# GRANDE RONDE BASIN SPRING CHINOOK SALMON CAPTIVE BROODSTOCK PROGRAM: $F_1$ GENERATION PERFORMANCE

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# INTRODUCTION

This paper summarizes a presentation given at the Lower Snake River Compensation Plan 2010 Spring Chinook Hatchery Program Review Symposium held on 30 November - 2 December 2010. This presentation provided background and history, along with preliminary results of data collected for monitoring the $F_1$ generation of the Grande Ronde Basin Spring Chinook Salmon Captive Broodstock Program and discussed three main topics:

1) Background - what got us here?
2) Captive Broodstock Rearing - basically, what worked and what didn't for rearing the salmon in captivity. This is a summary of important results pertaining to production parameters for the captive rearing phase of the Captive Broodstock Program. This phase lasts from parr collection through maturity and spawning.
3) Comparing the Captive Broodstock (CBS) Program with the Conventional Hatchery Program (CHP) and natural salmon – preliminary results regarding hatchery rearing to smolt and survival after release into nature.

# PROGRAM BACKGROUND

The Grande Ronde Basin of northeast Oregon historically supported multiple large populations of spring Chinook salmon *Oncorhynchus tshawytscha*, including Catherine Creek, the Lostine River and Upper Grande Ronde River populations. Annual escapement varied, however, there was a steady decline from 1960 through the mid-1990s, when populations reached severely low levels (Figure 1). Recreational fisheries were closed in 1974 and tribal fisheries were curtailed or closed, as well. Natural origin abundance declined to zero in the Upper Grande Ronde River in 1989 and in Catherine Creek in 1990. Natural escapement was less than 70 spawners for five of seven years (1989-1995) for the Lostine River.

This steady decline in Grande Ronde Basin spring Chinook salmon escapement necessitated hatchery intervention. The Lower Snake River Compensation Plan (LSRCP) was initiated in the late 1970s and hatchery programs began in Oregon in 1982. Initially, non-endemic Carson (BY 1982-1987) and Rapid River (BY 1986-1996) stocks were used for supplementation. However, neither stock performed well in the Grande Ronde Basin, having low survival and high stray rates. Snake River spring Chinook salmon were listed as threatened under the Endangered Species Act in 1992 and the last releases of these non-endemic stocks occurred in 2000 (1999 BY). Since the Grande Ronde Basin streams still had genetically distinct populations, the co-managers (Oregon Department of Fish and Wildlife, Confederated Tribes of the Umatilla Indian Reservation and Nez Perce Tribe) began to manage for naturally reproducing populations of native stocks. The Grande Ronde Basin Spring Chinook Salmon Captive Broodstock Program began in 1995 with the collection of 1994 brood year natural parr from each of the three program streams: Catherine Creek, Lostine River and Upper Grande Ronde River. Conventional Hatchery programs (collecting returning adults) have been operating continuously in the Lostine River since 2000 (starting in 1997 but skipping 1998 and 1999) and since 2001 in Catherine Creek and the Upper Grande Ronde River.

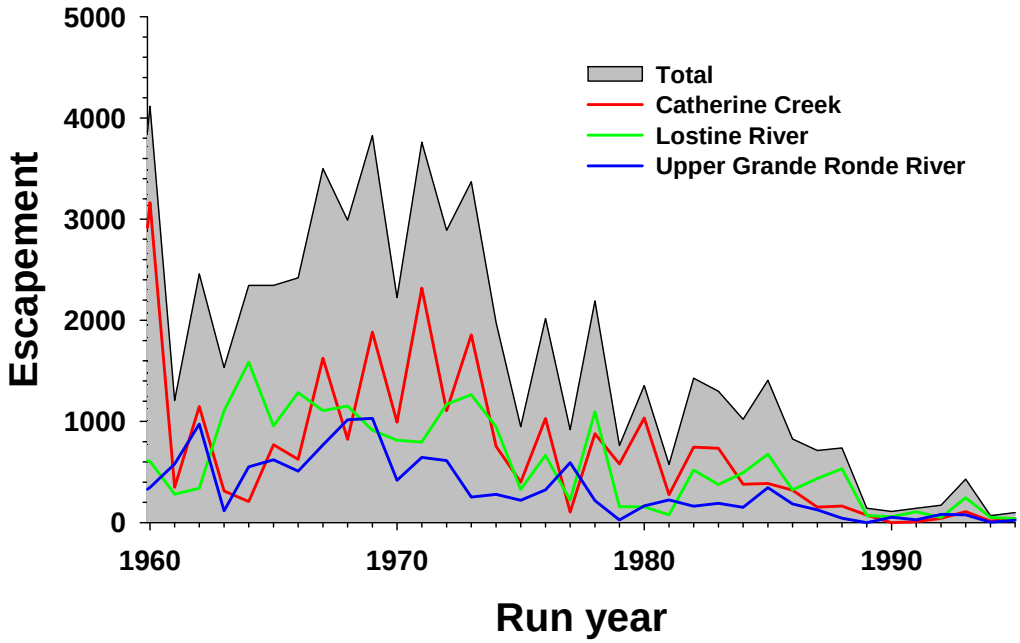


Figure 1. Natural Chinook salmon escapement to Catherine Creek, the Lostine River and Upper Grande Ronde River in northeast Oregon, 1960-1995.

The Oregon LSRCP Chinook salmon program has production goals and nine management objectives for the program populations in the Grande Ronde Basin to guide the program:

- Prevent extinction of Catherine Creek Chinook salmon population
- Establish adequate broodstock to meet annual production needs
- Establish an annual return of hatchery fish to the compensation area
- Provide a demographic foundation to rebuild from after the key limiting factors and threats are addressed
- Maintain and enhance natural production while maintaining long term fitness
- Maintain genetic and life history characteristics of the natural population
- Operate the hatchery program so that the genetic and life history characteristics of hatchery fish mimic wild fish
- Re-establish historical tribal and recreational fisheries
- Maintain endemic wild populations of spring Chinook salmon in the Minam and Wenaha rivers – minimize straying.

The CBS Program was designed to quickly increase total escapement, thereby increasing the total adults spawning in nature, by greatly increasing the survival advantage that hatchery fish possess over naturally produced salmon - even more so than for conventional hatchery programs. It does so by holding fish in captivity for just over one complete life cycle (parr of the $F_0$ generation through smolt of the $F_1$ generation), greatly reducing the smolt-to-adult mortality rate. The overall goal of the CBS program is to increase the number of natural origin adults returning to spawn in the target populations. Therefore, the success of the Program will be determined by changes in natural origin adult abundance (the $F_2$ generation).

The CBS program was integrated with LSRCP production. Eggs produced ($F_1$ generation) from the Captive Broodstock Program are incorporated into the LSRCP production, as needed. In the early years of the CBS, it comprised the entirety of the LSRCP smolt production. As the CHPs in these streams developed, CBS production became less important and these programs were mostly terminated. The last CBS spawn for the Catherine Creek and the Lostine River populations occurred in 2010 (BY 2005). The Upper Grande Ronde River population is the most severely depressed and its CBS Program is transitioning to a Safety Net Program, beginning with BY 2009. The final CBS spawn for the Upper Grande Ronde River will occur in 2013 (BY 2008). Thereafter, the Safety Net Program salmon will be spawned only when needed to supplement CHP production. Otherwise, the mature adults will be released into unseeded Upper Grande Ronde River tributaries to spawn naturally.

Like the LSRCP, the CBS Program has specific objectives aimed at the overall goal of restoring natural populations of Chinook salmon and minimizing impacts on wild populations:

- Prevent extinction of the native Catherine Creek, Lostine River and Upper Grande Ronde River Chinook salmon populations.
- Maintain genetic diversity of indigenous artificially propagated Chinook salmon populations.
- Maintain the genetic diversity in wild, endemic Chinook salmon populations in the Minam and Wenaha rivers.
- Provide a future basis and methodologies to reverse declines in stock abundance and ensure a high probability of population persistence until causes of population declines have been addressed.
- Establish an annual supply of spring Chinook salmon broodstock capable of meeting annual hatchery production goals.
- Restore and maintain naturally spawning populations of spring Chinook salmon.

The CBS Program is also an experimental program, with the charge of developing recommended strategies for future captive broodstock/rearing programs. As such, monitoring and evaluation are integral components with their own set of objectives:

- Monitor, assess and compare the effects of pre- and post-smolt rearing treatments.
- Develop and evaluate the effectiveness of innovative methodologies for rearing, spawning and disease treatment and prevention.
- Monitor and compare aspects of life history and production performance between Captive and Conventional broodstock programs.
- Monitor and assess the performance of captive broodstock offspring ($F_1$ generation) in captivity (pre-smolt) and in nature (post-smolt) and their offspring ($F_2$ generation).
- Assess our ability to achieve the genetic conservation goals and production benchmarks.
- Develop and maintain a comprehensive database for the program.

There are also specific experimental rearing, spawning and disease treatment/prevention strategies that were implemented and must be evaluated. Some of these evaluations (e.g., rearing regimes and spawning protocols) were part of the original program design, while others (e.g., disease treatment/prevention and early sex and maturation determination) were developed in response to issues that developed as the program developed.


Figure 2. Life history of Chinook salmon in the Grande Ronde Basin Spring Chinook Salmon Captive Broodstock Program.

Captive broodstock salmon were collected as natural parr from each of the populations and reared in captivity in separate tanks, for each stock and cohort, from collection through maturity (Figure 2). Rearing to smolt was conducted first at Lookingglass Hatchery and later at Wallowa Hatchery (Figure 3).

At smoltification, approximately half of the smolts were sent to Manchester Research Station (NOAA Fisheries), on Puget Sound, for rearing in saltwater and the other half to Bonneville Hatchery (ODFW) for freshwater rearing. Upon maturation, saltwater-reared salmon were transported to Bonneville Hatchery for spawning within stocks. The resulting offspring (incorporated into the LSRCP production) were reared to smoltification at Lookingglass Hatchery, at which time they were transported to acclimation sites on the natal streams of their parents. After a period of acclimation, they were released to complete their life cycles (including spawning) in nature – CBS salmon were visibly differentially marked so that they were not collected for broodstock upon their return.

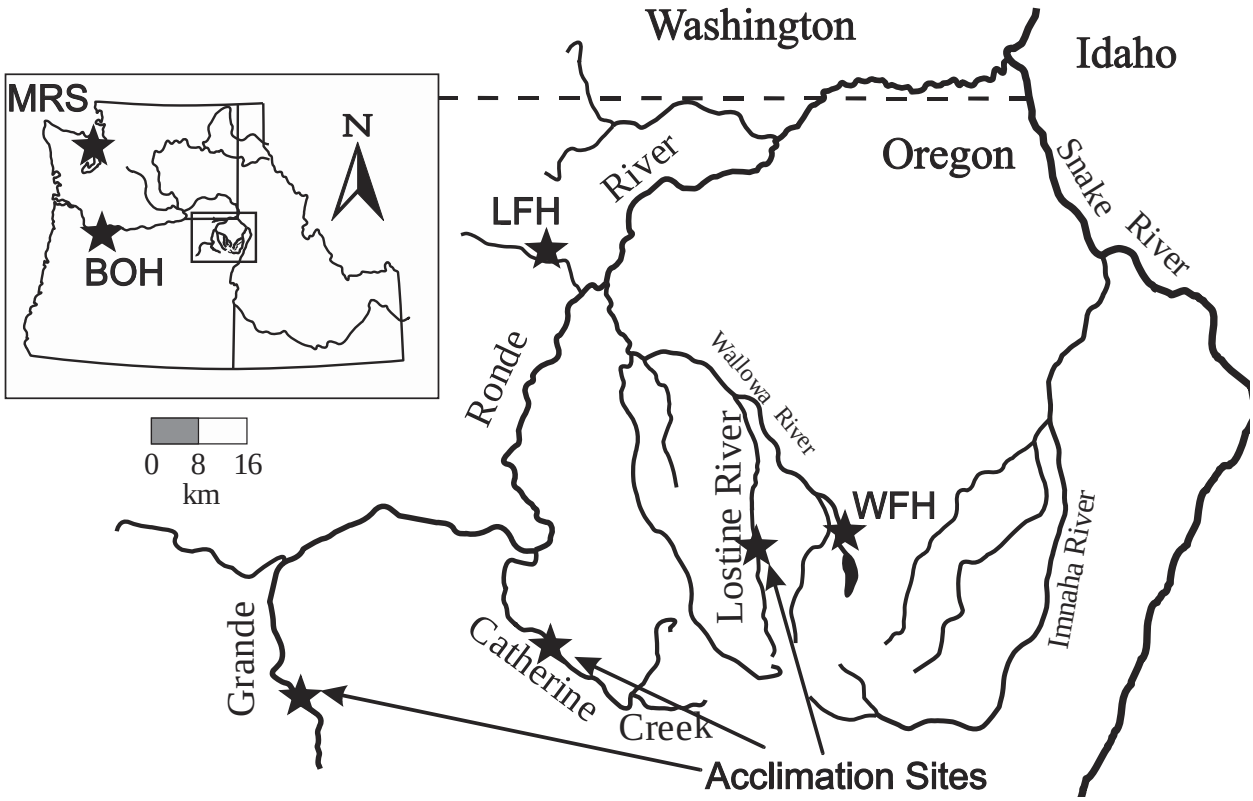


Figure 3. Program populations, hatcheries and acclimation sites used by the Grande Ronde Basin Spring Chinook Salmon Captive Broodstock Program. Note: LFH = Lookingglass Hatchery, WFH = Wallowa Hatchery, MRS = Manchester Research Station and BOH = Bonneville Hatchery.

## CAPTIVE BROODSTOCK RESULTS

The CBS had specific performance targets for the captive rearing phase of the program. These were developed based on assumptions that were made when the program was designed. Here, we assess program success by comparing actual performance with these performance targets.

We were generally able to collect the goal of 500 parr / stream / brood year, except for three years for the Upper Grande Ronde River (Table 1). In 1995 we were able to collect only 110 BY 1994 parr and were unable to collect any BY 1995 or BY 1999 parr in 1996 and 2000, respectively, due to extremely low abundance of natural spawners (20 and 4 salmon in 1995 and 1999, respectively). Our sex ratio was nearly 1F:1M, as expected. Growth was much slower than expected, with adults being approximately 35% smaller (at age) than naturally reared adults (the expected size). Survival was slightly better than expected, particularly from parr to smolt.

Males matured much earlier than expected, with 89% maturing at ages 2 or 3 and only 1% at age 5 (Table 2). Nearly all (88%) females matured at age 4, making their age composition much closer to that expected than the males. This actually worked well for the program, as it made it

Table 1. Assumptions/targets and results for captive rearing of the $F_0$ generation of the Grande Ronde Basin Spring Chinook Salmon Captive Broodstock Program.

| Parameter | | Assumption/target | Result |
|---|---|---|---|
| Parr collection | | 500 | Yes, except GR 1994, 1995 and 1999 |
| Sex ratio | | 1F:1M | 1F:1.08M |
| Growth | | Similar to natural | ~35% smaller |
| Survival | Parr-smolt | 90% | 97% |
| | Smolt-adult | 55% | 55% |
| | Parr-adult | 50% | 53% |

easy for us to avoid sibling mating. There was little overlap in spawn timing between the CBS and CHP or naturally spawning salmon. CBS spawn timing was about 3 weeks later than salmon in nature or in the CHP at Lookingglass Hatchery. Fecundity was less than half of that expected, due to the small size of the females. Approximately 20% (range: 0-77% for a given stock and spawn year) of all eggs collected were culled to prevent vertical transmission of bacterial kidney disease (BKD) – effective fecundity was 38% of expected.

Mean fertility (green egg-to-eyed egg survival) and eyed egg-to-smolt survival rates of the $F_1$ generation were higher than expected (Table 3). However, this was not enough to overcome low fecundity and eggs lost due to BKD culling. Mean smolt-to-adult return rate (SAR) was 0.35%, 250% higher than expected for the CBS Program (0.1%), but well below the Oregon LSRCP goal of 0.65%. Age composition of the $F_1$ generation was younger than expected, but typical for Northeast Oregon spring Chinook hatchery programs.

Table 2. Assumptions/targets and results for maturation and spawning of the $F_0$ generation of the Grande Ronde Basin Spring Chinook Salmon Captive Broodstock Program.

| | Age 2 | | Age 3 | | Age 4 | | Age 5 | |
|---|---|---|---|---|---|---|---|---|
| Sex | Target | Result | Target | Result | Target | Result | Target | Result |
| Females | 0% | 0% | 6% | 1% | 78% | 88% | 16% | 11% |
| Males | 2% | 20% | 35% | 69% | 48% | 10% | 15% | 1% |

| | Expected | Result |
|---|---|---|
| Spawn timing | ~ 15 August - 15 September | ~ 6 September - 21 October |

| Fecundity | Age 3 | Age 4 | Age 5 |
|---|---|---|---|
| Predicted | 1200 | 3000 | 4000 |
| Actual | 1232 | 1715 | 1588 |

Table 3. Assumptions/targets and results of the $F_1$ generation of the Grande Ronde Basin Spring Chinook Salmon Captive Broodstock Program.

| Parameter | | Target | Result |
|---|---|---|---|
| Fertility (green-to-eyed egg) | | 75% | 85% |
| Eyed egg-smolt survival | | 80% | 83% |
| Smolt production | | 150,000 | 78,720 |
| Return rate (SAR) | | 0.1% | 0.35% |
| | | Age at maturation | |
| Age Composition | Age 3 | Age 4 | Age 5 |
| Target | 10% | 60% | 30% |
| Result | 15% | 71% | 14% |

The CBS Program's annual smolt production goal was 150,000 smolts per population, which would result in a targeted return of 150 adults at an SAR of 0.1%. Actual smolt production was highly variable but seldom attained the goal of 150,000 smolts (Figure 4). This was mostly due to the lower than expected fecundity and the unexpectedly high rate of culling for BKD prevention. The Catherine Creek and Lostine River stocks had more consistent production than the Upper Grande Ronde River stock, which had the lowest and highest smolt production numbers. The first two production years for the Upper Grande Ronde River were very low due to few parr being collected for BY 1994 and none for BY 1995. After that, smolt production in the Upper Grande Ronde River varied from zero smolts in 2008 (BY 2006 – we had a large Conventional Hatchery Program production) to 210,637 smolts in 2003 (BY 2001) and 190,531 smolts in 2010 (BY 2008). In 2006, we released only 76 Upper Grande Ronde River CBS smolts because we euthanized the remaining 2000 brood year salmon in 2004 due to the development of oral tumors of an unknown cause.

The smolt-to-adult return rate for the CBS Program $F_1$ generation was generally above the expected rate of 0.1% (Figure 5). However, the numbers of smolts released were generally below the target of 150,000. susequently, adult escapement rarely exceeded the goal of 150 adults/stream.

As the Program progressed, issues arose that impeded our ability to reach our smolt production goals. To begin with, we were unable to collect 500 parr each year in the Upper Grande Ronde River, due to dramatically low escapement in several years. The salmon reared in saltwater were smaller at maturity than those reared in freshwater, which resulted in lower fecundity. We initially had a hard time detecting all maturing salmon during our spring sorting for maturing adults, leaving many salmon in saltwater longer than they would be naturally. Green egg-to-smolt survival for the CBS program was not as high as that of the CHP. We have also had the beneficial problem of smolt production in excess of the CBS target (150,000) in some years (Catherine Creek BY 200 and 2003; Upper Grande Ronde River BY 2001 and 2008). Bacterial kidney disease was the most pressing issue, as over half of all captive broodstock mortalities

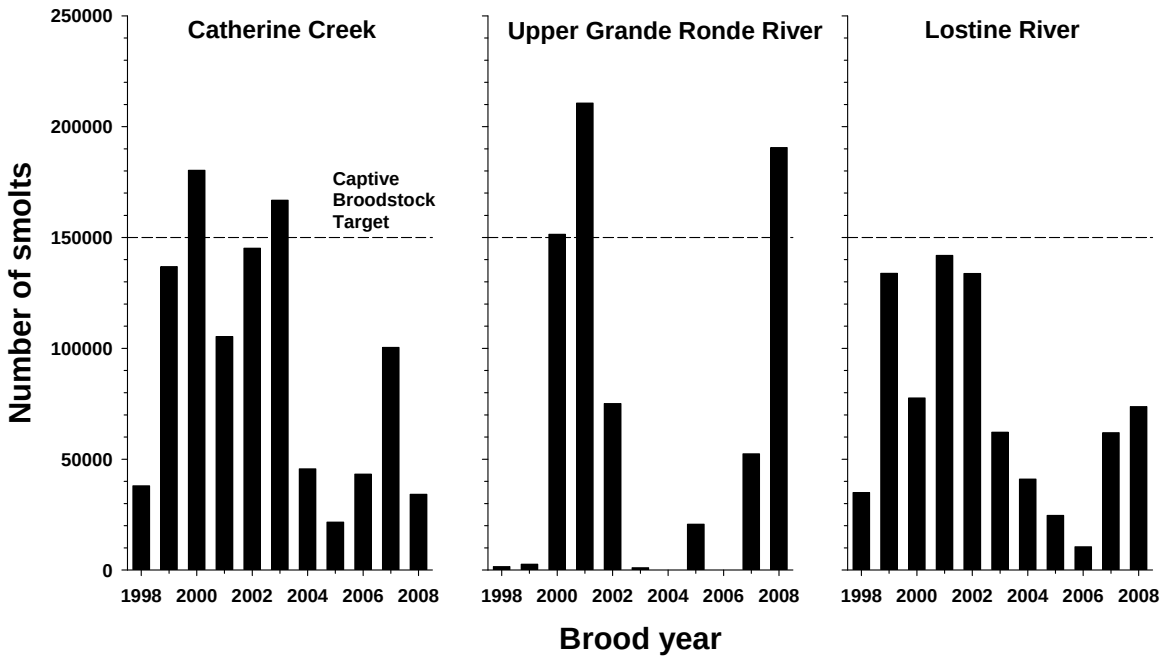


Figure 4. $F_1$ generation smolts released into Catherine Creek, the Upper Grande Ronde River and Lostine River from the Grande Ronde Basin Spring Chinook Salmon Captive Broodstock Program, 1998-2008 brood years.

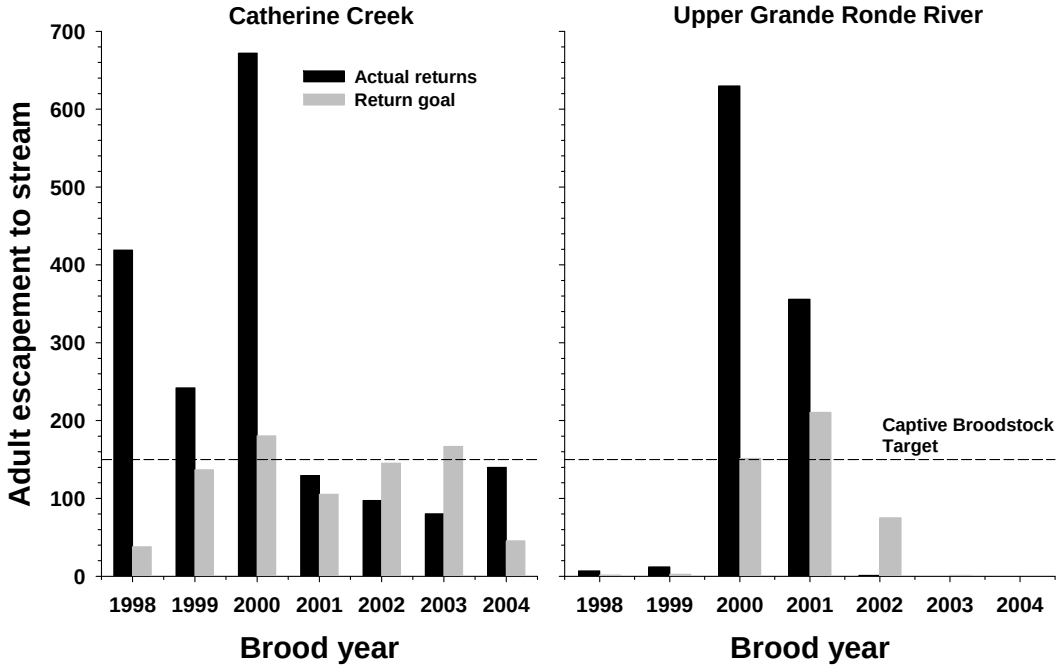


Figure 5. Escapement of $F_1$ generation Chinook salmon from the Grande Ronde Basin Spring Chinook Salmon Captive Broodstock Program to Catherine Creek and the Upper Grande Ronde River, 1998-2004 brood years.

were caused by BKD and up to 77% of the eggs collected for a given stock and spawn year were culled to prevent vertical transmission of the bacterium that causes BKD. We also found that the spawn timing of the CBS adults at Bonneville Hatchery was 3-4 weeks later than that of salmon spawning in nature or at Lookingglass Hatchery, which removed the option of releasing CBS adults into nature to spawn with naturally spawning salmon.

We have addressed and continue to address many of these issues. To improve our ability to detect maturing salmon (and thereby move them from saltwater to freshwater at a more natural time) and determine their sex, we tested both ultrasound and near infrared spectroscopy and found that ultrasound was the more practical method. When we had excess $F_1$ generation production from the CBS Program, we released them as eggs or as parr into pre-designated outlet streams (unseeded tributaries of their parents' natal stream). For BKD, we tested vaccines and drugs to prevent and treat the disease. We found that the vaccines did not work and the drugs were of limited use. Additionally, we are looking for new ways to detect BKD in salmon, before they exhibit externally visible symptoms, and from samples of raceway water, in order to treat them sooner and use fewer prophylactic drugs treatments. We are also testing new methods for the detection of BKD in adult salmon for predicting the likelihood of vertical transmission. This will reduce the rate of culling, as it appears that using the enzyme-linked immunosorbent assay for this purpose may have caused us to cull more eggs than were necessary. We suspect that the water temperature in Tanner Creek (the water source for the adult holding ponds at Bonneville Hatchery) did not get sufficiently cold at an early date (Tanner Creek is at least 1,000 m lower elevation) for the CBS salmon to ripen as early as they would in northeast Oregon.

## COMPARISONS OF CAPTIVE, CONVENTIONAL AND NATURAL SALMON

Here we compare the performance of the Captive Broodstock $F_1$ generation with that of the Conventional Hatchery Program and both groups of hatchery offspring with natural origin salmon, when data for natural salmon are available. We also evaluate whether the CBS Program met its $F_1$ generation goals and whether we met the LSRCP production and smolt-to-adult survival (SAR) goals.

Mean eyed egg-to-smolt survival of CBS salmon was 78%, below the CBS Program goal of 80% (Figure 6). Eyed egg-to-smolt survival for the CBS Program was also worse than that of the Conventional Hatchery Program, which achieved 96%. Mean eyed egg-to-smolt survival for both programs greatly exceeded that of natural salmon in these streams, which averages approximately 8% (ODFW Early Life History Project, unpublished data).

Smolt releases for the CBS Program rarely reached the CBS target of 150,000 smolts/stream and never reached the LSRCP release goal of 250,000 smolts (Figure 7). However, increased adult escapement, in part due to the CBS Program, allowed us to collect sufficient adults for the CHP. As a result, smolt release numbers have begun to achieve the target for each stream (the Catherine Creek LSRCP target was reduced to 150,000 in 2005) and are likely to continue achieving the release goal. The Lostine River program consistently approached the LSRCP production goal and will greatly exceed the LSRCP target for BY 2010 due to overcollection of adults for the CHP.

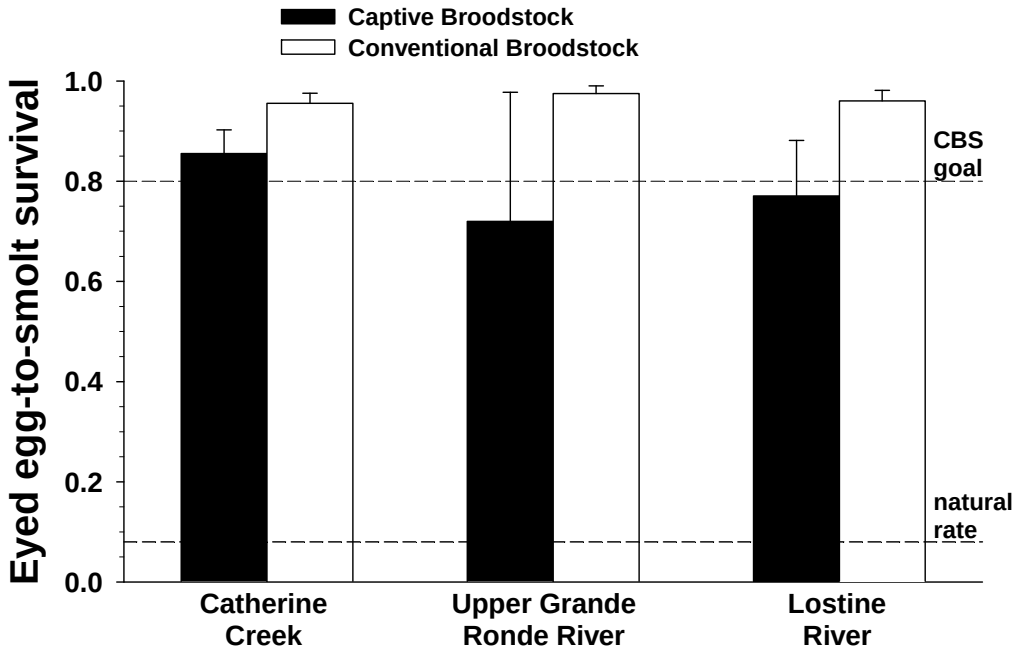


Figure 6. Mean (±1 SD) eyed egg-to-smolt survival for the $F_1$ generation of the Captive Broodstock Program and Conventional Hatchery Program in Catherine Creek, the Lostine River and Upper Grande Ronde River.

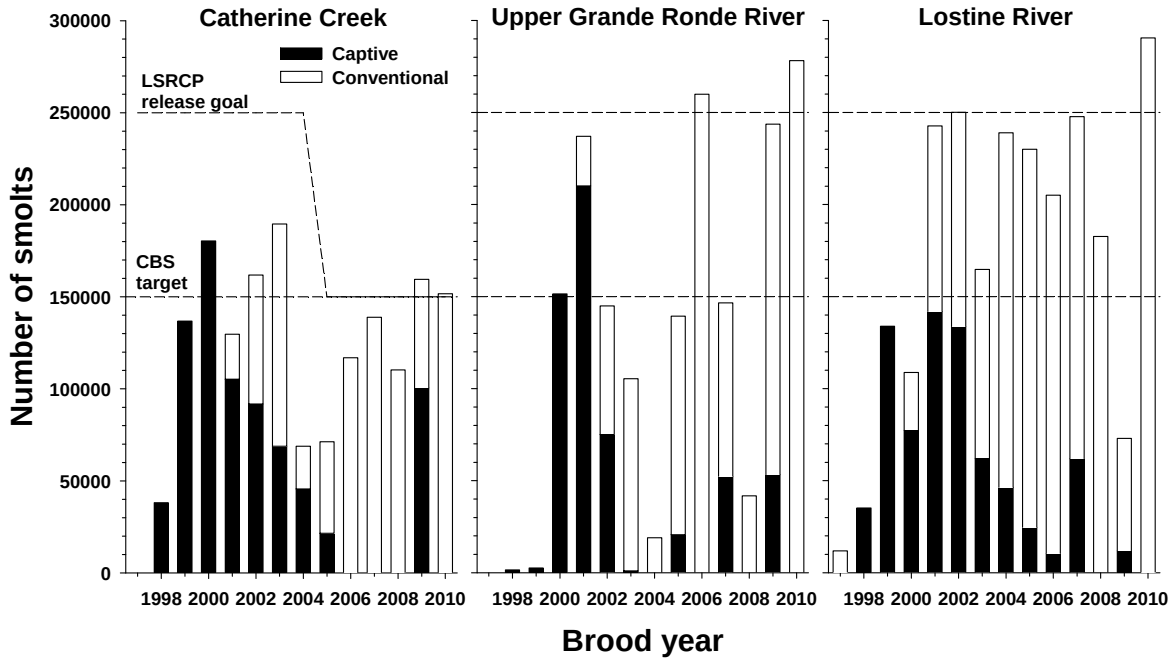


Figure 7. Number of $F_1$ smolts released from the Captive Broodstock and Conventional Hatchery programs into Catherine Creek and the Lostine and Upper Grande Ronde rivers, 1997-2010 brood years. Note: smolt numbers for the 2009 and 2010 brood years are estimates, based on parr and eggs, respectively, on hand as of November 2010.

We monitored downstream migration survival and timing of smolt using PIT tag detections at the outflow of the acclimation ponds and at Snake and Columbia river dams. Downstream migration survival to Lower Granite Dam was usually better for the CHP smolts than for CBS smolts but not significantly so (P=0.319; Figure 8). Natural smolts generally survived better than smolts from either hatchery program, but not significantly so (P=0.317).

We measured length of returning adults at weirs, at Lookingglass Hatchery and on spawning ground surveys. Size at maturity for the CBS $F_1$ generation and CHP salmon was similar to that of natural salmon for both sexes (Figure 9). The $F_1$ generation was much larger than their parents, which were reared from parr to adult in captivity. CBS parents were approximately 35% smaller and had less than half the fecundity of their offspring, which had their post-smolt rearing in nature. It seems that something integral is missing in the post-smolt captive rearing regime of the CBS Program.

The Upper Grande Ronde River CBS salmon seem to be closer to mimicking the natural age composition than the CHP salmon (Figure 10). In Catherine Creek, the CBS salmon demonstrate the more typical hatchery age composition of greater numbers of age 3 and fewer age 5 adults. CHP salmon demonstrate the typical hatchery age composition in both streams.

We estimated run timing by the arrival time of salmon at the weirs. Unfortunately, due to periods of high stream discharge, the weirs could not always be installed before the first salmon arrived or operated continuously thereafter, resulting in an incomplete picture of the true run timing at each stream. Adult arrival at the weir seems to be similar to that of the natural salmon but compressed for both hatchery programs (Figure 11).

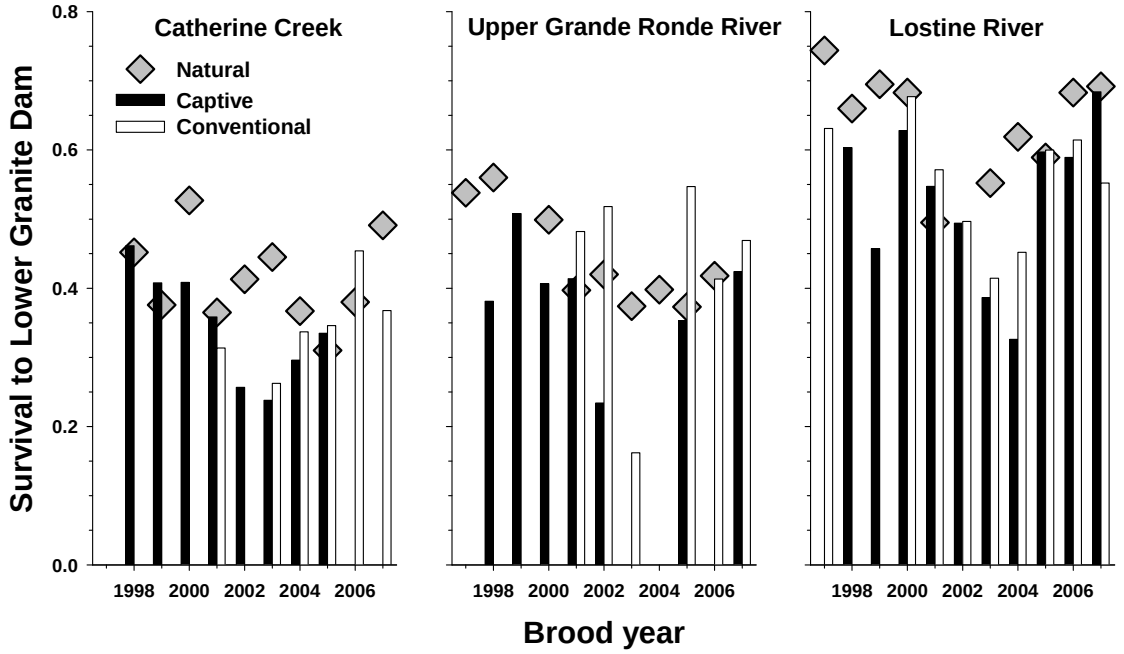


Figure 8. Downstream migration survival to Lower Granite Dam for natural and $F_1$ generation Captive Broodstock Program and Conventional Hatchery Program Chinook salmon smolts, 1997-2007 brood years.

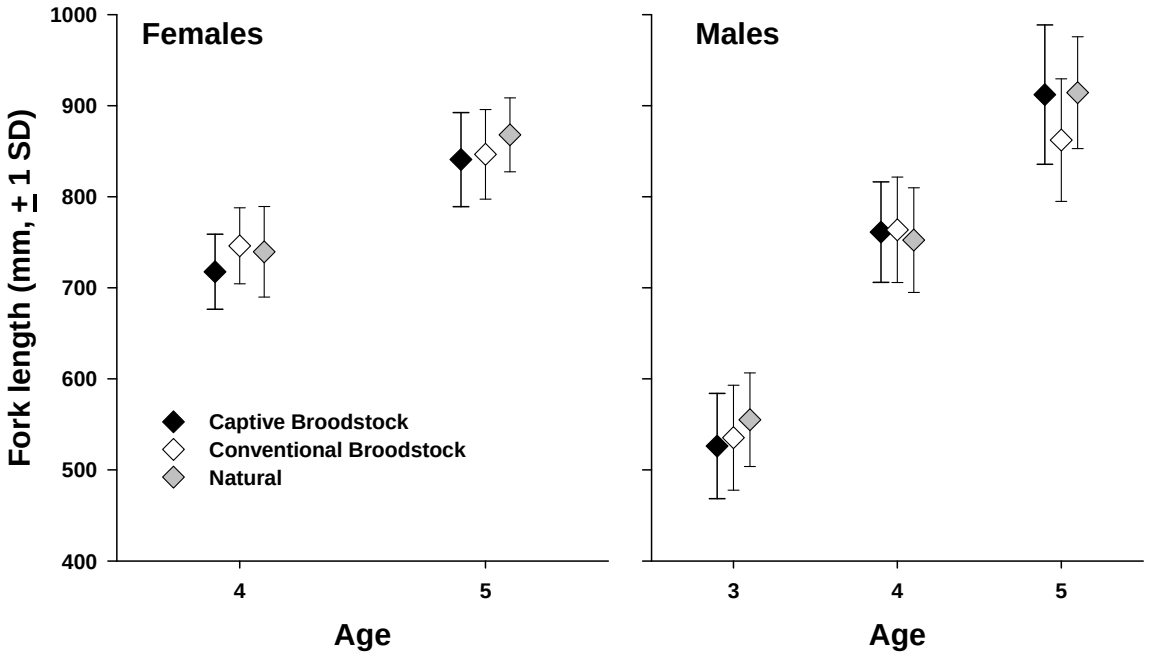


Figure 9. Mean (±1 SD) fork length at maturity of male and female natural and $F_1$ generation Captive Broodstock Program and Conventional Hatchery Program Chinook salmon.

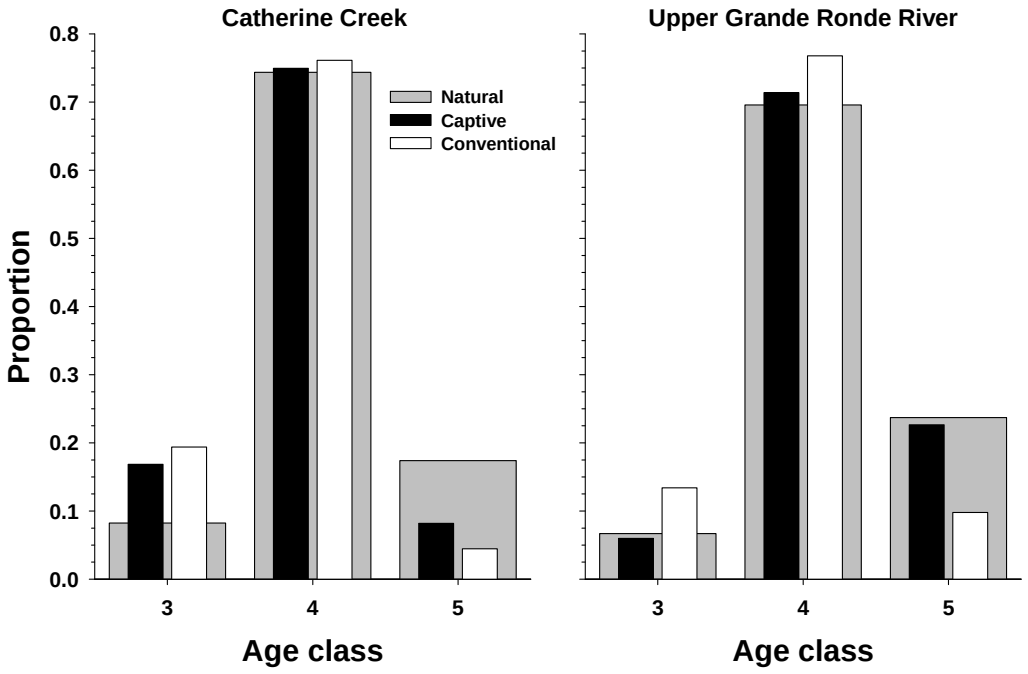


Figure 10. Age composition of Catherine Creek and Upper Grande Ronde River natural and $F_1$ generation Captive Broodstock Program and Conventional Hatchery Program Chinook salmon.

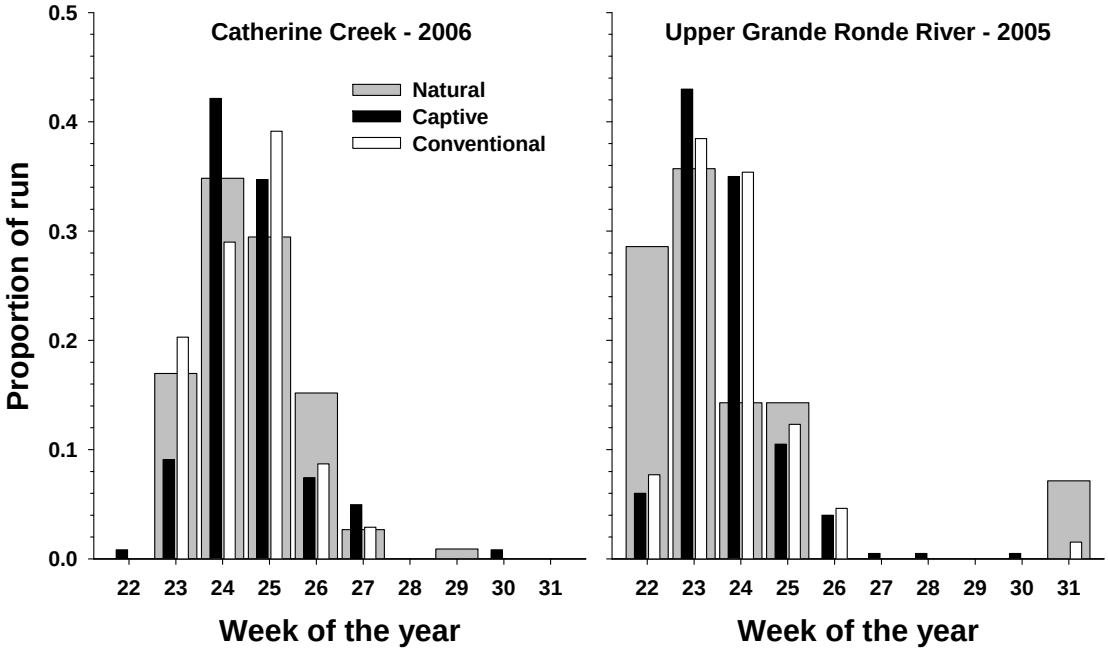


Figure 11. Representative run timing (arrival at weir) to Catherine Creek (2006 run year) and the Upper Grande Ronde River (2005 run year) for natural and $F_1$ generation Captive Broodstock Program and Conventional Hatchery Program Chinook salmon

We defined strays as any salmon collected outside of the direct migration route to its expected spawning or collection location. Mean stray rates were 5.0% and 5.2% for the Catherine Creek and Upper Grande Ronde River populations, respectively, right at the accepted maximum of 5%, and ranged from 0-12.5% (Figure 12). However, a closer look at the data shows that straying is not a big problem for either of these programs. Nearly all of the strays for both programs were recovered within the Grande Ronde Basin – and nearly all of those returned to Lookingglass Hatchery (where they were reared and which they had to swim past on their way to their parents' natal stream, where they were released and where we hoped they would return.

We determined spawning distribution in nature based on the locations of female carcasses recovered during spawning ground surveys. Acclimation sites in all three streams are located reasonably high in the spawning area and/or in areas of good spawning habitat (especially the Lostine River). Spawning distributions of both CBS and CHP adults tended to focus around the acclimation sites, although there is complete overlap with the natural salmon spawning distributions in all three populations (Figure 13). The Lostine River acclimation site is located in some of the best spawning gravel in the river. As a result, spawning distributions in of the CBS and CHP salmon in the Lostine River is similar to that of natural salmon. In Catherine Creek, natural Chinook salmon are more evenly distributed, whereas adults from both hatchery programs are more likely to spawn in the reaches directly below the acclimation site. The Upper Grande Ronde River acclimation site is located in the reach furthest upstream and >70% of the hatchery salmon spawn that reach, whereas natural salmon are more evenly distributed throughout the total spawning area.

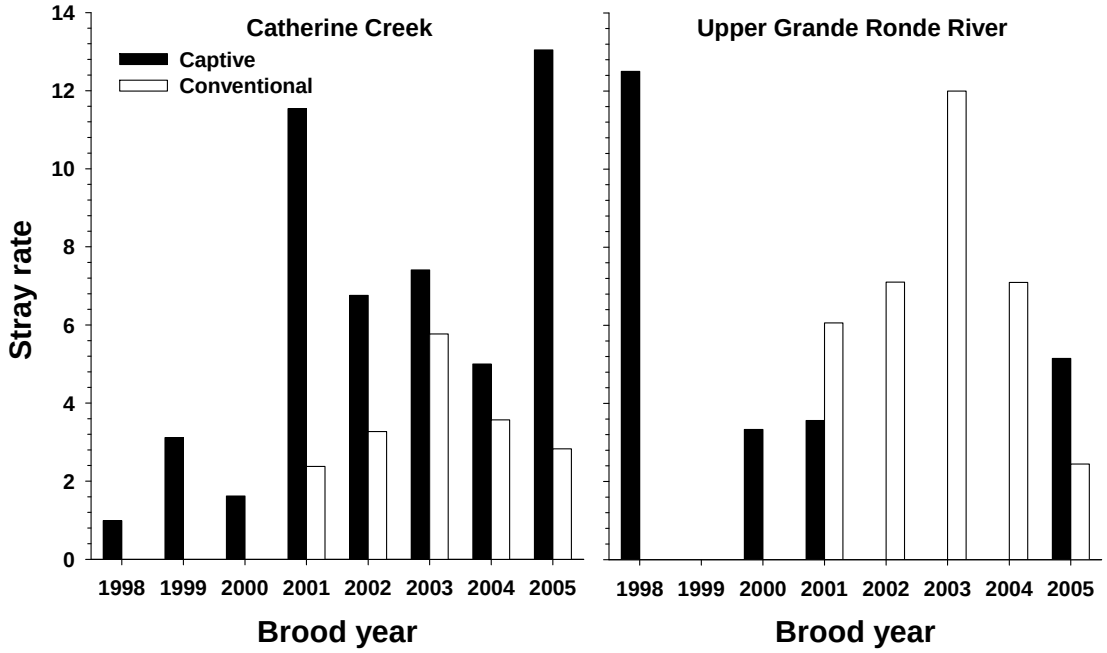


Figure 12. Stray rates for Catherine Creek and Upper Grande Ronde River $F_1$ generation Chinook salmon, 1998-2004 brood years.

CBS salmon usually met the CBS SAR target - mean SAR for BY 1998-2004 was 0.300 (Figure 14). However, the CBS program was only was able to meet the LSRCP SAR target of 0.65 twice and the CHP reached this goal only once. Mean SAR for the natural salmon (BY 1998-2004) in CC and GR was 0.64%. For the brood years for which we have data from natural salmon and the CBS and CHP programs (BY 2001-2004), mean SARs were 0.40%, 0.32% and 0.24% for the three origins, respectively.

Annual adult escapement for the CBS program has often reached the CBS escapement goal of 150 adults to each stream, particularly in the early years (Figure 15). However, escapements for the combined CBS and CHP programs have not approached LSRCP goals of 970 and 1,617 adults above LGD for the Catherine Creek and the Upper Grande Ronde River populations, respectively. The largest hatchery returns over LGD were 601 salmon from Catherine Creek and 888 adults from the Upper Grande Ronde River, both in 2009.

It may be that the LSRCP SAR target of 0.65% is unrealistic. Mean SAR for the 1998-2004 brood years of natural salmon in Catherine Creek and the Upper Grande Ronde River was 0.64%, nearly achieving the LSRCP goal. However, the SAR for the natural salmon exceeded the LSRCP goal in only one of those brood years (1.834 for BY 1998, which dramatically increased the mean) and ranged from 0.247 - 0.639 for the remaining BYs, 1999-2004). Given this and that the mean SARs for either hatchery program are well below the LSRCP target of 0.65%, it may be that neither the SAR nor the adult return goal are consistently attainable for these streams in their present condition and/or that of their migration corridor.

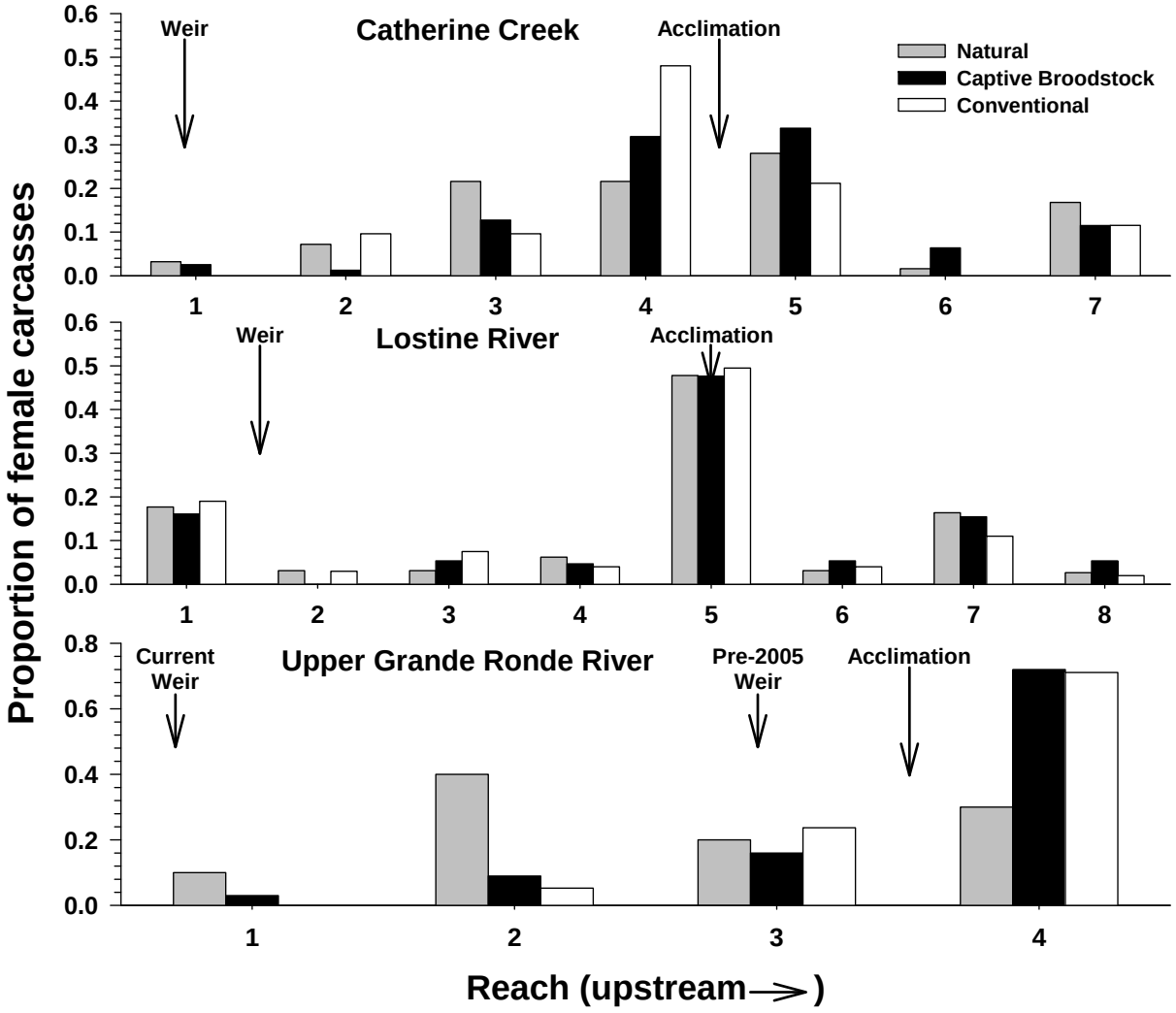


Figure 13. Spawning distributions (based on locations of female carcass recoveries) of natural and $F_1$ generation Captive Broodstock Program and Conventional Hatchery Program Chinook salmon for all spawn years in which hatchery salmon were present in Catherine Creek (2002-2009), the Lostine River (2001-2009) and Upper Grande Ronde River (2004-2009).

Lower fecundity (due to small size of females), fertility and survival to smolt have resulted in the CBS Program having much lower R:S than the CHP, often <1 (Figure 16). Mean R:S for the CBS Program was 1.5 recruits / female parent (BY 1998-2005), compared to 14.3 recruits / female parent for the CHP (BY 2001-2006).

However, these data are not a completely accurate comparison of the two hatchery programs. We compared adult spawner production for natural salmon with those of the CBS and CHP programs using mean rates for the natural salmon and each hatchery program to estimate the number of adults that would be produced, based on the 500 natural parr that were collected for each CBS Program cohort (natural rates included estimates from the ODFW Early Life History

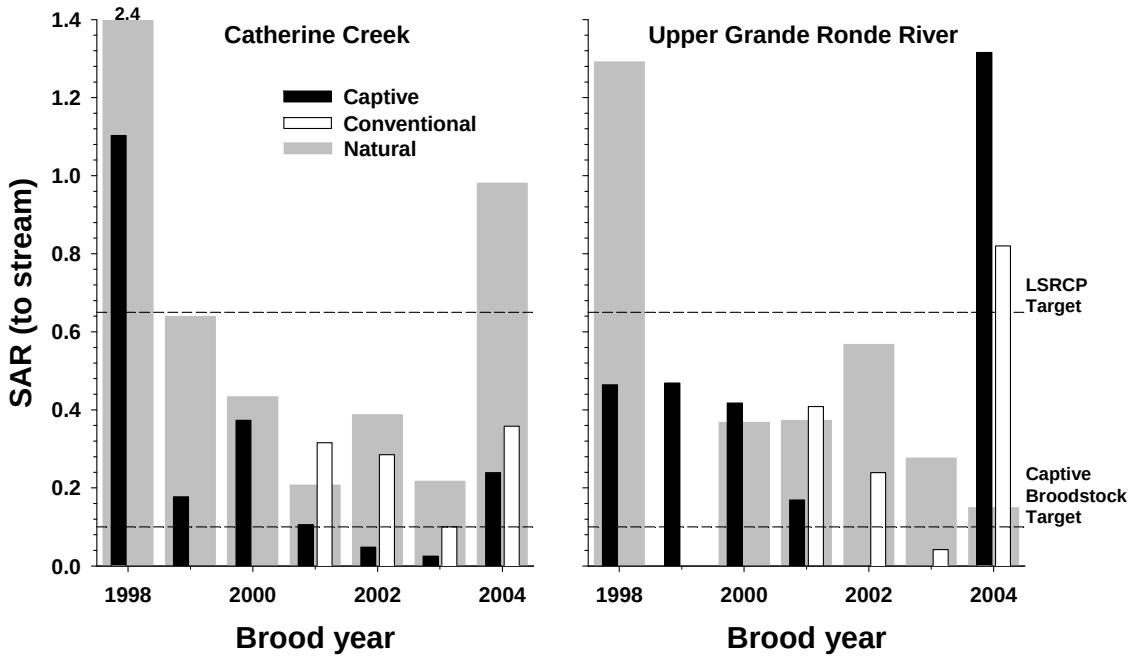


Figure 14. Smolt-to-adult return (SAR) rates for natural, $F_1$ generation Captive Broodstock Program and Conventional Hatchery Program Chinook salmon from Catherine Creek and the Upper Grande Ronde River, 1998-2004 brood years.

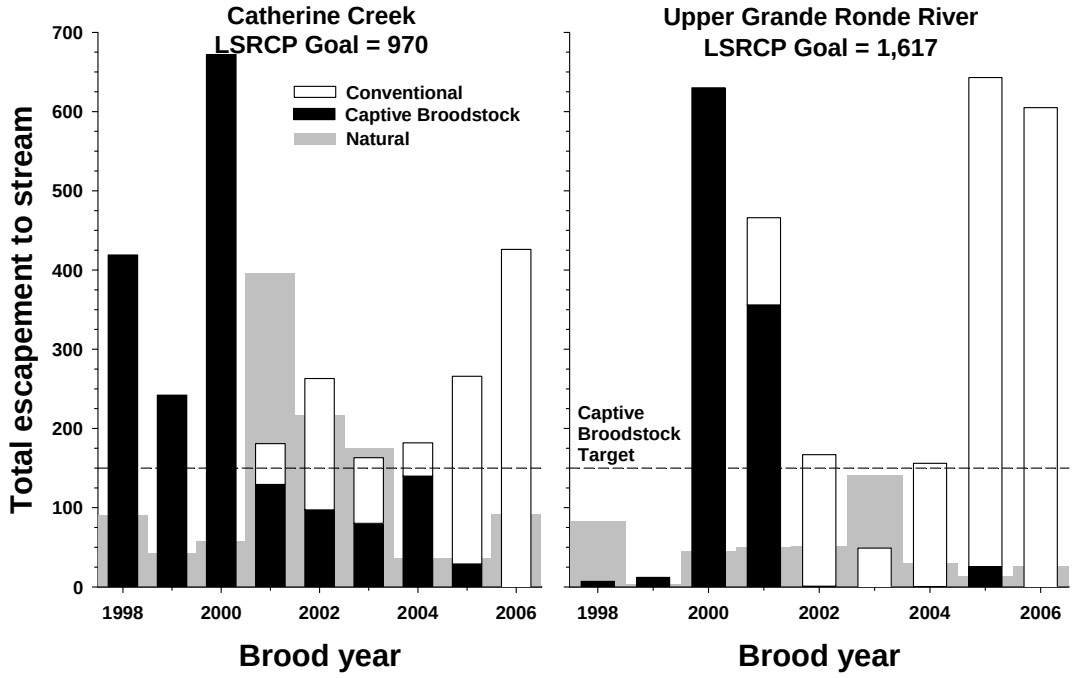


Figure 15. Total escapement to Catherine Creek and the Upper Grande Ronde River for the $F_1$ generation of the Captive Broodstock and Conventional Hatchery programs, 1998-2006 brood years. Note: 2006 brood year escapement is for ages 3 and 4 adults, only.

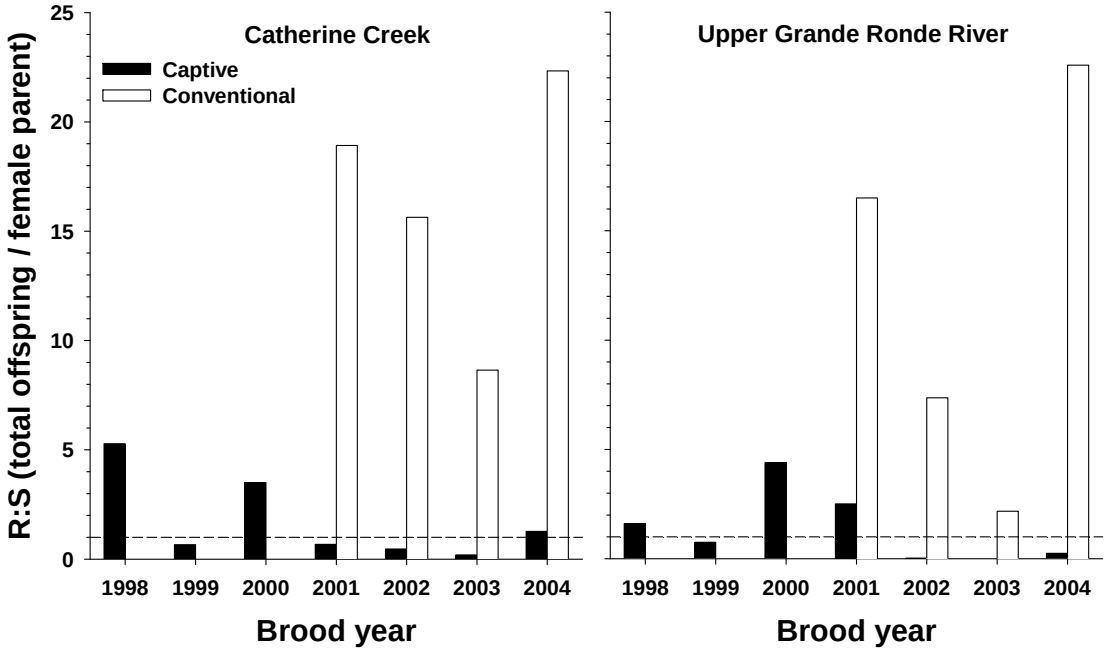


Figure 16. Recruits-per-female spawner ratios for $F_1$ generation Captive Broodstock Program and Conventional Hatchery Program Chinook salmon from Catherine Creek and the Upper Grande Ronde River, 1998-2004 brood years.

Program, B. Jonasson, personal communication; Table 4). For each rearing strategy, the data in Table 4 begin with 500 parr, the number of natural parr collected for the CBS Program. Working backwards, it takes 0.44 females spawning in nature to produce 500 natural parr (to rear in nature or in the CBS Program) and 0.14 females to produce 500 CHP parr. Moving forward from the 500 parr, we find that CBS parents ($F_0$ generation) have a huge survival advantage while being reared in captivity: >50% parr-to-adult survival, compared to <0.5% for the CHP and ~0.2% for natural salmon. This results in a greater number of $F_1$ generation spawners on the spawning ground per 500 $F_0$ generation parr from the CBS Program over either the CHP or natural salmon. We get nearly 2 adults in the next generation of natural salmon and approximately 18 $F_1$ generation adults from the CHP. In contrast, the CBS program produces approximately 370 $F_1$ generation adults, about 20 times more adults than the CHP and nearly 200 times more than natural rearing.

## SUMMARY AND CONCLUSIONS

Smolt production for the Captive Broodstock Program rarely achieved the CBS $F_1$ generation production goals but often reached its total escapement goal for the program populations. However, the combined CBS and CHP programs rarely achieved the LSRCP production goal until recently, when sufficiently large escapements made it possible to attain full LSRCP production in each of the Grande Ronde Basin programs. Egg-to-smolt and downstream migration survival rates to Lower Granite Dam were better in the Conventional Hatchery

Table 4. Production comparison among natural Chinook salmon, a Conventional Hatchery Program and a Captive Broodstock Program, based on 500 parr, the number collected for captive rearing in the Captive Broodstock Program. Note: shaded areas indicate parts of the life cycle occurring in nature.

| | | Natural | | CHP | | CBS | |
|---|---|---|---|---|---|---|---|
| Parameter | Units | Rate | Number | Rate | Number | Rate | Number |
| Fecundity | Females | 4,141 | 0.44 | 3,977 | 0.14 | 4,141 | 0.44 |
| Fertility | Green Eggs | 0.906 | 1,840 | 0.891 | 570 | 0.906 | 1,840 |
| Eyed-to-Parr | Eyed Eggs | 0.3 | 1,667 | 0.965 | 508 | 0.3 | 1,667 |
| **Number of parr** | **Parr** | | **500** | | **500** | | **500** |
| Parr-to-Smolt | Smolts | 0.13 | 65 | 0.98 | 490 | 0.97 | 485 |
| Smolt-to-Adult | Adults | 0.019 | 1.2 | 0.005 | 2.3 | 0.55 | 227 |
| Sex Ratio | Females | 0.5 | 0.6 | 0.5 | 1.1 | 0.5 | 133 |
| Fecundity | Green Eggs | 4,141 | 2,492 | 3,977 | 4,492 | 1,795 | 239,408 |
| Fertility | Eyed Eggs | 0.906 | 2,258 | 0.891 | 4,002 | 0.811 | 194,160 |
| BKD culling | Eyed Eggs | 0 | 2,258 | 0.01 | 3,962 | 0.8 | 155,328 |
| Eyed-to-Smolt | Smolts | 0.039 | 88 | 0.965 | 3,824 | 0.688 | 106,866 |
| Smolt-to-Adult | Adults | 0.019 | **2** | 0.005 | **18** | 0.003 | **370** |

Program than for the Captive Broodstock Program $F_1$ generation. Escapement of CBS $F_1$ generation back to the program streams often met the CBS Program escapement and SAR goals but the combined CBS/CHP programs rarely met the LSRCP SAR goal and never met the LSRCP escapement goal. Size at maturity for both programs was similar to that of natural salmon at each age, which was the expectation. Age composition of mature salmon in both the CBS and CHP was generally typical for hatchery programs, having more age 3 and less age 5 adults than natural salmon. Stray rates were higher than desired for both programs but the straying occurred nearly completely within the Grande Ronde Basin and was largely a result of adults straying to Lookingglass Hatchery (where they were raised), instead of the streams into which they were released as smolts. Run timing and spawning distribution were similar between programs and with natural salmon. Recruits-per-spawner ratios were higher in the Conventional Hatchery Program. Smolt production and R:S ratios were low for the CBS $F_1$ generation due to low fecundity and fertility of the CBS parents and culling for BKD prevention.

The Grande Ronde Basin Spring Chinook Salmon Captive Broodstock Program was successful in increasing the numbers of adults spawning in nature in each of the program streams, its primary goal. However, there are issues that must be addressed for future captive broodstock programs. Slow growth and the resulting low fecundity were the prime causes for not reaching the smolt production goals of the CBS Program. Disease (particularly bacterial kidney disease) caused us to barely achieve our parr-to-adult survival goal. Worse, culling to prevent vertical transmission of BKD further reduced our smolt production, often dramatically (up to 77%). The

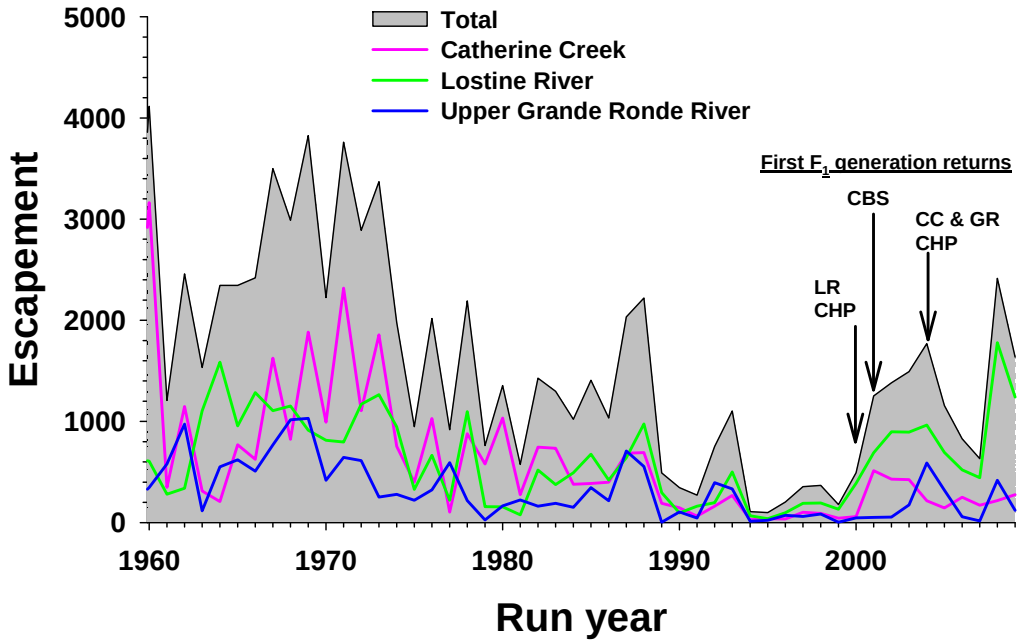


Figure 17. Total escapement for Chinook salmon to Catherine Creek, the Lostine River and Upper Grande Ronde River, 1960-2009 run years.

$F_1$ generation also did not perform very well in the hatchery, having lower fertility and hatching success than the Conventional Hatchery Program. Lastly, gene amplification and domestication are potential hazards to any hatchery program but are particularly risky to captive broodstock programs.

CBS $F_1$ generation adults first returned in 2001 (BY 1998). The first CHP adults returned to the Lostine River in 2000 and to Catherine Creek and the Upper Grande Ronde River in 2004. As expected, total escapement to the Grande Ronde Basin has increased since the inception of the CBS and CHP programs (Figure 17). The Lostine River population had the greatest increase, while the Upper Grande Ronde River population had boom and bust years and was more dependent upon hatchery production than the other two populations.

We have always considered that the ultimate measure of the success or failure of the CBS Program would hinge on an increase in the number of natural adults returning to and producing offspring in each of the program streams. Although the numbers of total adults returning to these streams have increased, we are seeing little evidence of an increase in the numbers of natural adults being produced in the program populations (Figure 18). This is the ultimate goal of the CBS and CHP programs and we cannot say that they have succeeded in attaining that goal.

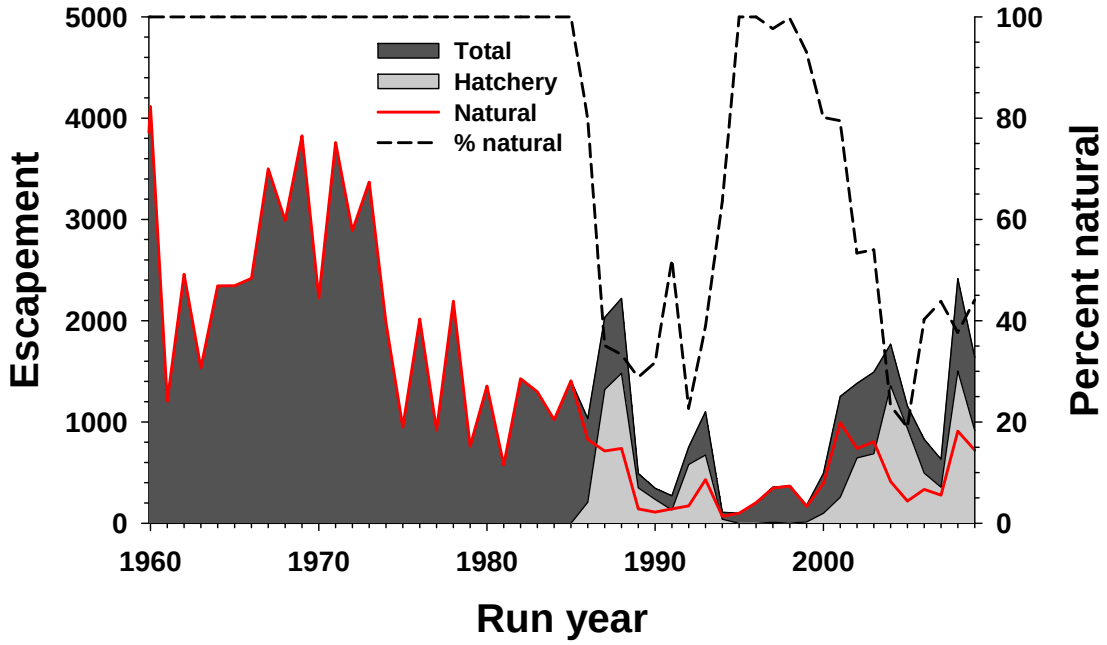


Figure 18. Combined total and hatchery escapement for Chinook salmon and percent of the run comprised of natural salmon in Catherine Creek, the Lostine River and Upper Grande Ronde River of the Grande Ronde Basin, 1960-2009 run years. Note: non-endemic Rapid River and Carson stock Chinook salmon produced the 1986-1994 hatchery returns. Endemic stock Chinook salmon comprised the 2000 - 2009 hatchery returns.