Success of Hatchery-reared Juvenile White Sturgeon (Acipenser transmontanus) Following Release in the Kootenai River, Idaho

SUSAN C. IRELAND AND JOHN T. SIPLE
Kootenai Tribe of Idaho, P.O. Box 1269, Bonners Ferry, Idaho 83805

RAYMOND C. P. BEAMESDERFER
S. P. Cramer and Associates, Inc., 39330 Proctor Blvd., Sandy, Oregon 97055

VAUGHN L. PARAGAMIAN AND VIRGINIA D. WAKKINEN
Idaho Department of Fish and Game, 2750 Kathleen Ave., Coeur d'Alene, Idaho 83815

Abstract. — 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. Due a virtual lack of recruitment during the last 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 4-12 separate families per year of 4 to 10 adults per family at breeding age. We released 2,630 age 1-4 juvenile white sturgeon from 1992 through 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 analysis 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 and 0.206 kg/year. 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 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 to supplement natural spawning but are now 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 the natural population (Evans & Wilcox 1991; Hindar et al. 1991; Waples 1991; Fleming 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 about 10,000 years (Northcote 1973; Paragamian & Kruse 2001; Paragamian et al. 2001). Recruitment ceased after the completion of Libby Dam in 1972 (Anders et al. 2002). Now, the population consists of a dwindling number of adults that were listed as endangered under the U. S. Endangered Species Act on September 6, 1994. Efforts to stimulate natural recruitment with flow augmentation have failed (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 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, numbers of adult spawners are sufficient to produce recruitment that maintains the population size and age distribution at a stable level, habitat improvements are sufficient to allow natural spawning to maintain the population in the absence of hatchery supplementation, and 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 & 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). Since the remaining population is small and food resources may be limited, the initial objectives of the hatchery program are to produce 4-12 separate families per year and 4 to 10 adults per family that survive to breeding age (Kincaid 1993). The stocking goal is currently 1,000 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: 1) it's ability to collect and spawn wild broodstock and to rear juvenile fish for release; 2) successful adaptation of hatchery fish released into the wild; 3) survival of hatchery fish to sexual maturity in sufficient numbers to rebuild the natural age structure and provide the next generation of broodstock; 4) retention of wild sturgeon life history characteristics and genetics in the hatchery reared population; and 5) 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.

Material and Methods

Hatchery Releases.— Small groups of juvenile white sturgeon produced from wild broodstock and reared in the hatchery for 1 to 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 a effective long-term mark that can be applied with little impact to 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 (FIGURE 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 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 where spring was March-May, summer was June-August, and fall was September-November.

Survival Rates. — Annual survival rate of each released group was estimated using 1) maximum likelihood estimators (MLE) and 2) 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:

$$\boldsymbol{R}(\mathrm{t}) = f\,[\boldsymbol{N}(\mathrm{t}), \boldsymbol{\emptyset}(\mathrm{t}), \boldsymbol{p}(\mathrm{t})]$$

where

R(t) = Number of recaptures from cohort c in period t,

N(t) = Number of marked fish released from cohort c,

Ø(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 [***Ø***(t)] and recapture rates [***p***(t)] with survival [***Ø.***] 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 curves 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 (A) 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.

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 nonparametric 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 (Wr). 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 2,630 hatchery-reared juvenile white sturgeon from 1992 through 1999 (Table 1). Release numbers by year class ranged from 13 fish of the 1990 year class in 1992 to the release of 1,075 fish of the 1995 year class in 1997. Sampling effort with gillnets included a total 237 hours in 1993 and 1994 and totals of 277, 443, 535, 593, and 343 h for 1995 through 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% to 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 rate was observed for the oldest release group 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 through 1999 in contrast to 620 hatchery recaptures.

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 [$\boldsymbol{\emptyset}$(t), $\boldsymbol{p}$(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% (FIGURE 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% (FIGURE 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 the result of increasing catchability with size for the 95/97 spring release 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 fall 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 (FIGURE 4). Average growth increments for all recaptured hatchery fish were estimated at 0.0176 cm/d and 6.4 cm/yr based on a regression of growth increment versus days-at-large with the y-intercept forced through 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 three years varied from near zero to 40 cm.

Average growth rates varied from 0.002 to 0.023 cm/d (0.8 to 8.4 cm/yr) among different release groups (FIGURE 5). Non-parametric Kruskal-Wallis tests indicated 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 based on the slope of a regression of change in weight between release and recapture versus days at large (FIGURE 4). Wide individual variation in weight change was apparent with weight increasing little or decreasing among many fish recaptured within two years of release. The rate of increase in fish weight increased with 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/yr to 0.268 kg/yr (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 differences among release groups of hatchery fish were significant (p<0.0001).

Relative Weight

Relative weight at recapture averaged 78% of standard weight for all release groups and generally increased with period at large (FIGURE 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 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 larger for fish at-large for longer periods because they represent only those fish that have 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 of 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 less than 20 fish per year. These numbers are far too small to sustain a viable sturgeon population and highlight the continuing importance of the conservation hatchery program.

Recapture data from the monitoring program indicates that after an initial adjustment period of 1 to 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 to 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 & 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 & 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 to those observed in wild populations throughout the basin, growth rates and condition factors were 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 (FIGURE 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/yr) was also greater than the average annual increment for wild Kootenai River sturgeon (4.6 cm/yr) reported by Partridge (1983) although it is unclear 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 & 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 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, so 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 and 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 has concerned appropriate stocking levels and the expected population response. The Kootenai River white sturgeon recovery plans 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 numbers of adults needed in the next generation.

Future evaluations will determine whether: 1) hatchery fish survive to sexual maturity in sufficient numbers to rebuild the natural age structure and provide the next generation of broodstock, 2) the hatchery-reared population can successfully preserve life history and genetic characteristics of the wild population; and 3) 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 long 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.

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List of Tables

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Table 1

Year	Release				Number recaptured[1]									Avg.	Indiv.	Growth[5]		Relative weight[6]	
Class	Year	Period	Number	Size[2]	1993	1994	1995	1996	1997	1998	1999	2000	Total	rate[3]	recap.[4]	(cm/yr)	(kg/yr)	Rel.	Recap
1990	1992	Sum	13	45				2		1	1		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	Fall	10	72			4	4	1	2	1	2	14	23.3%	80%	0.8	-0.005	78	83
1995	1997	Spr	1,075	23					33	62	53	68	216	5.0%	18%	8.2	0.117	95	75
1995	1997	Fall	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	Fall	306	26								8	8	2.6%	3%	5.9	0.040	86	75
Totals			*2,630*	*--*	*1*	*1*	*26*	*42*	*55*	*185*	*140*	*170*	*620*	*9.7%*	*20%*	*6.4*[7]	*0.206*	*88*	*78*

[1] *Multiple recaptures not included within a year but are included among years.*

[2] *Mean total length in cm at release.*

[3] *Average annual recapture rate based on release number and years where available for recapture.*

[4] *Percentage of release group recaptured at least once.*

[5] *Based on regression slopes for 1992-1998 release groups where regression was significant ($p<0.05$) and individual fish averages for 1999 release groups.*

[6] *Index of condition factor expressed as percent of a standard weight identified as optimum for white sturgeon (Beamesderfer 1993).*

[7] *Based on regression slope of all recaptures pooled.*

Table 2

Model	Rank in Fit	AICc[1]	No. parameters	Deviance
Ø(t = 1 or 1+), ***p***(t)	1	4081	10	125
Ø(t), ***p***(t)	2	4108	15	142
Ø(.), ***p***(t)	3	4110	9	156
Ø(t), ***p***(.)	4	4165	9	211
Ø(.), ***p***(.)	5	4170	2	230

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

Figure 1

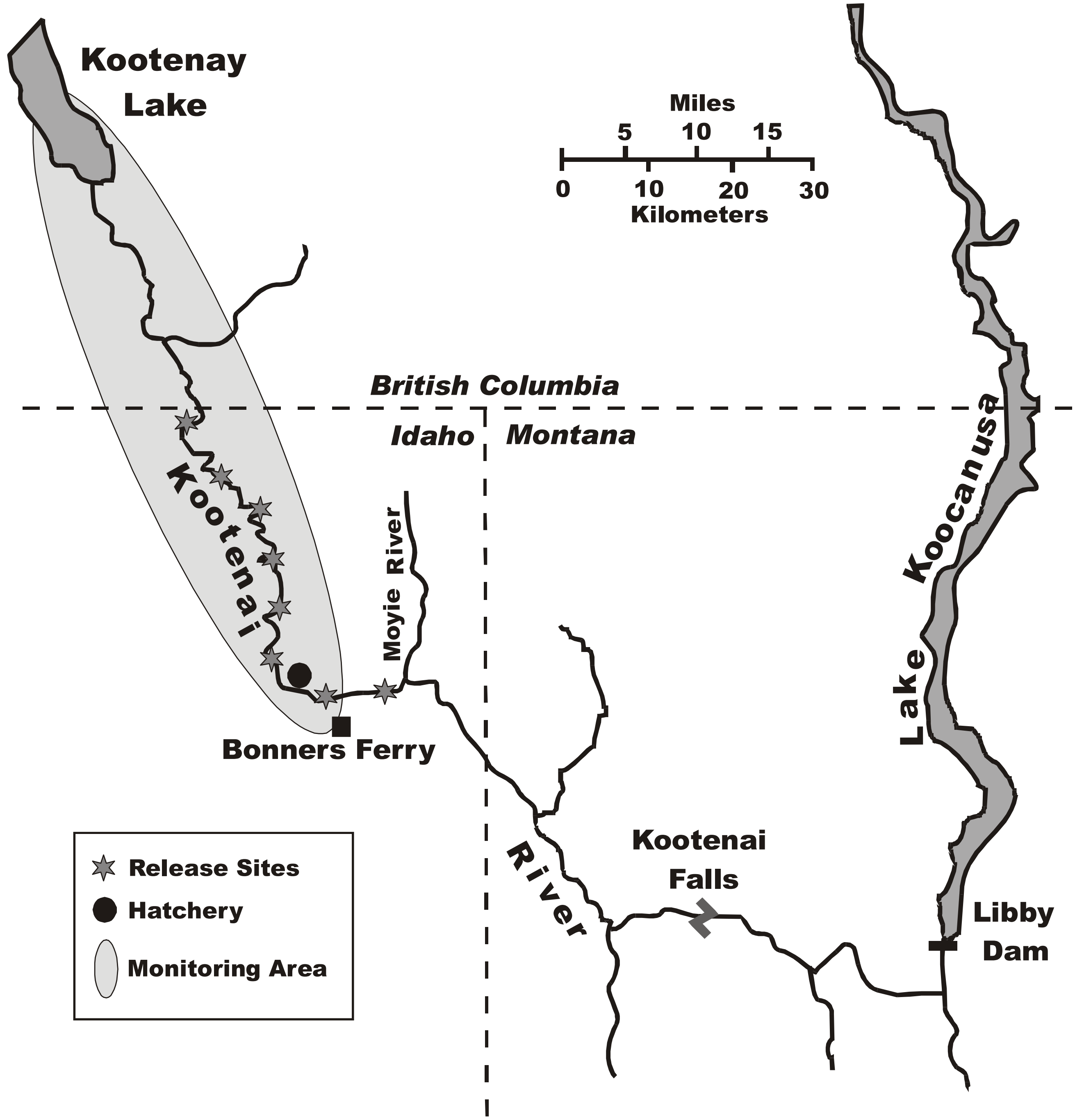
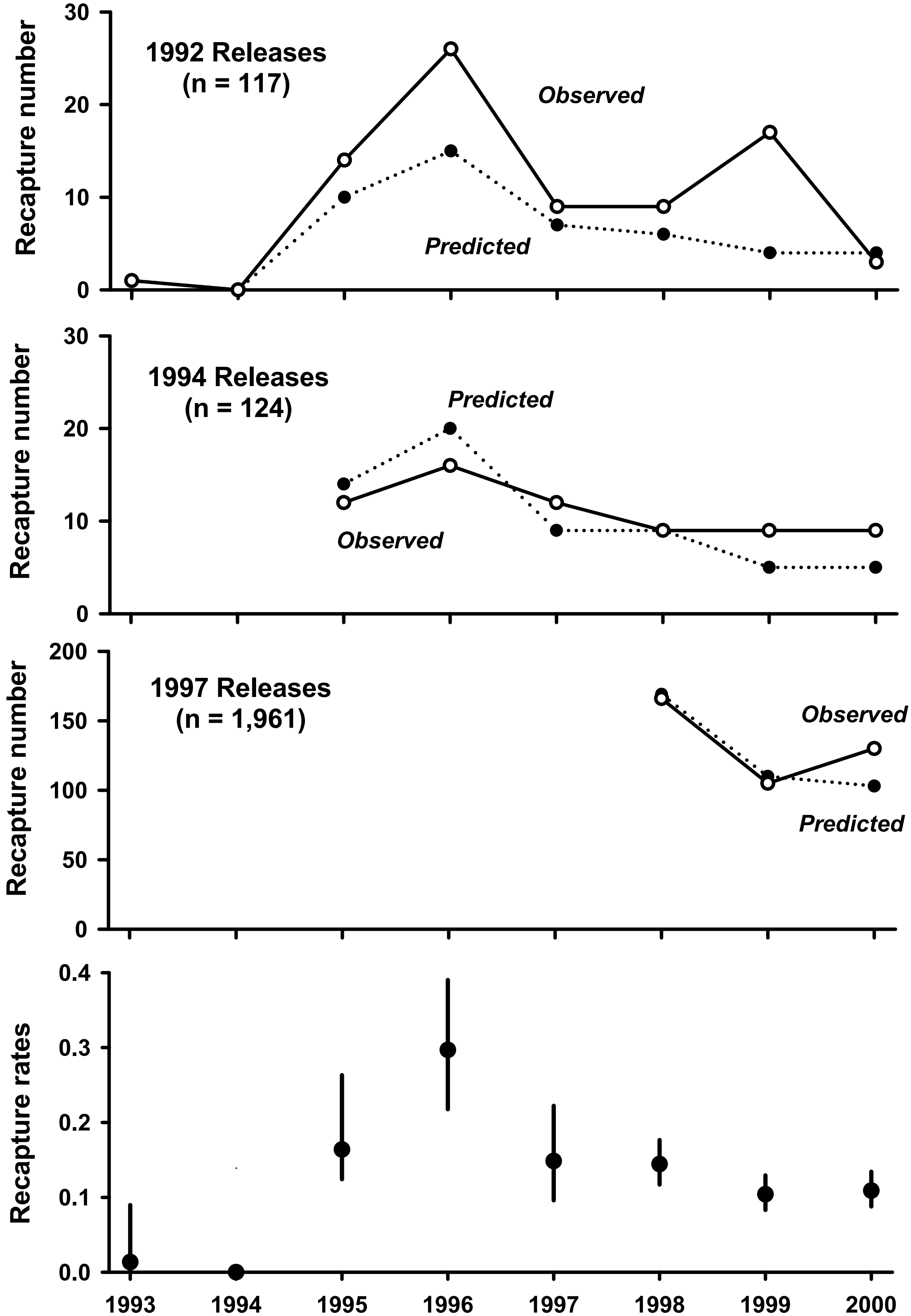
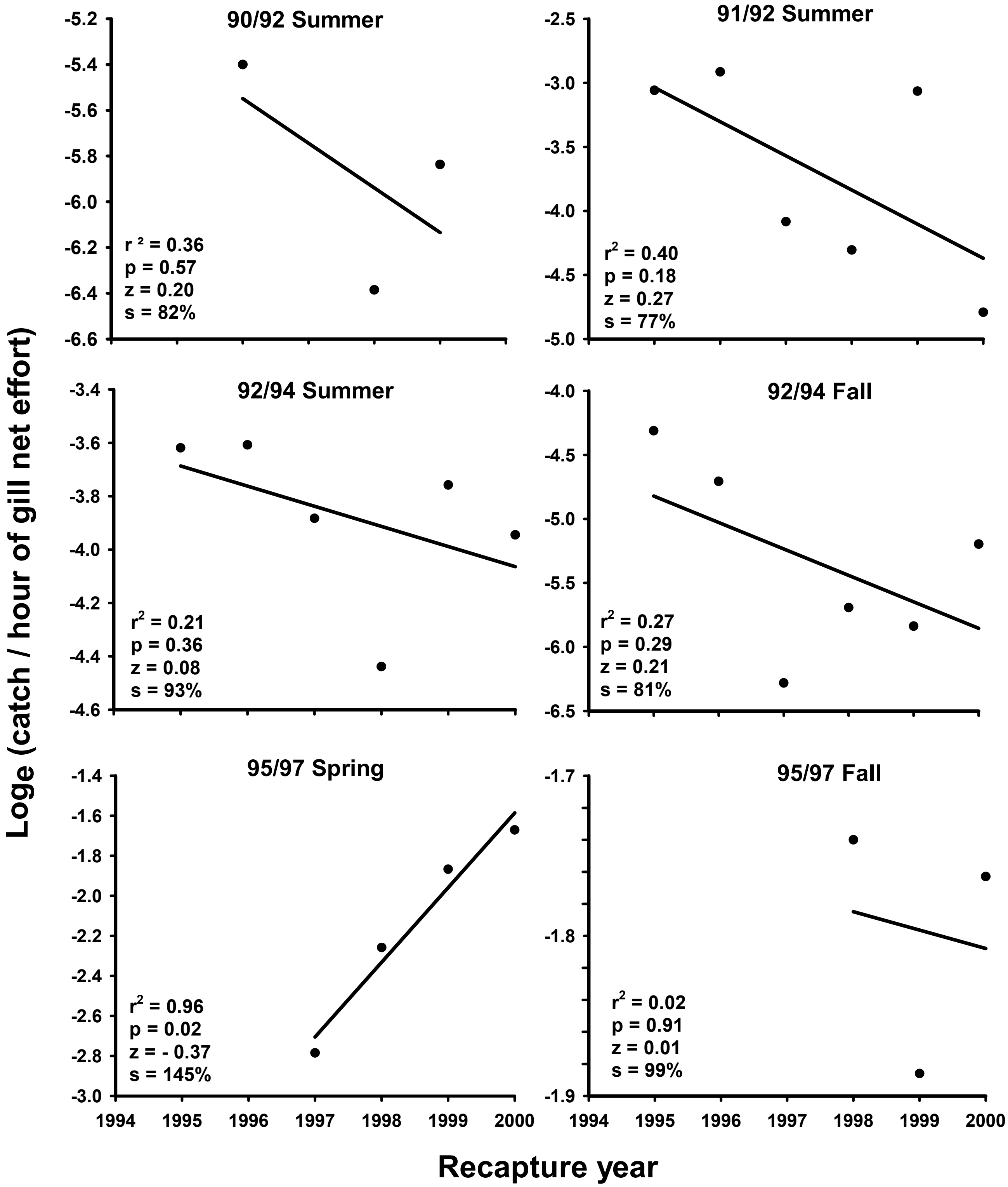

Kootenay
Lake
Miles
5
10
15
0
10
20
30
Kilometers
British Columbia
Idaho
Montana
Kootenai
Moyie River
Bonners Ferry
Release Sites
Hatchery
Monitoring Area
River
Kootenai
Falls
Lake Koocanusa
Libby
Dam

Figure 2



1992 Releases
(n = 117)
Observed
Predicted
Recapture number
30
20
10
0
1994 Releases
(n = 124)
Predicted
Observed
Recapture number
1997 Releases
(n = 1,961)
Observed
Predicted
Recapture number
200
150
100
50
Recapture rates
0.4
0.3
0.2
0.1
0.0
1993
1994
1995
1996
1997
1998
1999
2000

Figure 3



Loge (catch / hour of gill net effort)
90/92 Summer
r ² = 0.36
p = 0.57
z = 0.20
s = 82%
91/92 Summer
r² = 0.40
p = 0.18
z = 0.27
s = 77%
92/94 Summer
r² = 0.21
p = 0.36
z = 0.08
s = 93%
92/94 Fall
r² = 0.27
p = 0.29
z = 0.21
s = 81%
95/97 Spring
r² = 0.96
p = 0.02
z = - 0.37
s = 145%
95/97 Fall
r² = 0.02
p = 0.91
z = 0.01
s = 99%
Recapture year

Figure 4

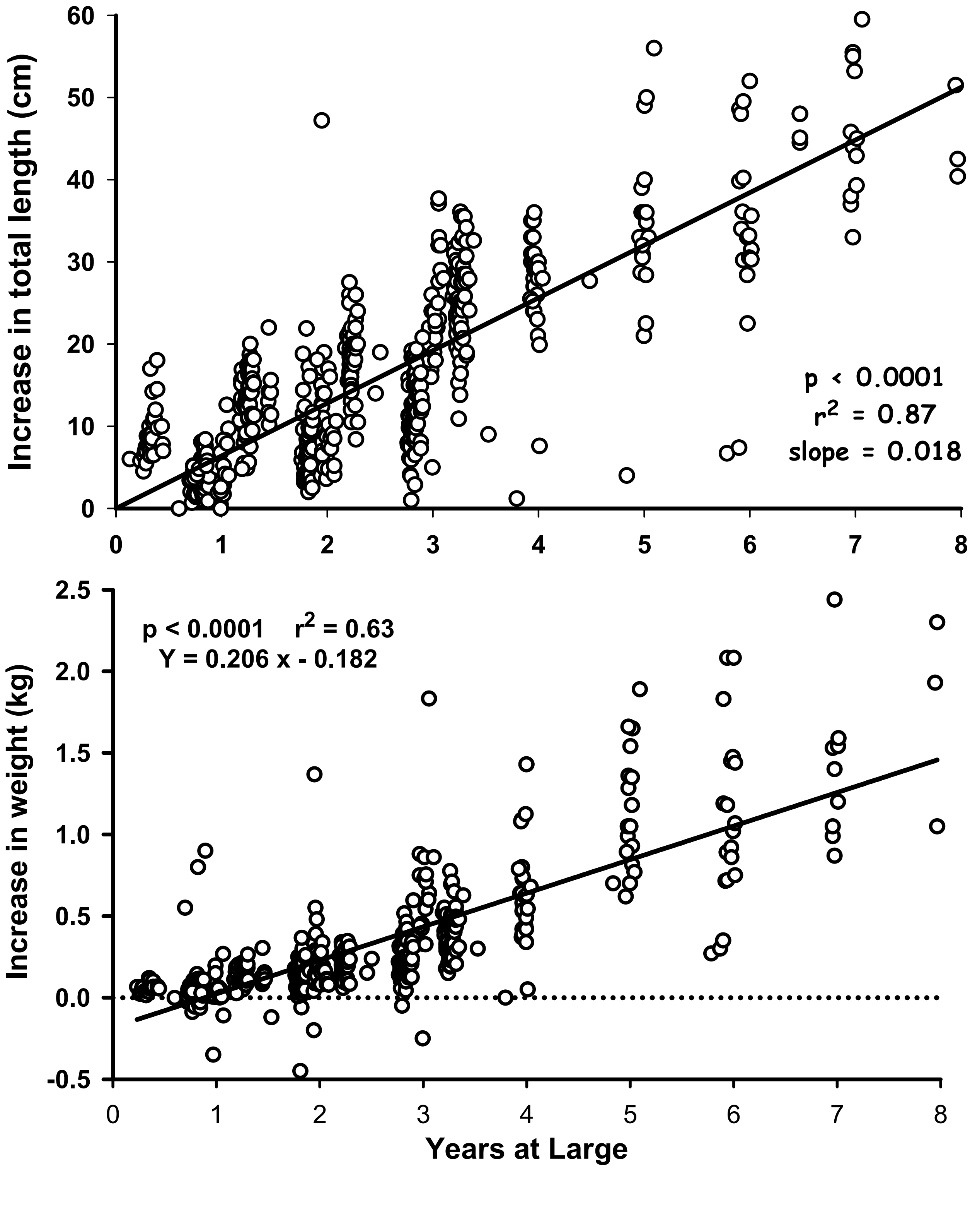
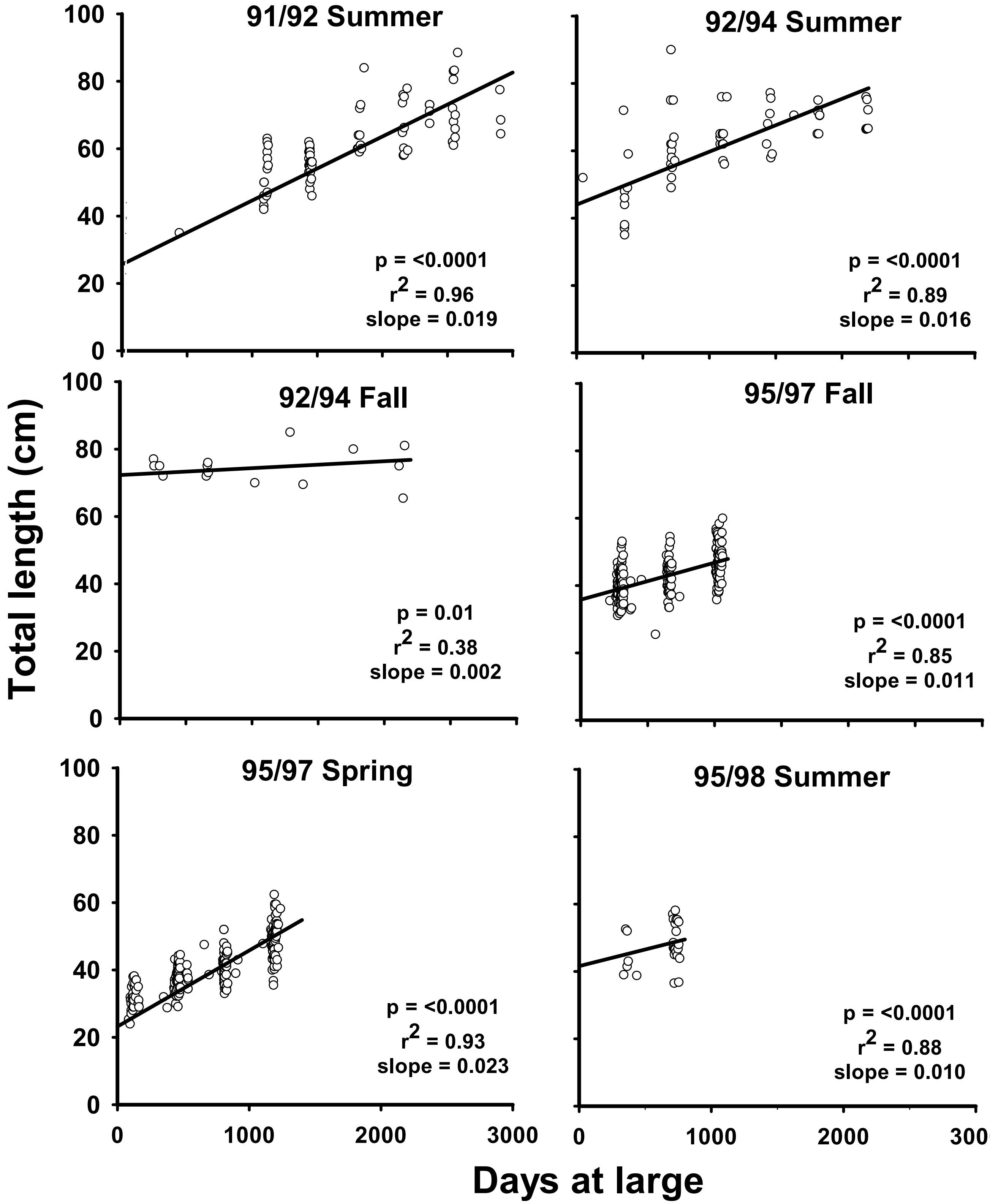
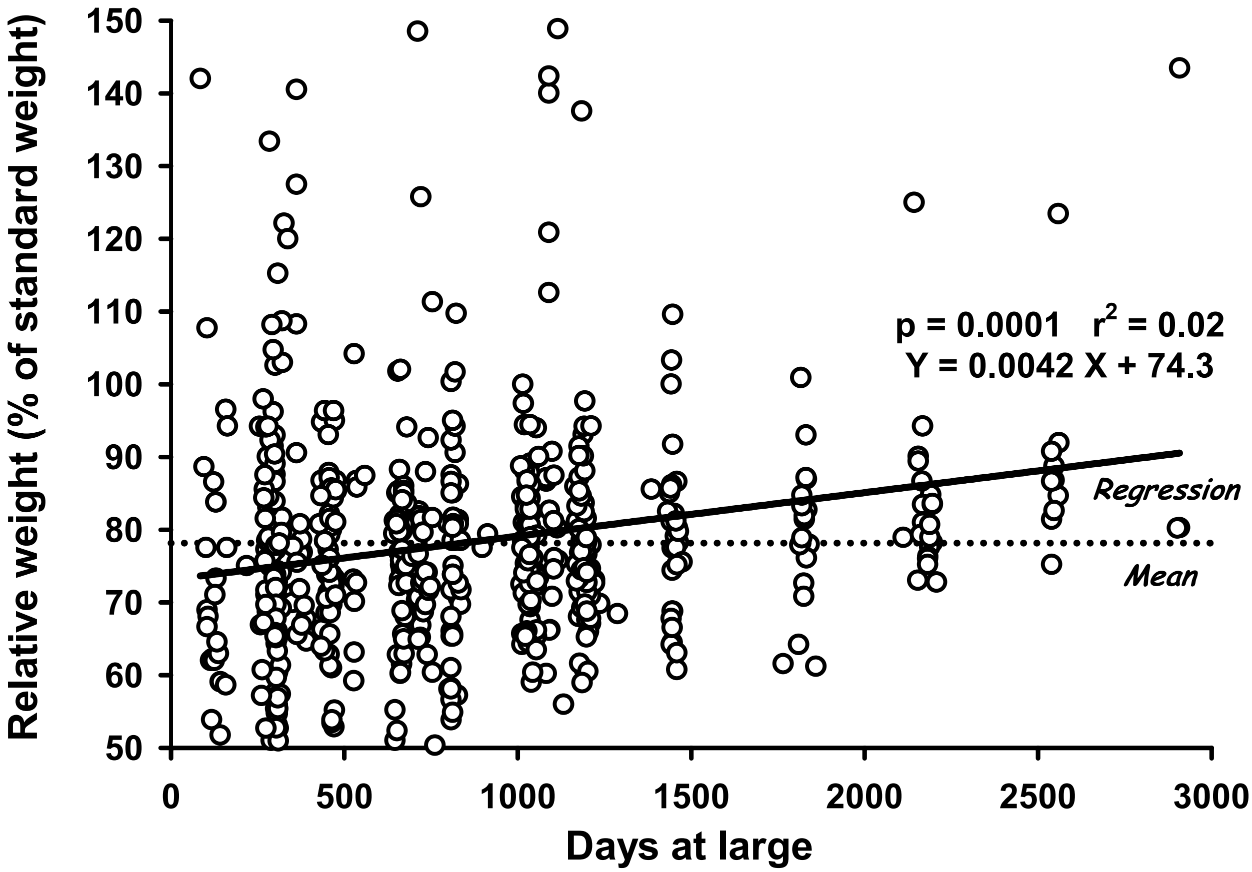

Increase in total length (cm)
p < 0.0001
r2 = 0.87
slope = 0.018
Increase in weight (kg)
p < 0.0001 r2 = 0.63
Y = 0.206 x - 0.182
Years at Large

Figure 5



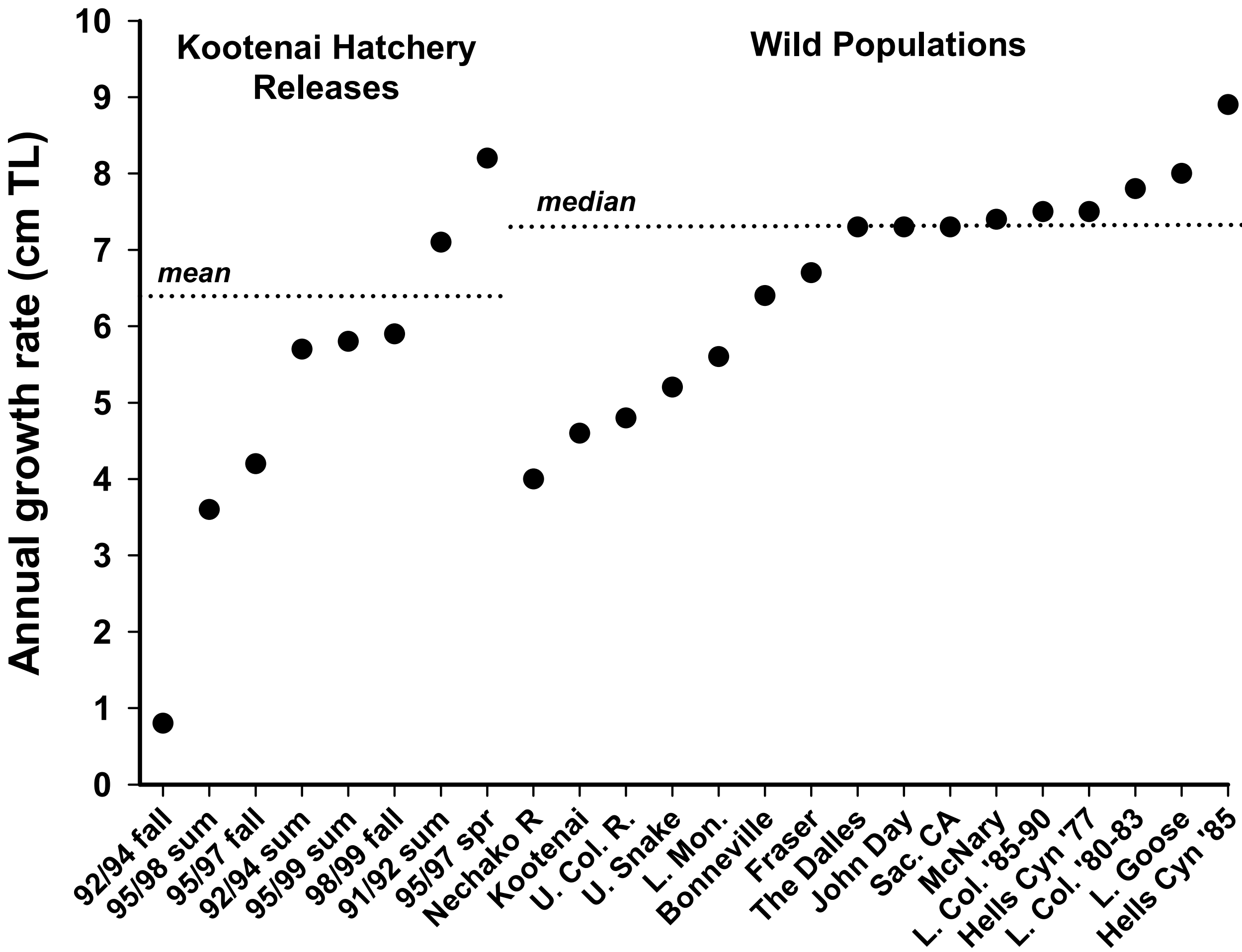
91/92 Summer
p = <0.0001
r2 = 0.96
slope = 0.019
92/94 Summer
p = <0.0001
r2 = 0.89
slope = 0.016
92/94 Fall
p = 0.01
r2 = 0.38
slope = 0.002
95/97 Fall
p = <0.0001
r2 = 0.85
slope = 0.011
95/97 Spring
p = <0.0001
r2 = 0.93
slope = 0.023
95/98 Summer
p = <0.0001
r2 = 0.88
slope = 0.010
Total length (cm)
Days at large
0
20
40
60
80
100
0
1000
2000
3000

Figure 6



p = 0.0001 r2 = 0.02
Y = 0.0042 X + 74.3
Regression
Mean
Relative weight (% of standard weight)
150
140
130
120
110
100
90
80
70
60
50
0
500
1000
1500
2000
2500
3000
Days at large

Figure 7



Kootenai Hatchery Releases
Wild Populations
Annual growth rate (cm TL)
mean
median
0
1
2
3
4
5
6
7
8
9
10
92/94 fall
95/98 sum
95/97 fall
92/94 sum
95/99 sum
98/99 fall
91/92 sum
95/97 spr
Nechako R
Kootenai
U. Col. R.
U. Snake
L. Mon.
Bonneville
Fraser
The Dalles
John Day
Sac. CA
McNary
L. Col. '85-90
Hells Cyn '77
L. Col. '80-83
L. Goose
Hells Cyn '85