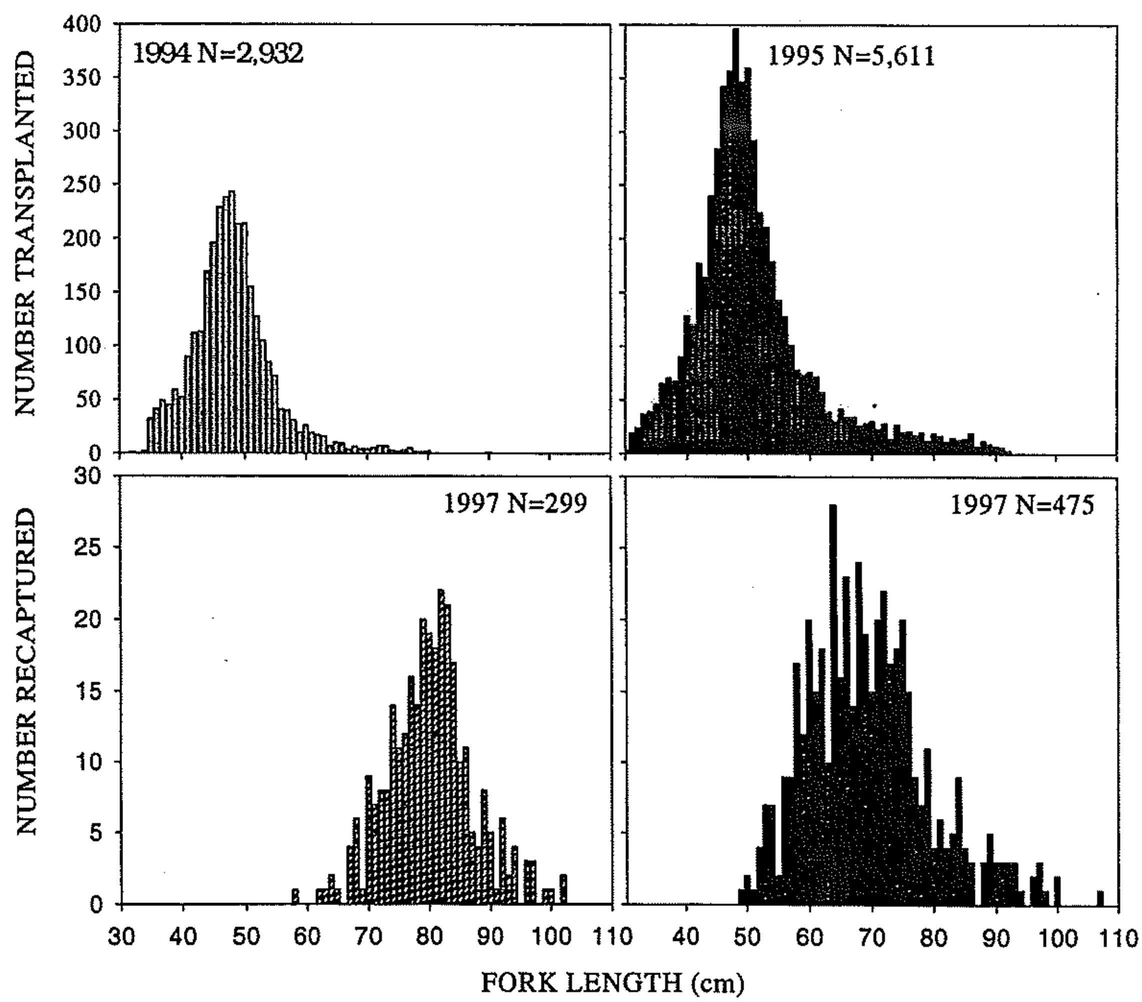


Figure 2. Fork lengths of transplanted white sturgeon when released in the Dalles Reservoir, in 1994 and 1995, and when recaptured, in 1996 and 1997.

Table 5. White sturgeon catch and recapture numbers by mark-recapture period in the Dalles Reservoir.

| Period | Dates | Catch | 1997 tags applied[a] | Recaptures[b] | 1994 transplants in catch | 1995 transplants in catch |
|---|---|---|---|---|---|---|
| 1 | 12/01/96–01/31/97 | 2,439 | 2,179 | 0 | 197 | 165 |
| 2 | 05/05/97–06/01/97 | 307 | 292 | 15 | 7 | 31 |
| 3 | 06/02/97–06/22/97 | 562 | 528 | 45 | 14 | 51 |
| 4 | 06/23/97–07/13/97 | 1,105 | 1,050 | 53 | 31 | 70 |
| 5 | 07/14/97–08/03/97 | 1,112 | 1,043 | 68 | 27 | 91 |
| 6 | 08/04/97–08/25/97 | 862 | 807 | 55 | 23 | 67 |
| All | 12/01/96–08/25/97 | 6,387 | 5,899 | 236 | 299 | 475 |

a. Includes recaptures of fish marked during previous years which are counted as new marks for population estimation.
b. Fish marked and recaptured in the same period were not counted as recaptures for population estimation.

13.2 cm/year, compared with 10.9 cm/year for 1995 transplants. The mean relative weight was significantly different between 2,209 resident and 493 transplanted fish (df = 2700; $t$=-10.10; $P <$ 0.0001). Relative weights for resident fish 70–109 cm averaged 104%, while transplants averaged 110% (113% for 1994 transplants and 108% for 1995 transplants; Figure 4). Most transplanted fish moved fewer than 10 km from their release point (Figure 5). The catch frequencies of resident and transplanted white sturgeon were significantly different ($c^2$=27.74; df = 5; $P < 0.0001$). The most apparent difference was the catches in the John Day Dam tailrace, where 5% of transplanted fish were caught and 14% of resident fish were caught. Downstream catches of resident and transplanted fish appeared quite similar (Figure 6).

### *Supplementation Levels*

We estimated 5,000–46,000 age-5 white sturgeon would be needed to restore a missing age-class in the Dalles Reservoir to densities observed in Bonneville Reservoir or in the lower Columbia River, respectively. About 2.6 times as many age-1 fish would be needed to achieve the same result. Achieving target densities in John Day Reservoir requires stocking rates 4.7 times greater than the Dalles Reservoir (due entirely to John Day's greater area). Restoration efforts of these magnitudes, if implemented in a single year, would require 2–71% of an individual age-class in the lower Columbia River (Table 7).

## Discussion

Mortality associated with capture and transplant of white sturgeon appears to be negligible. Differences between release number and abundance after one to two winters at large may be explained by a combination of losses due to capture mortality, transplant mortality, and natural mortality, as well as by emigration. While we have not been able to isolate each of these rates, their total approximates previous estimates of natural mortality alone (21.3% in Beamesderfer et al. 1995; 9% in DeVore et al. 1995).

Table 6. Summary of parameters used and estimates derived for transplanted white sturgeon abundance and survival. Fish were released into the Dalles Reservoir in 1994 and 1995. Numbers in parentheses are the 95% confidence limit for abundance of fish 50–109 cm and ranges based on that interval.

| Estimate or count | | |
|---|---|---|
| 1997 catch (all fish 50-109 cm) | 6,387 | |
| 1997 abundance (50-109 cm) | 60,183 (53,005–68,239) | |
| | **Transplant Year** | |
| | 1994 | 1995 |
| Number transplanted | 2,838 | 5,611 |
| Transplant recaptures in 1997 | 299 | 475 |
| Proportion of transplants in catch | 0.0468 | 0.0744 |
| Transplant abundance in 1997 | 2,817 (2,481–3,195) | 4,476 (3,942–5,075) |
| Survival since transplant | 99% (87–100%) | 80% (70–90%) |
| Annual mortality rate | >1% (0–6%) | 20% (10–30%) |

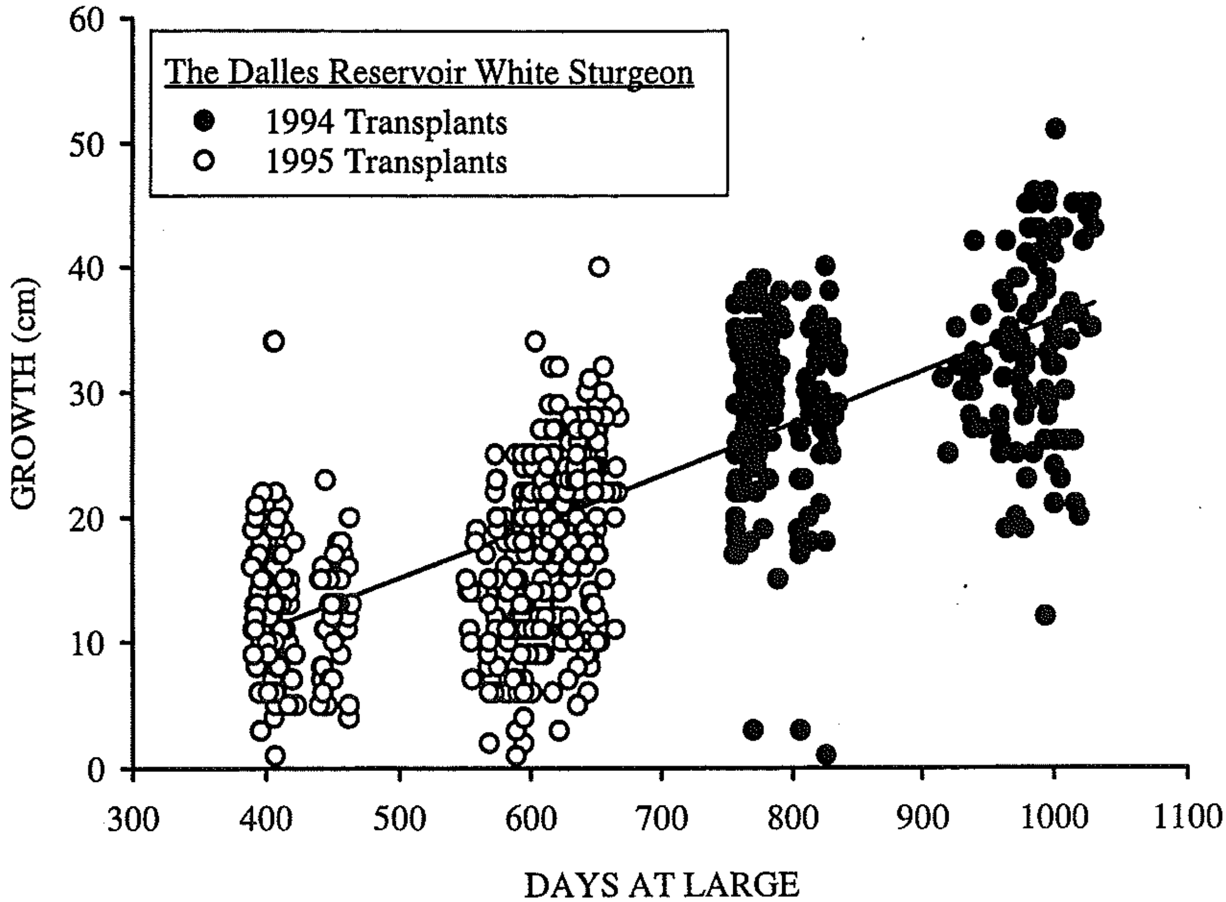


Figure 3. Growth of white sturgeon transplanted to the Dalles Reservoir, in 1994 and 1995, and recaptured, in 1996 and 1997.

It is unclear if differences in the survival of the 1994 and 1995 transplant groups are real. We might expect an initial transplant mortality followed by the real annual increment associated with natural mortality. Our study design did not allow us to apportion transplant mortality as a separate affect. During1994, transport times were nearly double those during 1995; confined processing conditions on the boats made handling more difficult; and the overall conditions during transport were more difficult to manage, yet estimated survival during 1994 was greater than during 1995. One explanation is that a bias may be introduced because the 1995 transplants were smaller (they had one less year to grow) and fish less than 70 cm are less vulnerable to capture with our gear (Elliott and Beamesderfer 1987; Beamesderfer et al. 1995); thus, comparison of catch rates between these two groups may not be appropriate. A less likely scenario is that OTC injection reduced survival in 1995. Past investigations did not demonstrate higher mortality rates among larger (>70 cm) OTC-injected white sturgeon in Columbia River reservoirs (Rien and Beamesderfer 1994). However, that result was in direct contrast to work conducted with sablefish *Anopopoma fimbria*, which showed increased mortality as dosages increased above our maximum of 25 mg OTC/kg of fish weight (McFarlane and Beamish 1987).

No substantial growth, condition, or behavioral differences were observed between resident and transplanted white sturgeon in this study. Prior to this experiment, we hypothesized that transplanted fish might not perform as well as fish naturally produced in the Dalles Reservoir, either due to regional adaptation differences or to an advantage of early rearing of naturally produced fish in the release area. However, transplanted white sturgeon had condition factors greater than resident fish, and observed growth rates were similar to previously reported rates in the Dalles Reservoir (Beamesderfer et al. 1995). Prior studies in the Dalles Reservoir showed that most white sturgeon tended to be recaptured near the original marking location, but a portion would move

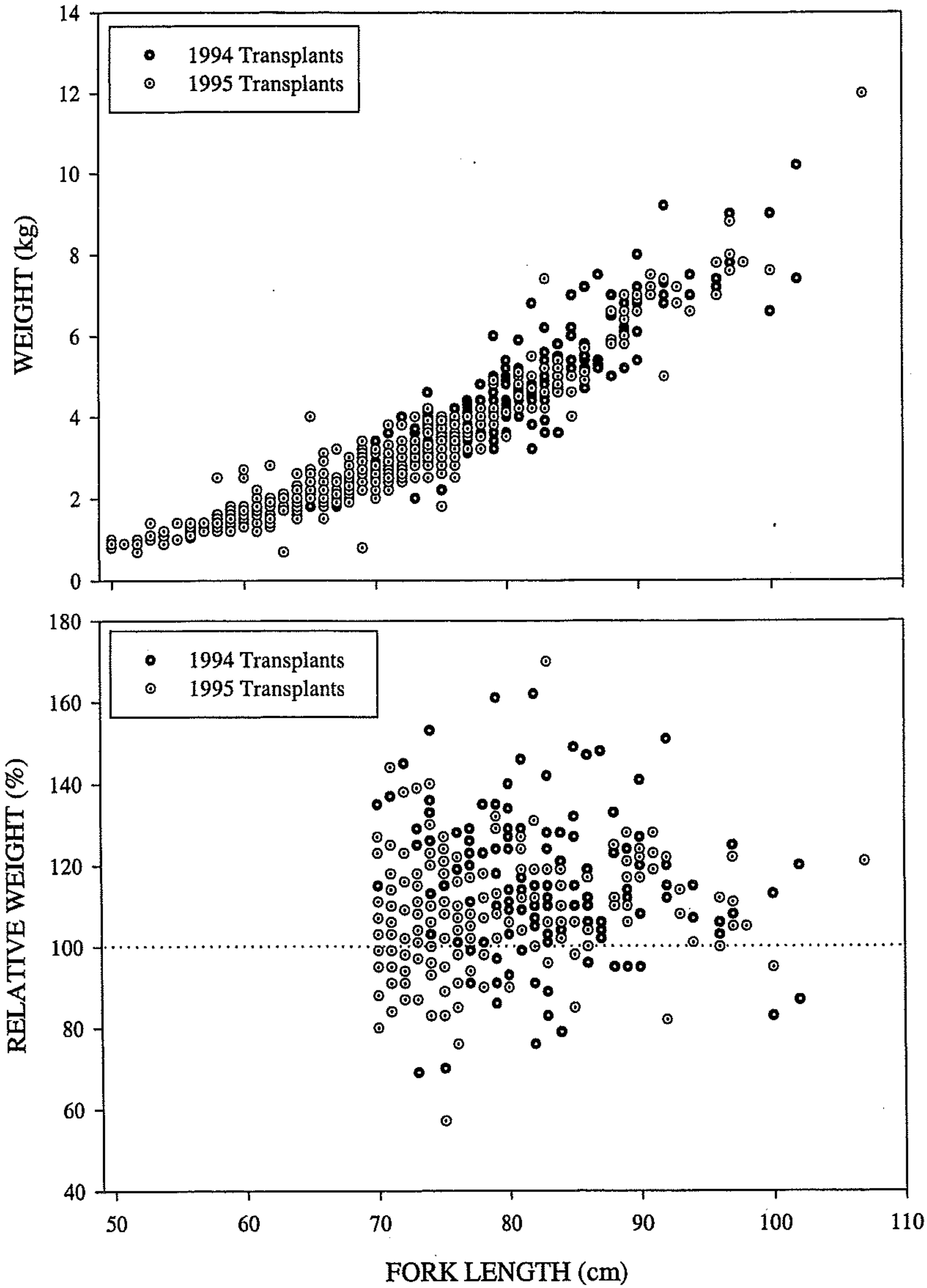


Figure 4. Weight and relative weight of white sturgeon transplanted to the Dalles Reservoir, in 1994 and 1995, and recaptured, in 1997.

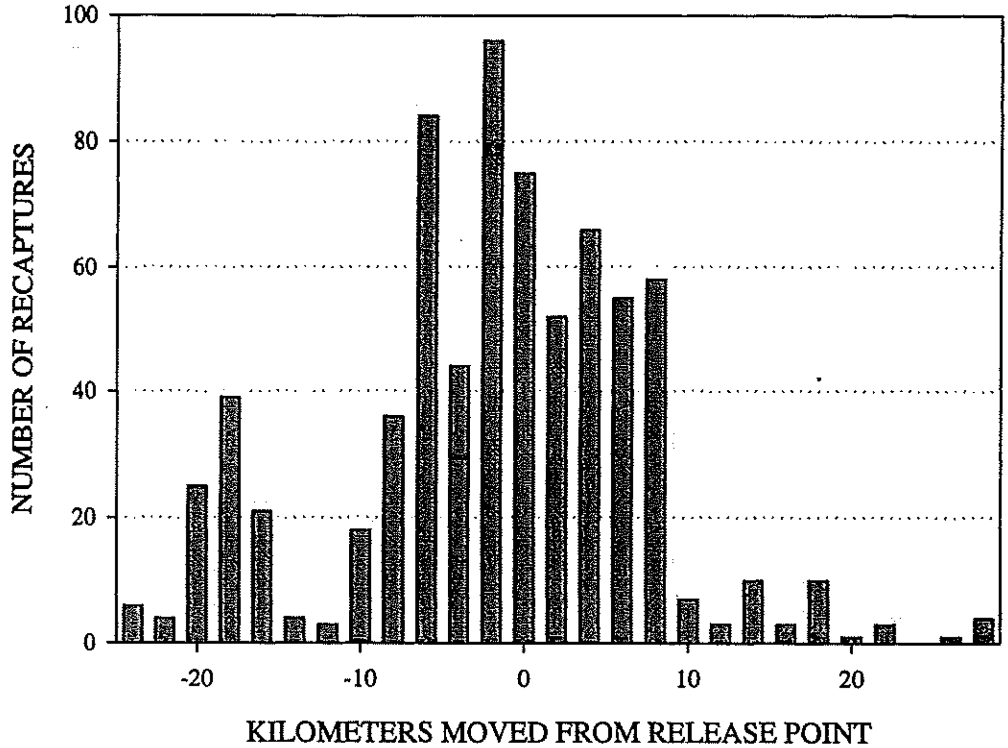


Figure 5. Distance between release and capture locations for white sturgeon transplanted to the Dalles Reservoir, in 1994 and 1995, and recaptured, in 1996 and 1997. Negative values indicate downstream movement.

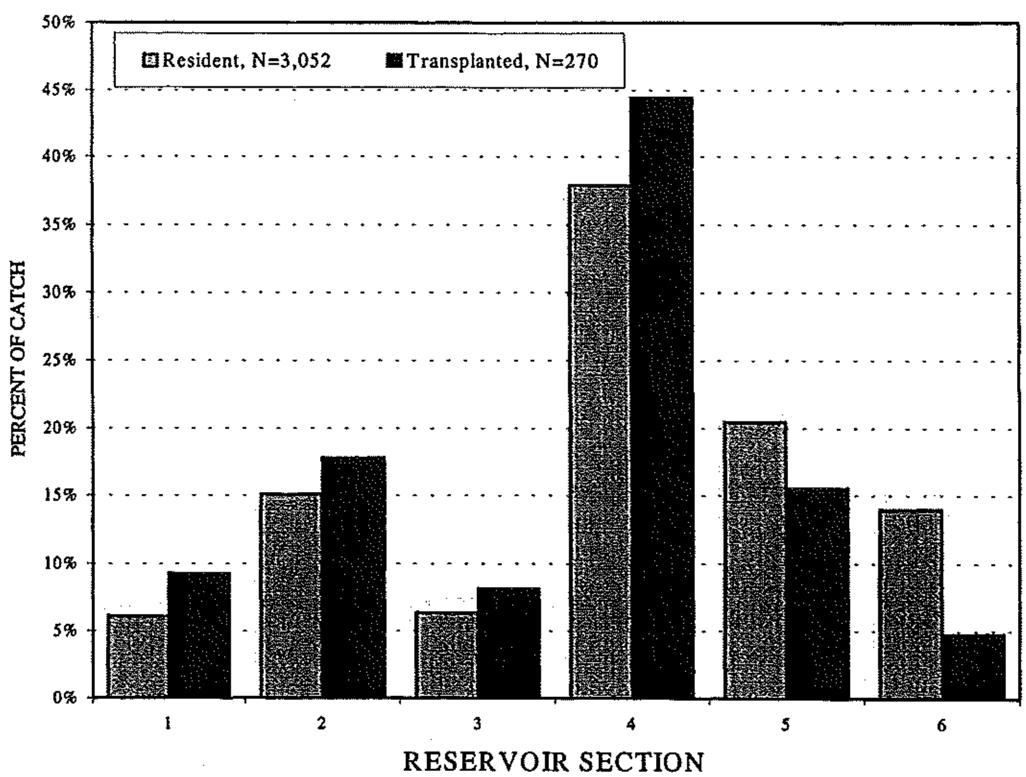


Figure 6. Distribution of setline catches of resident and transplanted white sturgeon among sampling sections in the Dalles Reservoir, 1997. Section 1 is furthest downstream and contains the forebay of the Dalles Dam. Section 6 is furthest upstream and contains the tailrace of John Day Dam.

Table 7. Modeled stocking rates for Zone 6 sturgeon populations.

| Characteristic | Columbia River Reach: Downstream from Bonneville Dam (LCR) | Bonneville Reservoir (BO) | The Dalles Reservoir | John Day Reservoir |
|---|---|---|---|---|
| Surface area of reach (ha) | 61,000 | 8,400 | 4,500 | 21,000 |
| Year of estimates | 1987[a] | 1989[b] | 1987[b] | 1996[b] |
| Natural mortality age 1-10 (n) | 0.09 | 0.213 | 0.213 | 0.213 |
| Maximum estimated abundance | | | | |
| Age 1 | 441,661 | 25,700 | 13,600 | 30,220 |
| Age 5 | 302,869 | 10,003 | 5,300 | 11,593 |
| Age 10 | 189,000 | 3,020 | 1,600 | 3,500 |
| Maximum estimated density (fish/ha) | | | | |
| Age 1 | 7.24 | 3.06 | 3.02 | 1.44 |
| Age 10 | 3.1 | 0.36 | 0.36 | 0.17 |
| Stocking to reach benchmark densities of age-10 fish (assumes no natural recruitment) | | | | |
| Benchmark | Stocked age-1 fish (9 years of n to reach age 10) | | | |
| 3.1 fish/ha (match LCR) | – | – | 120,449 | 562,093 |
| 0.72 fish/ha (double BO) | – | – | 27,975 | 130,551 |
| 0.36 fish/ha (match BO) | – | – | 13,988 | 65,275 |
| Benchmark | Stocked age 5 fish (5 years of n to reach age 10) | | | |
| 3.1 fish/ha (match LCR) | – | – | 46,206 | 215,629 |
| 0.72 fish/ha (double BO) | – | – | 10,732 | 50,082 |
| 0.36 fish/ha (match BO) | – | – | 5,366 | 25,041 |
| Benchmark | Proportion of LCR age-5 population needed to achieve benchmark | | | |
| 3.1 fish/ha (match LCR) | – | – | 15% | 71% |
| 0.72 fish/ha (double BO) | – | – | 4% | 17% |
| 0.36 fish/ha (match BO) | – | – | 2% | 8% |

a. Beamesderfer et al. 1995.
b. DeVore et al. 1995.

widely within the reservoir (North et al. 1993). This is similar to the pattern we observed with transplanted fish. After one to two years at large, few transplanted fish had moved more than 10 km from their release site, and the distribution of transplanted fish was significantly different from resident white sturgeon. Differences in distribution were greatest in the section downstream from John Day Dam. Distributions in sections further downstream appeared similar.

Study results suggest that transplantation is a viable option to mitigate for lost productivity in Columbia River impoundments. Abundance estimates for juvenile white sturgeon (54–81 cm) in the free-flowing lower Columbia River ranged from 496,200–788,300, during 1986–1990 (DeVore et al. 1995). Annual transplants to date have amounted to less than one percent of the donor population. At higher stocking rates, or if additional river reaches are designated for stocking, costs to lower Columbia River sturgeon fisheries will need to be carefully examined. Compared with fish in neighboring upstream reservoirs, white sturgeon in Bonneville Reservoir generally mature at older age but smaller size and they have lower condition factors (Beamesderfer et al. 1995). This suggests that each reservoir will have a limited carrying capacity. Determining an appropriate stocking rate might take three approaches: 1) A hypothetical bioenergetics approach—develop a model of the ecosystem and determine what the habitat can support based on available resources in the system. Uncertainty in many model parameters means we are years from an answer to this question. Once the model results are out, the true test would still be an implementation of some form of supplementation. 2) An empirical "camel's back" approach—stock the habitat until depensatory effects of overcrowding are observed. This method will not reveal much about impacts on the environment or on other native species and depensatory effects may only appear years after reservoir capacity is exceeded. Furthermore, with this approach, density-independent affects on performance measures may be difficult to separate from density-dependent effects. 3) A "benchmark" approach that attempts to match densities observed in other Columbia River reaches. This approach has the utility of providing measurable goals based on known populations. However, we know that each reservoir has a unique set of habitat conditions, thus optimum densities are not necessarily the same in any two reaches.

A recovery strategy that incorporates transplanting wild fish will ultimately be limited in magnitude by the availability of donor stocks, and, in geographic extent, by definition of evolutionary significant units. However, social pressures and agency policy may limit transplants beyond any biological basis. Moving fish upstream clearly means fewer fish are available for harvest in downstream areas. While some lost production may be "made up" through compensatory growth, this has not been demonstrated, and fisheries managers will need to balance the needs for mitigation in upstream reservoirs with harvest needs in the lower Columbia River.

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## References

Beamesderfer, R. C. P., and R. A. Farr. 1997. Alternatives for the protection and restoration of sturgeons and their habitat. Environmental Biology of Fishes 48:407–417.

Beamesderfer, R. C. 1993. A standard weight (Ws) equation for white sturgeon. California Fish and Game 79:63–69.

Beamesderfer, R. C. P., T. A. Rien, and A. A. Nigro. 1995. Differences in the dynamics and potential production of impounded and unimpounded white sturgeon populations in the lower Columbia River. Transactions of the American Fisheries Society 124:857–872.

DeVore, J. D., B. W. James, C. A. Tracy, and D. A. Hale. 1995. Dynamics and potential production of white sturgeon in the Columbia River downstream from Bonneville Dam. Transactions of the American Fisheries Society 124:845–856.

Elliott, J. C., and R. C. Beamesderfer. 1987. Comparison of efficiency and selectivity of three gears used to sample white sturgeon in a Columbia River reservoir. California Fish and Game 76:174–180.

McFarlane, G. A., and R. J. Beamish. 1987. Selection of dosages of oxytetracycline for age validation studies. Canadian Journal of Fisheries and Aquatic Sciences 44:905–909.

McCabe, G. T., Jr., and S, A. Hinton. 1994. Report D. Pages 145–180 *in* A. A. Nigro, editor. Status and habitat requirements of the white sturgeon populations in the Columbia downstream from McNary Dam. Report to Bonneville Power Administration (Project 86-50), Portland, Oregon.

McCabe, G. T., Jr. 1996. Report D. Pages 110–132 *in* K. T. Beiningen, editor. Effects of mitigative measures on productivity of white sturgeon populations in the Columbia River downstream from McNary Dam, and determine the status and habitat requirements of white sturgeon populations in the Columbia and Snake rivers upstream from McNary Dam. Report to Bonneville Power Administration (Project 86-50), Portland, Oregon.

North, J. A., R. C. Beamesderfer, and T. A. Rien. 1993. Distribution and movements of white sturgeon in three lower Columbia River reservoirs. Northwest Science 67(2):105–111.

Parsley, M. J., T. D. Counihan, and A. I. Miller. 1996. Report C. Pages 73–109 *in* K. T. Beiningen, editor. Effects of mitigative measures on productivity of white sturgeon populations in the Columbia River downstream from McNary Dam, and determine the status and habitat requirements of white sturgeon populations in the Columbia and Snake rivers upstream from McNary Dam. Report to Bonneville Power Administration (Project 86-50), Portland, Oregon.

Parsley, M. J., and L. G. Beckman. 1994. White Sturgeon spawning and rearing habitat in the Lower Columbia River. North American Journal of Fisheries Management 14:812–827.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Research Board of Canada Bulletin 191.

Rien, T. A., and R. C. Beamesderfer. 1994. Accuracy and precision of white sturgeon age estimates from pectoral fin rays. Transactions of the American Fisheries Society 123:255–265.

Rien, T. A., R. C. P. Beamesderfer, and C. A. Foster. 1994. Retention, recognition, and effects on survival of several tags and marks for white sturgeon. California Fish and Game 80:161–170.

SAS (Statistical Analysis System). 1988. Procedures guide, Version 6.03 edition. SAS Institute, Cary, North Carolina.

SAS (Statistical Analysis System). 1989. SAS/STAT user's guide, Version 6, 4th edition. SAS Institute, Cary, North Carolina.