

Success of hatchery-reared juvenile white sturgeon (*Acipenser transmontanus*) following release in the Kootenai River, Idaho, USA

By S. C. Irelands¹, R. C. P. Beamesderfer², V. L. Paragamian³, V. D. Wakkinen³ and J. T. Siple¹

¹Kootenai Tribe of Idaho, Bonners Ferry, ID, USA; ²S. P. Cramer and Associates, Inc., Sandy, OR, USA ³Idaho Department of Fish and Game, Coeur d'Alene, ID, USA

Summary

In 1990 a conservation program began to evaluate the feasibility of using aquaculture to aid recovery of the white sturgeon population in the Kootenai River. Because of a virtual lack of recruitment during the past two decades, the population was formally listed in 1994 as endangered under the U.S. Endangered Species Act of 1973. Recovery program goals are to preserve the genetic variability of the population, rebuild natural age class structure, prevent extinction, and restore natural recruitment. Mature wild fish are captured prior to spawning and bred to produce four to 12 separate families per year of four to 10 adults per family at breeding age: We released 2630 age 1-4 juvenile white sturgeon from 1992 to 1999. Subsequent catches of 39 wild and 620 hatchery juveniles in an annual monitoring program confirm that wild recruitment of Kootenai River white sturgeon is very low. Subsequent recaptures of hatchery fish indicate that significant numbers survived introduction and grew. Release-recapture and catch curve analyses suggest that average annual survival rates for hatchery-reared juveniles may approach 60% for the first year following release and 90% in subsequent years. Growth rates and condition factors within 3 years after release were often poor as many hatchery fish adapted to natural conditions. Growth rates increased after the initial adjustment period. Average growth increments for all recaptured hatchery fish were 6.4 cm year⁻¹ and 0.206 kg year⁻¹. These rates are slightly less than the median rate reported for other white sturgeon populations. Growth varied substantially among individuals. Some fish grew little even after 3 years but others grew up to 60 cm after 8 years at large. Relative weight decreased between release and recapture for 77% of recaptured hatchery sturgeon. Relative weights were 88% of optimum at release, 78 % of optimum at recapture, and increased with period at large. Relative weight at recapture was inversely correlated with growth in length and opposite to our initial expectations that higher condition would accompany faster growth. No obvious patterns in survival or growth of juveniles could be related to size, time, or condition of release. These initial results provide a basis for adjusting releases of hatchery fish consistent with the conservation goal of the hatchery program and also provide a baseline for comparison with the results of future monitoring to determine carrying capacity of the Kootenai River system for juvenile sturgeon.

Introduction

Fish hatcheries have traditionally produced fish for harvest or for supplementation of natural spawning but now are being

used to conserve wild stocks. Hatchery programs for sturgeon have demonstrated considerable success in collecting or developing broodstock, spawning, and rearing juveniles (Conte et al. 1988; Smith 1990). However, the successful use of sturgeon hatcheries for conservation will depend on how well the hatchery-reared sturgeon can adapt to natural habitat conditions and how well the hatchery can preserve genetic diversity and key attributes of the natural population (Kincaid 1993; Secor et al. 2002). Introductions of hatchery-reared fish do not always benefit natural populations and may often result in genetic changes to these natural populations (Evans and Wilcox 1991; Hindar et al. 1991; Waples 1991; Fleeting 1994; Brannon et al. 1999).

The Kootenai River contains a unique headwater population of white sturgeon, (*Acipenser transmontanus*), that has been isolated from other populations in the Columbia and Snake rivers for some 10 000 years (Northcote 1973; Paragamian and Kruse 2001; Paragamian et al. 2001). Recruitment ceased after the completion of the Libby Dam in 1972 (Anders et al. 2002). Currently the population consists of a dwindling number of *A. transmontanus* adults listed as endangered under the U.S. Endangered Species Act on September 6, 1994. To date, efforts to stimulate natural recruitment with flow augmentation have not been successful (Paragamian et al. 2001).

Hatcheries are a key element in the recovery plan for this species and have been regarded as a stopgap measure until more aggressive habitat restoration programs can restore natural recruitment (Duke et al. 1999; USFWS 1999). Hatcheries are currently the only viable option for stabilizing this sturgeon population and preserving genetic diversity. The white sturgeon population in the Kootenai River will be considered healthy, (i) when a combination of natural and hatchery production has restored a length and age frequency distribution in which most size and age classes are represented, (ii) numbers of adult spawners are sufficient to produce recruitment that maintains the population size and age distribution at a stable level, (iii) habitat improvements are sufficient to allow natural spawning to maintain the population in the absence of hatchery supplementation, and (iv) population size is sufficient to maintain genetic and life history diversity (Duke et al. 1999; USFWS 1999).

Hatchery breeding of wild Kootenai River white sturgeon broodstock was initiated in 1990 to examine gamete viability and exposure to water- and sediment-borne contaminants (Apperson and Anders 1991). The hatchery program was expanded when initial efforts demonstrated the feasibility of producing significant numbers of juvenile fish for release (Ireland, et al. 2002). Breeding and disease management plans

have been implemented to guide the systematic collection and spawning of wild adults, limit the genetic effects of stocking hatchery fish into a wild population, and control the spread of pathogens (Kincaid 1993; Anders 1998; LaPatra et al. 1999). As the remaining population is small and food resources may be limited, the initial objectives of the hatchery program are to produce four to 12 separate families per year and four to 10 adults per family that survive to the breeding age (Kincaid 1993). The stocking goal is currently 1000 fish per family at the age of 15-24 months. Stocking rates were based on expected survival rates during an 18-year post-stocking period (Kincaid 1993).

Success of the hatchery program will ultimately be determined by: (i) the ability to collect and spawn wild broodstock and to rear juvenile fish for release; (ii) successful adaptation of hatchery fish released into the wild; (iii) survival of hatchery fish to sexual maturity in sufficient numbers to rebuild the natural age structure and provide the next generation of broodstock; (iv) retention of wild sturgeon life history characteristics and genetics in the hatchery-reared population; and (v) identification of factors limiting natural recruitment of white sturgeon in the Kootenai River. The hatchery program has previously demonstrated that it can obtain and successfully spawn wild broodstock and rear juveniles to a size suitable for release (Ireland et al. 2002). This article focuses on adaptation to the wild of the first hatchery-reared groups of juvenile white sturgeon. We evaluated survival, growth, and condition of these fish during the first few years after release.

Materials and methods

Hatchery releases

Small groups of juvenile white sturgeon produced from wild broodstock and reared in the hatchery for 1-4 years have been released periodically since 1992. Prior to 1999, all releases of hatchery-reared Kootenai River white sturgeon were experimental, to assess growth, survival, and habitat use of juveniles in the wild.

Prior to release, hatchery-reared white sturgeon juveniles were measured (total length and fork length), weighed, tagged with a uniquely-numbered PIT tag, and scutes were removed for identification of the year-class in case of tag loss (e.g. the ninth left lateral and the eighth right lateral scutes were removed from juveniles from the 1998-year class) (Ireland et al. 2002). Scute removal has been found to be an effective long-term mark that can be applied with little impact on the fish (Rien et al. 1994). In order to determine post-stocking survival and potential genetic contribution to the next generation, each family consisting of the offspring of one male and one female were reared separately. Thus, family and year-class were known for each tagged fish.

Monitoring program

A monitoring program was initiated in 1993 to annually recapture hatchery-reared white sturgeon juveniles in the Kootenai River, using weighted multifilament gill nets with 1.5 or 2 cm bar mesh. Gill net samplings were completed at randomly selected locations between river kilometers (rkm) 170 and 236 during July, August, and early September of each year (Fig. 1). Gill nets were set during the day and checked every hour. Juvenile sturgeon were examined for a PIT tag and scute removal pattern to distinguish hatchery-produced fish

from wild fish, as well as the year-class of recaptured hatchery-produced juveniles. Fish were measured in total length (TL) and fork length (FL) to nearest cm, weighed .to nearest 10 g, and released.

Success of hatchery-released juvenile white sturgeon was evaluated based on survival rates, growth rates, and condition factors. Number caught, size, and condition were compared among release and recapture instances. Analyses were based on pooled and release group-specific data. Release groups were distinguished by year-class, year of release, and season of release whereby spring was March-May, summer was June-August, and autumn was September-November.

Survival rates

Annual survival rate of each released group was estimated using (i) maximum likelihood estimators (MLE) and (ii) among-year catch curves of recaptures of each release group.

MLE estimates were based on a release and recapture Cormack-Jolly-Seber model and the analysis program MARK (White and Burnham 1997; Cooch and White 2001). Approximate average first-year and subsequent year survival rates were estimated using pooled data for all groups. The model was:

$$R(t) = f[N(t), \phi(t), p(t)]$$

where, $R(t)$ = Number of recaptures from cohort c in period t , $N(t)$ = Number of marked fish released from cohort c , $\phi(t)$ = Survival rate of fish from cohort c in time period t , and $p(t)$ = Recapture probability of fish from cohort c in time period t .

Our model included nine time intervals (1992, 1993, ..., 2000) and only one group consisting of all marked hatchery fish released in each year. We compared results of models which assumed time-specific survival [$\phi(t)$] and recapture rates [$p(t)$] with survival [ϕ .] and recapture rates [p .] averaged across time periods. We also examined a model that distinguished year 1 ($t = 1$) and subsequent-year average ($t = 1 +$) survival rates using year-specific recapture rates.

Catch curve estimates were made in an attempt to corroborate MLE estimates. Catch curve estimates were derived from regressions of \log_e (number of recaptures/gillnet effort) on recapture year. Annual survival rate (S) is equal to e^{-z} where z is the slope of the regression line (Ricker 1975). Recapture numbers were expressed per hour of gillnet effort to account for differences in sampling years. Catch curves estimate average annual survival rates of hatchery release groups for the period following the first recapture year but do not provide an indication of survival between release and the first year of recapture.

We evaluated the potential for differential survival within each release group based on size and relative weight at release of fish that were recaptured. Relative weight is an index of condition factor. We suspected that larger or heavier fish might survive better than smaller or skinnier fish. If fish of different sizes or relative weights within a release group survived at different rates, then the distribution of, sizes or relative weights at release for fish that were recaptured would depart from the distribution in the release group. For instance, if large fish survived better, then the average length at release of recaptured fish would be greater than the average length at release of that release group. Significant differences ($P < 0.05$) were identified using chi-square tests comparing release and recapture numbers less than and greater than the median at release. This analysis assumes that the recaptured fish are representative of those that survive.

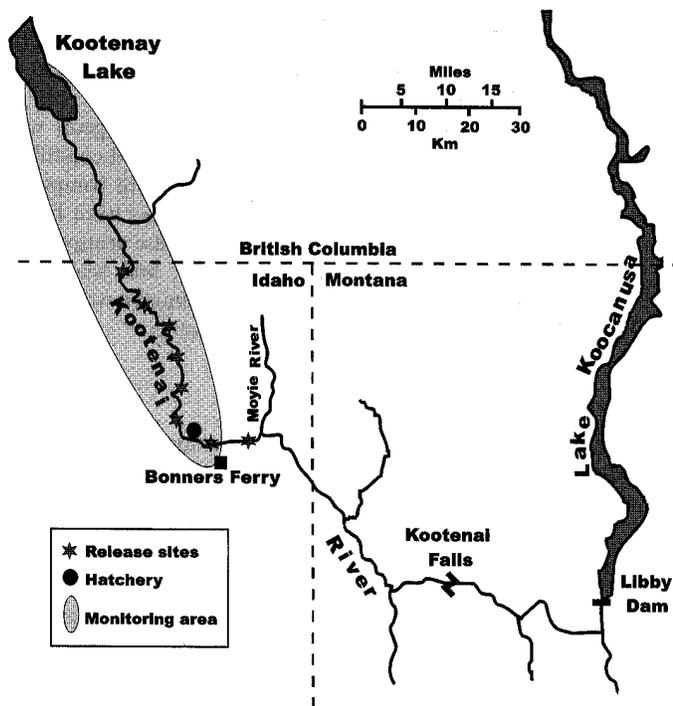


Fig. 1. Locations of white sturgeon release and monitoring sites in the Kootenai River, Idaho, USA

Estimated annual survival rates of hatchery release groups were compared with reported values for other white sturgeon populations from the Columbia and Snake rivers to evaluate whether rates in the Kootenai River population were typical. Rates were also compared with expectations in the current breeding plan (Kincaid 1993) to evaluate whether planned stocking rates of Kootenai hatchery white sturgeon were consistent with program assumptions.

Growth

We estimated growth in length and weight based on comparisons of individual fish release and recapture sizes. Average annual and daily growth rates of individual hatchery-raised white sturgeon juveniles were based on the slope of a regression line between the observed growth increment and the period at large. This approach allowed us to average out the effects of different release seasons. Regression intercepts were fixed consistent with actual average size at release because this was a known value. Growth increments were calculated for a pooled sample and for individual release groups. Significant differences ($P < 0.05$) in annual growth rate among release groups were identified with non-parametric Kruskal-Wallis tests using group as an effect factor in the linear model. Annual growth rates for Kootenai hatchery release groups were compared with reported rates for other white sturgeon stocks. Comparisons were standardized to fish younger than 10 years of age to minimize confounding effects of growth rate changes with size and age.

Relative weight

Condition factor is a description of weight for a given length of fish and should be one of the most sensitive indicators of forage, feeding, or health problems as hatchery fish adapt to the natural environment. We described condition factor for each cohort of marked hatchery white sturgeon using a relative

weight index (W_r). The relative weight index expresses condition factor relative to typical values observed for a given species. Relative weight is the observed weight expressed as a percent of a standard weight for a fish of that size based on the length-weight data for other sturgeon populations throughout their range in the Sacramento, Columbia, Snake, and Fraser river systems (Beamesderfer 1993). Standard weight has been defined based on the 75th percentile of weights for other sturgeon populations to represent an optimum management goal (Murphy et al. 1991). Average relative weight for all sturgeon is around 90% of the standard weight (Beamesderfer 1993). Some caution should be exercised in interpreting relative weight for these small hatchery sturgeon because sizes are generally less than the 70 cm threshold identified by Beamesderfer (1993) where errors in the accuracy of individual weight measurements significantly increase variance in the index.

Results

Release and recapture of hatchery white sturgeon

We released 2630 hatchery-reared juvenile white sturgeon from 1992 to 1999 (Table 1). Release numbers by year-class ranged from 13 fish of the 1990-year class in 1992 to the release of 1075 fish of the 1995-year class in 1997. Sampling effort with gillnets included a total 237 h in 1993 and 1994 and totals of 277, 443, 535, 593, and 343 h for 1995 to 1999, respectively.

The total recaptures in each year of sampling ranged from one hatchery white sturgeon in 1993 and 1994, to 185 in 1998 (Table 1). Mean annual recapture rates of hatchery fish averaged 2.6-23.3% for different release groups. Between 3 and 80% of the fish in a release group have been recaptured at least once in subsequent years. The greatest recapture rates were observed for the oldest release groups that had been subjected to sampling for several years post-release.

Hatchery fish comprised 94% of all juveniles captured. Only 39 unmarked juveniles were captured from 1992 to 1999, in contrast to 620 hatchery recaptures.

Table 1
Release and recapture numbers for juvenile white sturgeon released from the Kootenai Hatchery, 1990-2000

Year	Release		Number recaptured ¹								Total	Avg. rate ³	Indiv. recap ⁴	Growths ⁵		Relative weight ⁶			
	Year	Period	Number	Size ²	1993	1994	1995	1996	1997	1998				1999	2000	(cm/yr)	(kg/yr)	Rel.	Recap
1990	1992	Sum	13	45			2						4	3.8 %	31 %	-	-	-	79
1991	1992	Sum	104	25	1	14	24		9	8	16	3	75	9.0%	49%	7.1	0.268	97	94
1992	1994	Sum	114	46		1	8	12	11	7	8	7	54	7.7%	30%	5.7	0.223	86	87
1992	1994	Aut	10	72			4	4	1	2	1	2	14	23.3%	80%	0.8	-0.005	78	83
1995	1997	Spr	1075	23					33	62	53	68	216	5.0%	18%	8.2	0.117	95	75
1995	1997	Aut	886	34					1	104	52	62	219	8.2%	22%	4.2	0.093	79	75
1995	1998	Sum	97	41						1	7	16	24	11.9%	22%	3.6	0.114	84	79
1995	1999	Sum	25	58							2	4	6	16.0%	20%	5.8	-0.010	97	68
1998	1999	Aut	306	26								8	8	2.6%	3%	5.9	0.040	86	75
Totals			2630	-	1	1	26	42	55	185	140	170	620	9.7%	20%	6.4 ⁷	0.206	88	78

¹Multiple recaptures not included within a year but are included among years. ²Mean total length in cm at release. ³Average annual recapture rate based on release number and years where available for recapture. ⁴Percentage of release group recaptured at least once. ⁵Based on regression slopes for 1992-1998 release groups where regression was significant ($P < 0.05$) and individual fish averages for 1999 release groups. ⁶Index of condition factor expressed as percent of a standard weight identified as optimum for white sturgeon (Beamesderfer 1993). ⁷Based on regression slope of all recaptures pooled.

Survival rates

The MARK release-recapture models yielded plausible estimates of survival and recapture rates. The fit of the underlying model to the hatchery sturgeon recapture data was significant at the 95% level (observed $P < 0.01$). A basic model with year-specific rates [$\hat{\phi}(t), \hat{p}(t)$] produced survival rates ranging from 29 to 100% and recapture rates ranging from near 0 to 29%. The model, assuming constant survival and recapture rates across years, estimated annual survival at 95% and annual recapture rates at 8%. The model, assuming constant survival and year-specific recapture rates, estimated annual survival at 95% with annual recapture rates ranging from near 0 to 20%. Of the simple models we examined, the best fit was provided by a model that assumed year-specific recapture rates and separate year-1 and subsequent-year survival rates (Table 2); this model estimated an average first year survival rate of 60% and average survival rates during subsequent years which approached 100%. This model also estimated year-specific recapture rates which ranged from near 0 to 29% (Fig. 2). The survival and recovery rates estimated by the MLE method are obviously heavily dependent on the structure of the underlying model. We infer from this analysis that average annual survival rates for hatchery-reared juveniles were likely between 60 and 95%.

Although catch curves failed to provide definitive point estimates of survival, they corroborated the high MLE survival estimates. Annual survival rates derived from catch curves ranged from 77 to 145% (Fig. 3). The sole significant regression ($P < 0.05$) was for the 95/97 spring release group

which yielded an obviously, incorrect 145% survival-rate estimate. This positive slope was likely to be the result of increasing catchability with size for the 95/97 spring release

Table 2
Results of maximum likelihood estimates of survival and recapture rate models using the maximum likelihood multiple mark-recapture model MARK

Model	Rank in Fit	AICc1	No. parameters	Deviance
$\hat{\phi}(t=1 \text{ or } 1+), \hat{p}(t)$	1	4081	10	125
$\hat{\phi}(t), \hat{p}(t)$	2	4108	15	142
$\hat{\phi}(\cdot), \hat{p}(t)$	3	4110	9	156
$\hat{\phi}(t), \hat{p}(\cdot)$	4	4165	9	211
$\hat{\phi}(\cdot), \hat{p}(\cdot)$	5	4170	2	230

¹Akaike's Information Criterion (White and Burnham 1997; Cooch and White 2001).

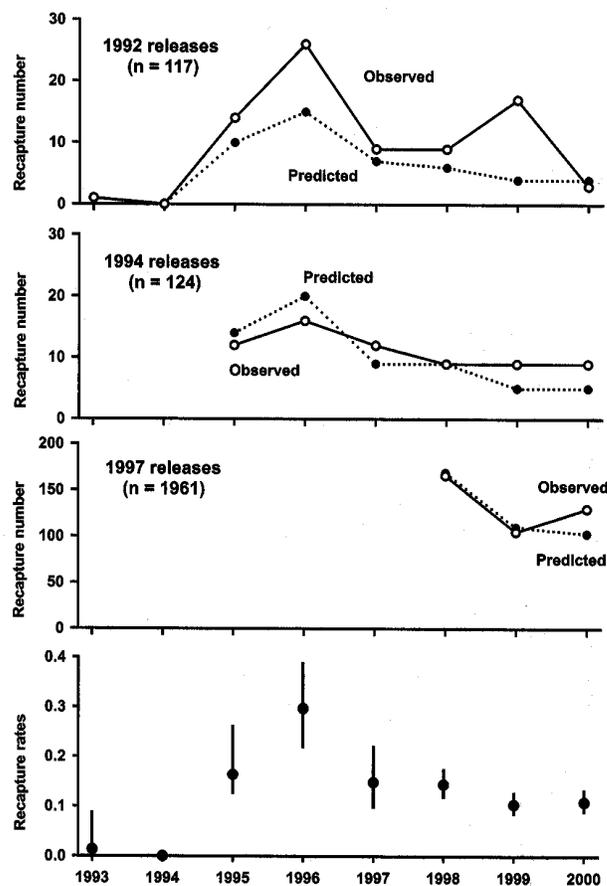


Fig. 2. *Acipenser transmontanus* release-recapture program: Observed and predicted recapture numbers by release group (1992, 1994, 1997) and estimated annual recapture rates (lower panel) derived from MARK release-recapture analyses which assumed year-specific rates which did not vary among release groups. Error bars are 95% confidence intervals. Model on recapture rates also included 1998 and 1999 release groups.

group that was comprised of smaller-than-average juveniles which were poorly recruited to the sampling gear.

No obvious patterns in survival were apparent in comparisons of size or relative weight distributions of released and recaptured fish. Some differences in distributions were observed but few differences were significant and differences were not consistent among groups or between size and relative weight. We observed a significant difference in total length frequency at release only for the 95/97 fall release group where fish greater than the median size at release comprised 12% more of the recovery group than of the release group. Changes in size for other release groups ranged from -12 to +11%. We observed a significant difference in relative weight at release only for the 98/99 autumn release group where fish with greater than the median condition factor at release comprised 38% less of the recovery group than of the release group. Changes in size for other release groups ranged from -2 to +14%. We concluded from these results that subsequent survival was generally independent of size or condition at release over the range of variation observed within each release group.

Growth

Significant growth in TL between release and recapture was observed among most sturgeon released from the hatchery and 87% of the variation in length was accounted for by a linear model with days-at-large (Fig. 4). Average growth increments

for all recaptured hatchery fish were estimated at 0.0176 cm day⁻¹ and 6.4 cm year⁻¹ based on a regression of growth increment vs. days-at-large with the y-intercept forced to zero. Length increases of up to 60 cm were noted among fish recaptured up to 8 years following release. Growth varied substantially among individuals. For instance, growth increments of fish at-large for 3 years varied from near zero to 40 cm.

Average growth rates varied from 0.002 to 0.023 cm day⁻¹ (0.8 to 8.4 cm year⁻¹ among different release groups (Fig. 5). Non-parametric Kruskal-Wallis tests indicated that differences among groups were significant (observed $P < 0.0001$). At least some of these differences were related to length at release, with greater growth occurring among smaller fish.

Juvenile hatchery sturgeon increased in weight at an average rate of 0.206 kg year⁻¹ based on the slope of a regression of change in weight between release and recapture vs days-at-large (Fig. 4). Wide individual variation in weight change was apparent, with weight increasing little or decreasing among many fish recaptured within 2 years of release. The rate of increase in fish weight increased with the period-at-large and corresponding increases in length as is typical of juvenile fish. Weight change between release and recapture varied among release groups from 0.010 kg year⁻¹ to 0.268 kg yr⁻¹ (Table 1). Low sample sizes and few years-at-large were associated with groups where weight was lost or weight gains were small. Non-parametric Kruskal-Wallis tests indicated that differences among-release groups of hatchery fish were significant ($P < 0.0001$).

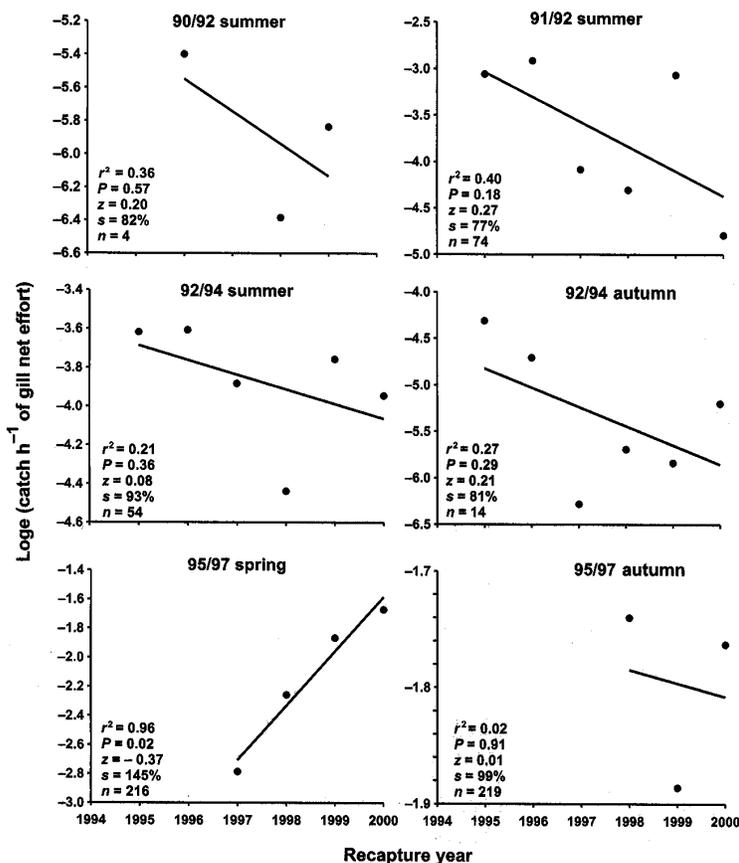


Fig. 3. Catch curves of white sturgeon recaptures of release group cohorts expressed per hour of gillnet effort. Points represent mean catch per unit effort of fish from each release group in each year, r^2 = correlation coefficient of determination, P = observed significance level, z = instantaneous mortality rate (-slope), s = annual survival rate ($1 - e^{-z}$), and n = sample size

Relative weight

Relative weight at recapture averaged 78% of standard weight for all release groups and generally increases with the period at large (Fig. 6). Relative weight decreased between release and recapture for 77% of recaptured hatchery sturgeon. Large variation in relative weight was apparent among recaptured hatchery sturgeon. Some variation in relative weight results from measurement error for these small fish but some could reflect the highly variable success of individual hatchery fish in adapting to the natural environment. Many hatchery fish appear to do very well, while others seem to fare poorly.

Some differences in relative weight at recapture were observed among different hatchery release groups (Table 1), but many of these differences seemed to be related to differences in the interval between release and recapture. Average relative weight was higher for fish at-large for longer periods because they represented only those fish that successfully adapted and survived.

Relative weight at recapture was inversely and significantly correlated with growth in total length at the 95% level ($P = 0.0008$, $r^2 = 0.02$, slope = -0.38). This observation is opposite to our initial expectations that higher condition fish would also grow faster. Instead, fish that increased substantially in length tended to be thinner than fish that grew more slowly. It is unclear to what extent gillnet selectivity may have contributed to this result. Gillnets would be expected to select for higher-condition individuals from among fish sizes not fully recruited to capture.

Discussion

Comparisons of wild and hatchery juvenile sample numbers confirm that wild recruitment of Kootenai River white

sturgeon is very low. Relative catches of wild and hatchery juveniles and hatchery release numbers indicate that natural recruitment may be < 20 fish per year. These numbers are far too small to sustain a viable sturgeon population and thus highlight the continuing importance of the conservation hatchery program.

Recapture data from the monitoring program indicates that after an initial adjustment period of 1-3 years, most juvenile white sturgeon released from the hatchery are successfully adapting to natural conditions. The survival rate analysis was not definitive but did suggest that annual survival rates of juvenile hatchery fish were high. Using MLE methods, we estimated that initial survival may approach 60% and survival during subsequent years may approach 90%. Multiple mark-recapture models appeared to provide robust estimates of survival and recapture rates in the Kootenai hatchery evaluation where recapture numbers were small but data were available for many years and release groups.

Survival rates based on catch curves may be biased by gear selectivity for larger fish and should be interpreted with caution. For instance, the 145% survival rate produced by the catch curve analysis for the 95/97 spring release group may reflect the ascending limb of the catch curve as fish were recruited to size-selective gillnets. Catch per unit effort of these fish apparently increased as fish grew into the catchable size range of the gillnets. Obvious descending limbs in catch curves for other release groups could indicate that other groups were less affected by gear vulnerability because of larger sizes at release and longer-periods-at-large.

Survival rates of hatchery white sturgeon were similar to the few available estimates for wild populations. Beamesderfer et al. (1995) estimated annual survival rates for ages 5-10 at 76% in Bonneville Reservoir and 82% in The Dalles Reservoir, although these estimates may include incidental handling mortality in sport and commercial fisheries. Annual survival rates were estimated at 87% for fish 7-21 years of age in the Bliss to C. J. Strike reach of the Snake River (Lepla and Chandler 1997) and 87% for fish 6-13 years of age in the Hells Canyon Dam to Salmon River reach of the Snake River (Lepla et al. 2001). Rien and North (2002) estimated average survival rates of 80-99% between release and recapture of wild juvenile sturgeon transplanted into Columbia River reservoirs. Our estimates of survival rates of hatchery fish are substantially greater than rates of 50-80% per year assumed by Kincaid (1993) as the basis for release group sizes of hatchery fish in the Kootenai River.

Growth rates and condition factors within the first 1-3 years after release were often poor. However, highly variable growth rates and conditions factors suggest that adaptation is easier for some individuals than others. After several years at large, most of the fish that remain have shown significant growth in length and/or weight, and average condition also begins to increase. Fish that initially struggled may have adapted or may have died, leaving only the hardy survivors. Comparisons of size and condition at release of the fish that survived to be recaptured indicate that survival during the first 1-3 years was independent of differences in size or condition at release within a release group: Thus, how well fish performed in the hatchery did not appear strongly related to how well they survived in the wild.

While survival rates of Kootenai hatchery sturgeon may be comparable with those observed in wild populations throughout the basin, growth rates and condition factors were

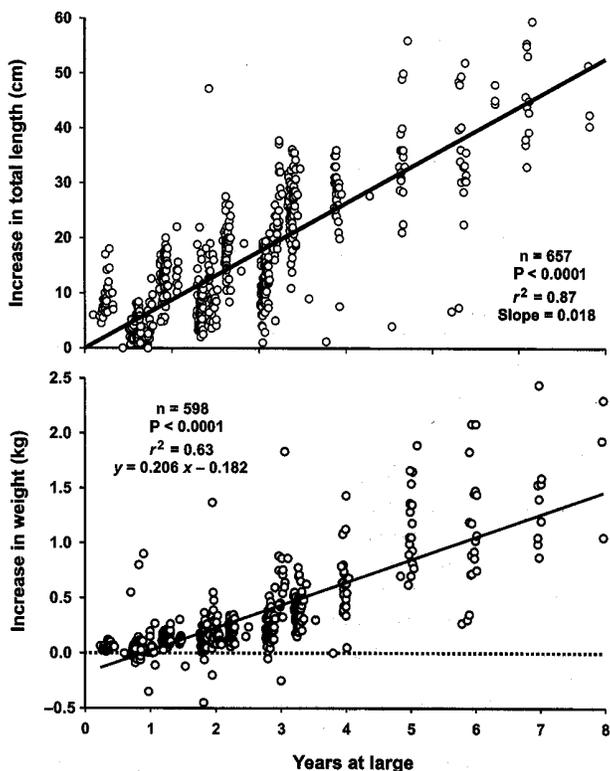


Fig. 4. Growth increment and weight change between release and recapture (all release groups pooled)

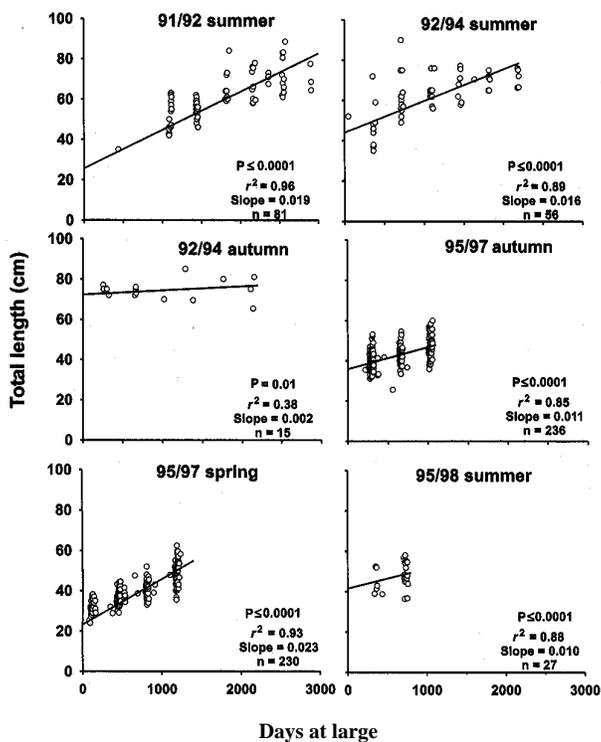


Fig. 5. Size of *Acipenser transmontanus* at recapture vs days since release by hatchery release group with regression results based on growth increment between release and recapture. Slope corresponds to average daily growth rate

generally lower than averages for other populations. The mean annual growth increment for hatchery release groups was slightly less than the median rate for 16 samples from wild sturgeon populations in California, Oregon, Washington, Idaho, and British Columbia (Fig. 7), although this comparison is somewhat confounded by interactions of size and growth rate. For instance, the lowest growth rate among hatchery releases groups was for the release group with the largest size at release. The average annual growth increment for juvenile hatchery fish (6.4 cm year^{-1}) was also greater than the average annual increment for wild Kootenai River sturgeon (4.6 cm year^{-1}) reported by Partridge (1983), although it is unclear as to what extent Kootenai hatchery and wild differences may have resulted from different estimation methods (direct mark-recapture estimates vs average length at age from fin rays), sample years (1990-99 vs 1977-82), or different ages of juvenile fish included in the sample (predominately age-5 or younger vs predominately age 5-10). Based on reported difficulties in aging slow-growing white sturgeon (Rien and Beamesderfer 1994), we suspect ages from fin rays are likely to be underestimates. If so, corresponding growth rates from fin rays are overestimated and hatchery fish are growing at a substantially greater rate than has been reported for larger, older wild Kootenai River sturgeon in the recent past (Paragamian et al. 1998).

Similar patterns of low growth rate and poor relative weight have also been observed for other headwater populations in the upper Columbia, Snake, and Fraser rivers. This pattern may reflect the colder temperatures, lower productivity, and a lack of anadromous food resources. It remains unclear what effect sturgeon density might have on survival, growth, and condition in the Kootenai River. Our data shows no obvious

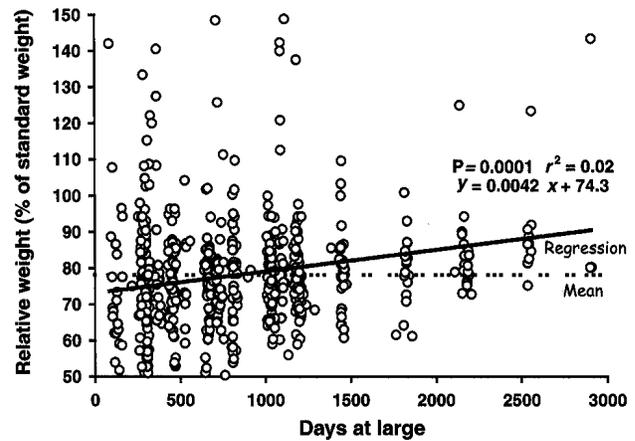


Fig. 6. Relative weight vs the time interval between release and recapture (all release groups pooled). Relative weight is an index of condition factor based on observed weight expressed as a percent of a standard weight for a fish of that size. Standard weight has been defined based on the 75th percentile of weights for other sturgeon populations throughout their range to represent an optimum management goal

reductions in survival, growth, or condition with releases to date. These initial results will provide a baseline for comparison with the results of future monitoring. If competition begins to reduce food availability, we might expect to see declines in growth and condition with increasing density. Increased competition might also stimulate increased emigration from the Kootenai River downstream into Kootenay Lake habitats, therefore future evaluation should also consider changes in distribution patterns. Competition might also compromise growth and condition of wild juvenile white sturgeon.

No obvious patterns in survival or growth of juveniles could be related to size or time of release, although initial releases were not designed to provide this information. Substantial differences in survival, growth, and condition were observed among release groups but comparisons are hampered by small sample sizes for some groups as well as the lack of a replicated design. Future release strategies and production levels will afford the opportunity to identify beneficial rearing or release strategies using replicated release groups in a more formal experimental design.

During planning and development of the Kootenai sturgeon aquaculture program, a great deal of debate concerned appropriate stocking levels and the expected population response. The Kootenai River white sturgeon recovery plan recognized the considerable uncertainty in implementing a new program and included a detailed monitoring and evaluation component. Initial monitoring results reported in this paper provide the first indication of how well hatchery fish are adapting to the natural environment. Initial results are promising. Our analysis confirms that the hatchery produces juveniles that can succeed in the wild. Our data will also be useful for tuning release numbers and strategies consistent with program goals for the numbers of adults needed in the next generation.

Future evaluations will determine whether: (i) hatchery fish survive to sexual maturity in sufficient numbers to rebuild the natural age structure and provide the next generation of broodstock, (ii) the hatchery-reared population can successfully preserve life history and genetic characteristics of the wild

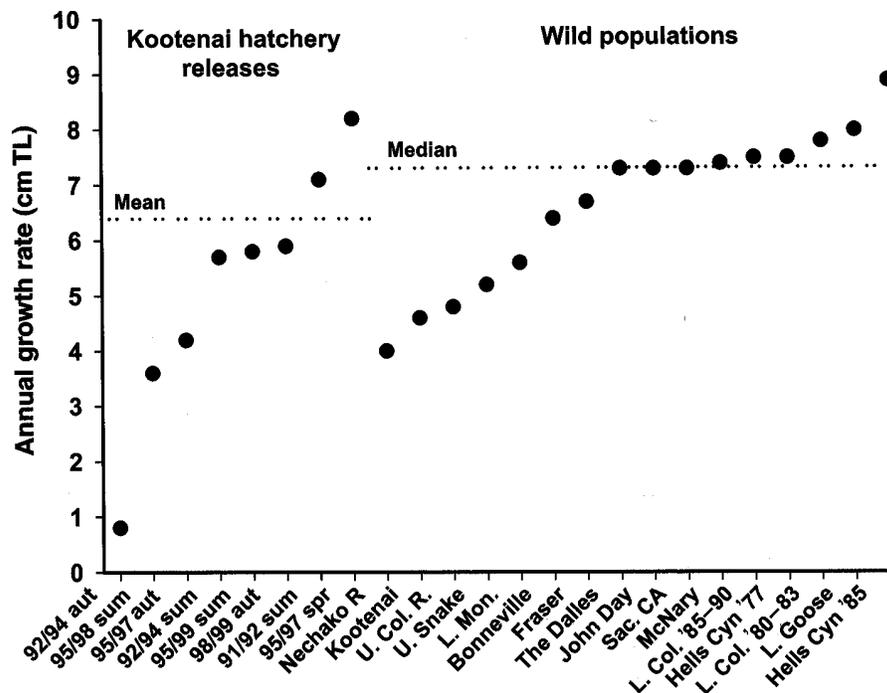


Fig. 7. Comparison of annual growth increments for juvenile white sturgeon (ages 10 and less) among Kootenai hatchery release groups and wild populations in the Fraser, Columbia, Snake, and San Joaquin rivers. Data for other populations from Semakula and Larkin (1968); Coon et al (1977), Kohlhorst et al (1980), Lukens (1982, 1985), Partridge (1983), Hess (1984), Dixon (1986), Beamesderfer et al (1995), North et al (1996), R. L. and L. Environmental Services (1996), and DeVore et al. (1999)

population, and (iii) hatchery fish can help identify critical habitats and conditions required for natural production. Monitoring and evaluation of hatchery program performance will be a long-term commitment because of the lengthy generation interval of the species. Because the Kootenai River drainage lies within Montana, Idaho, and British Columbia, effective monitoring, evaluation, and recovery efforts will also depend upon continued close cooperation and coordination among many researchers and agencies.

Acknowledgements

We thank Kim Apperson, Pat Marcuson, Gretchen Kruse, Genny Hoyle, and Vint Whitman of the Idaho Department of Fish and Game and the many biological aides for data collection and other project implementation efforts. We thank Robert Aitken, Ralph Bahe, Chris Lewandowski, Eric Wagner, Dennis David, Larry Aitken and Gary Aitken of the Kootenai Tribe of Idaho for their dedication and effort in rearing white sturgeon at the Kootenai Tribal Hatchery and assistance with data collection. We also acknowledge the cooperative efforts and sampling assistance from Joy Hammond, Colin Spence, Don Miller, and Les Fleck of the British Columbia Ministry of Environment. Ken Lepla and Tom Rien provided unpublished sturgeon data for purposes of comparison. The Bonneville Power Administration provided funding for this study. Dr. Harald Rosenthal and three anonymous reviewers provided comments that improved the quality of this manuscript.

References

- Anders, P. J., 1998: Conservation aquaculture and endangered species: Can objective science prevail over risk anxiety? *Fisheries* 23(11), 28-31.
- Anders, P. J.; Richards, D. L.; Powell, M. S., 2002: The first endangered white sturgeon population (*Acipenser transmontanus*): repercussions in an altered large river-floodplain ecosystem. *Am. Fish. Soc. Symp.* 28, 67-82.
- Apperson, K.; Anders, P. J., 1991: Kootenai River white sturgeon investigations and experimental culture. Idaho Dept. Fish and Game. Prepared for Bonneville Power Admin. Ann. Prog., Rep., Proj. 88-65, Boise ID, USA.
- Beamesderfer, R. C., 1993: A standard weight (Ws) equation for white sturgeon. *Calif. Fish and Game* 79(2), 63-69.
- Beamesderfer, R. C.; Rien, T. A.; Nigro, A. A., 1995: Differences in the dynamics and potential production of impounded and unimpounded white sturgeon populations in the lower Columbia River. *Trans. Am. Fish. Soc.* 124: 857-872.
- Brannon, E. L.; Currens, K. P.; Goodman, D.; Lichatowich, J. A.; McConnaha, W. E.; Riddell, B. E.; Williams, R. N., 1999: Review of artificial production of anadromous and resident fish in the Columbia River Basin, Part I: A Scientific Basis for Columbia River Production Program, Northwest Power Planning Council, 139 pp.
- Conte, F. S.; Doroshov, S. I.; Lutes, P. B.; Strange, M. E., 1988: Hatchery manual for tile white sturgeon (*Acipenser transmontanus*) with application to other North American Acipenseridae. Publ. 3322. Agriculture and National Research, Univ. California, Oakland.
- Cooch, E.; White, G., 2001: Using MARK - A Gentle Introduction, 2nd edn. Cornell Univ., New York, USA.
- Coon, J. C.; Rings, R. R.; Bjorn, T. C., 1977: Abundance, growth, distribution and movements of white sturgeon in the mid-Snake River. Idaho Water Resources Research Institute Research Technical Completion Report (Project B-026-IDA) to Off. Water Res. and Tech., Washington, D. C.
- Devore, J.; James, B.; Beamesderfer, R., 1999: Lower Columbia River white sturgeon current stock status and management implications. Oregon Department of Fish and Wildlife and Washington Department of Fish and Wildlife, Olympia, WA.
- Dixon, B. M., 1986: Age, growth and migration of white sturgeon in the Nechako and upper Fraser rivers of British Columbia. *Fish. Tech. Circ. No. 70*. Min. Environ., Fish. Branch, Prince George.
- Duke, S.; Anders, P.; Ennis, G.; Hallock, R.; Hammond, J.; Ireland, S.; Lauffle, J.; Lauzier, R.; Lockhard, L.; Marotz, B.; Paragamian, V. L.; Westerhof R., 1999: Recovery plan for Kootenai River white sturgeon (*Acipenser transmontanus*). *J. Appl. Ichthyol.* 15, 157-163.
- Evans, D. O.; Wilcox, C. C., 1991: Loss of exploited; indigenous populations of lake trout, *Salvelinus namaycush*, by stocking of non-native stocks. *Can. J. Fish. Aquat. Sci.* 48(Suppl. 1), 134-147.
- Fleming, I. A., 1994: Captive breeding and conservation of wild salmon populations. *Conserv. Biol.* 8(3), 886-888.

- Hess, S. S., 1984: Age and growth of white sturgeon in the lower Columbia River, 1980-83. Oregon Department of Fish and Wildlife, unpublished report.
- Hindar, K. N.; Ryman, N.; Utter F., 1991: Genetic effects of cultured fish on natural populations. *Can. J. Fish. Aquat. Sci.* 48(Suppl. 1), 124-133.
- Ireland, S. C.; Anders, P. J.; Siple, J. T., 2002: Conservation aquaculture: an adaptive approach to prevent extinction of an endangered white sturgeon population. *Am. Fish. Soc. Symp.* 28, 211-222.
- Kincaid, H., 1993: Breeding plan to preserve the genetic variability of the Kootenai River white sturgeon. U.S. Fish and Wildlife Service report (Proj. 93-27) to Bonneville Power Administration. Portland, USA.
- Kohlhorst, D. W.; Miller, L. W.; Orsi, J. J., 1980: Age and growth of white sturgeon collected in the Sacramento-San Joaquin estuary, California: 1965-1970 and 1973-1976. *Calif. Fish and Game* 66(2), 83-95.
- LaPatra, S. E.; Ireland, S. C.; Groff, J. M.; Clemens, K. M.; Siple, J. T., 1999: Adaptive disease management strategies for the endangered population of Kootenai River white sturgeon. *Fisheries* 24(5), 6-13.
- Lepla, K. B.; Chandler, J. A., 1997: Status of white sturgeon in the C. J. Strike Reach of the Middle Snake River, Idaho. Technical Report Appendix E.3.1-B to the C. J. Strike relicensing Application. Idaho Power Co., Boise, ID, USA.
- Lepla, K. B.; Chandler, J. A.; Bates, P., 2001: Status and habitat use of white sturgeon in the Hells Canyon Complex. Technical Report Appendix E.3.1-6 to the Hells Canyon Complex Relicensing Application. Idaho Power Co., Boise, ID, USA.
- Lukens, J. R., 1982: Status of white sturgeon populations in the Snake River, Bliss Dam to Givens Hot Springs. Idaho Department of Fish and Game Federation Aid to Fish and Wildlife Restoration Job Performance Report. F-73-R-4.
- Lukens, J. R., 1985: Hells Canyon White Sturgeon Investigations. Idaho Department of Fish and Game Federation for Aid in Fish Restoration Job Performance Report F-73-R-7.
- Murphy, B. R.; Willis, D. W.; Springer, T. A., 1991: The relative weight index in fisheries management: status and needs. *Fisheries* 16(2), 30-38.
- North, J. A.; Rien, T. A.; Farr, R. A., 1996: Report A. In: Effects of mitigative measures on productivity of white sturgeon populations in the Columbia River downstream from McNary Dam, and determine status and habitat requirements of white sturgeon populations in the Columbia and Snake rivers upstream from the McNary Dam, April 1994-March 1995. K. T. Beiningen (Ed.). Oregon Dept. Fish and Wildl. Ann. Prog. Rep. (Proj. 86-50) to Bonneville Power Admin, Portland. pp. 5-36.
- Northcote, T. C., 1973: Some impacts of man on Kootenay Lake and its salmonids. Great Lakes Fishery Community, Technical Report. Nr 2, Ann Arbor, Michigan..
- Paragamian, V. L.; Kruse, G.; Wakkinen, V., 1998: Kootenai River white sturgeon spawning and recruitment evaluation. Idaho Department of Fish and Wildlife Annual Program Report (Project 88-65) to Bonneville Power Admin, Portland, USA.
- Paragamian, V. L.; Kruse, G., 2001: Kootenai River white sturgeon spawning migration behavior and a predictive model. *No. Am. J. Fish. Manage.* 21, 10-21.
- Paragamian, V. L.; Kruse, G.; Wakkinen, V., 2001: Spawning habitat of Kootenai River white sturgeon, post-Libby Dam. *No. Am. J. Fish. Manage.* 21, 22-33.
- Partridge, F., 1983: Kootenai River fisheries investigations. Idaho Dept. Fish and Game Fed. Aid to Fish and Wildlife Research Job Completion Report. F-73-R-5.
- R. L. and L. Environmental Services Ltd., 1996: Columbia River white sturgeon investigations, 1996 study results. Rep. (97-CR515F) to B.C. Ministry of Environment, Lands, and Parks, Nelson Region.
- Ricker, W. E., 1975: Computation and interpretation of biological statistics of fish populations. *Bulletin Fisheries Research Board of Canada* 191.
- Rien, T. A.; Beamesderfer, R. C., 1994: Accuracy and precision of white sturgeon age estimates from pectoral fin rays. *Trans. Am. Fish. Soc.* 123, 255-265.
- Rien, T. A.; Beamesderfer, R. C.; Foster, C. F., 1994: Retention, recognition, and effects on survival of several tags and marks for white sturgeon. *Calif. Fish and Game* 80(4), 161-170.
- Rien, T. A.; North, J. A., 2002: White sturgeon transplants in the Columbia River. *Am. Fish. Soc. Symp.* 28, 223-236.
- Secor, D. H.; Anders, P. J.; Van Winkle, W.; Dixon, D. A., 2002: Can we study sturgeons to extinction? What we do and don't know about the conservation of North American sturgeons. *Am. Fish. Soc. Symp.* 28, 3-10.
- Semakula, S. N.; Larkin, P. A., 1968: Age, growth, food, and yield of the white sturgeon (*Acipenser transmontanus*) of the Fraser River, British Columbia. *J. Fish. Res. Board Can.* 25, 2589-2602.
- Smith, T. I. J., 1990: Culture of North American sturgeons for fishery enhancement. National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Services Technical Report 85.
- USFWS (U.S. Fish and Wildlife Service), 1999: Recovery plan for the Kootenai River population of the white sturgeon (*Acipenser transmontanus*). Portland, USA.
- Waples, R., 1991: Genetic interactions between hatchery and wild salmonids: lessons from the Pacific Northwest. *Can. J. Fish. and Aquat. Sci.* 48 (Suppl. 1), 124-133.
- White, G. C.; Burnham, K. P., 1997: Program MARK: Survival Estimation from Populations of Marked Animals. Colorado State Univ., Fort Collins, Co, USA

Author's address: Susan C. Ireland, Kootenai Tribe of Idaho, P.O.
Box 1269, Bonners Ferry, ID 83805, USA.
E-mail: Ireland@kootenai.org