BACK FROM THE BRINK: THE CULTUS LAKE SOCKEYE SALMON ENHANCEMENT PROGRAM FROM 2000 - 2014

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ABSTRACT

Cultus Lake sockeye salmon (*Oncorhynchus nerka*) experienced a steady decline in adult abundance for three decades prior to a collapse in 2000 that prompted an 'endangered' assessment of the population in 2003. The critically low abundance also induced a cross-sectoral recovery effort within DFO, involving staff from salmon enhancement (SEP), science, and fisheries management. The program has consisted of traditional enhancement (supplementation) and captive breeding conducted to safeguard the population in captivity, provide juveniles to assist in wild population restoration, and maintain existing genetic diversity in the remnant population. The recovery effort has successfully increased and stabilized adult abundance, and maintained genetic diversity in terms of the genetically effective population size. However, long-term success of the population in the wild remains uncertain as both freshwater and marine mortality (including exploitation) remain highly variable. This overview of the Cultus Lake Sockeye Salmon Enhancement Recovery Effort outlines the enhancement actions and protocols undertaken for the population and provides annual progress summaries from inception in 2000 until 2013. In 2013, the Cultus sockeye captive brood program was terminated due to an operational review that indicated supplementation alone could provide a sufficient level of population security and maintain the existing genetic diversity during ongoing wild population restoration.

RÉSUMÉ

Après un déclin régulier de l'abondance des adultes de saumon sockeye (saumon rouge) du lac Cultus (*Oncorhynchus nerka*) pendant trois décennies, la population a connu un brusque effondrement en 2000. En 2003, elle a été considérée comme « en voie de disparition ». En raison des niveaux critiques de son abondance, le MPO a lancé une action multisectorielle de rétablissement, à laquelle prenait part le personnel du Programme de mise en valeur des salmonidés (PMVS), des Sciences et de la Gestion des pêches. Le programme a consisté à mettre en place une mise en valeur des stocks classique (par apport de compléments alimentaires) et un élevage en captivité pour protéger la population en captivité, fournir des juvéniles en vue du rétablissement de la population en liberté et préserver la diversité génétique chez les autres populations. Le programme de rétablissement a réussi à augmenter et stabiliser l'abondance des adultes ainsi qu'à préserver la diversité génétique de la taille efficace des populations. Le succès de la population sauvage à long terme reste toutefois incertain, car la mortalité en mer et en eau douce (notamment fonction du taux d'exploitation) est très variable. Le présent aperçu sur l'action de rétablissement du saumon sockeye du lac Cultus décrit les protocoles et les mesures de mise en valeur des stocks adoptés pour cette population et comporte des récapitulatifs annuels sur l'état d'avancement du programme de son lancement en 2000 à 2013. En 2013, le programme d'élevage de classes de recrutement a été fermé, à la suite d'un examen opérationnel qui indiquait que les compléments alimentaires suffiraient à obtenir un niveau de sécurité satisfaisant pour la population et à préserver la diversité génétique pendant le rétablissement de la population en liberté.

INTRODUCTION

Cultus Lake is located 100 kilometres east of Vancouver B.C. in the lower Fraser River valley. It is a small body of water with a large footprint in the scientific literature. Cultus Lake sockeye salmon have been monitored for abundance, lake rearing characteristics, and smolt production since the 1920's; longer than any other salmon population in B.C. (Johnson & Schubert 2001, Ricker 1937). Installation and operation of fences has afforded the ability to accurately enumerate adult returns since 1925 (Johnson & Schubert 2001). The predominantly four-year maturation schedule has produced largely discrete year-classes that are important components of the species' diversity (COSEWIC 2003). However, some variation in age at maturity (i.e., small numbers, generally ≤10%, of individuals mature at ages three or five) maintain gene flow across year-classes and facilitate modest demographic stability. Salmon populations typically fluctuate in abundance but by 2001 the abundance of all life stages of Cultus Lake sockeye had declined by as much as 93% to unprecedented low levels (Johnson & Schubert 2001) and 2003 adult abundance estimates were among the lowest on record (DFO 2003). From historic abundances of greater than 70,000 spawners, the population had declined to <100 fish in 2004, exacerbating concern that genetic diversity was being irreplaceably lost and increasing the likelihood of wild population extirpation.

The Cultus sockeye salmon population collapsed primarily due to overexploitation, including directed and incidental catches in mixed-stock fisheries above sustainable levels (CSRT 2005). Reductions in survival were also attributed to El Niño events in the 1990's (DFO 2003, Beamish et al. 1997). The decline in adult abundances coincided with a progressive shift to earlier timing of adult freshwater entry and migration. Since 1995, the earlier migration had been associated with adult pre-spawn mortality in Cultus Lake, possibly related to heavy infestations with the parasite *Parvicapsula minibicornis* (St-Hilaire et al. 2002, Jones et al. 2003). Ecological impacts to lake-habitat from colonization by Eurasian milfoil, land development, stream channelization, nutrient input, and recreational use were also potentially involved in the population decline. The drastic decline culminated in an absence of observed successful spawning between 1999 and 2001, although fry and smolt monitoring indicated a low level of reproductive success each year (Johnson & Schubert 2001).

In 2000, the low abundance and high pre-spawning mortality led to an ad hoc initiation of hatchery supplementation by DFO enhancement staff**.** A small number of adults were collected and their progeny were reared at the Cultus Lake Laboratory. In the fall of 2001, broodstock collection and fish culture activities were repeated with similar success.

In December 2001, at the Cultus Lake Community Hall, the Soowalie First Nation hosted a meeting of parties, including DFO staff, concerned about the status of Cultus Lake sockeye salmon. The public meeting led to the formation of an interdisciplinary group, the Cultus Sockeye Recovery Team (CSRT), and the subsequent development of a draft enhancement-based recovery plan for the population (CSRT 2005). A 2002 review of population status increased awareness of the critical state of Cultus Lake sockeye (Schubert et al., 2002). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) subsequently determined that there was a high probability of extinction of Cultus Lake sockeye salmon in the absence of successful remediation efforts (COSEWIC 2003).

The COSEWIC listing prompted a federal cabinet review of Cultus Lake sockeye salmon population status and socioeconomic considerations to determine if the population should be formally listed under SARA, the Canadian Species at Risk Act (Irvine et al 2005). A SARA listing would dictate legal protection of the population as well as finalization and implementation of the recovery plan Recovery planning and enhancement activities continued while the decision was formulated. In early 2005, the Canadian government decided to not list Cultus sockeye under SARA but expressed a commitment to protect and rebuild the population.

The lack of a legal listing for Cultus Lake sockeye salmon terminated the formal recovery planning that DFO had undertaken for the population; the recovery plan was not finalized as such. Instead, it was eventually published as a ‘National conservation strategy' (CSCT 2009). Recovery activities, now considered ‘conservation efforts’ without a strong legal mandate, continued. These included hatchery supplementation (enhancement) and captive breeding, predator control, milfoil removal, and harvest control measures dictated primarily by those taken for other Fraser River Late run sockeye populations of conservation concern. A recent review of the success of these conservation activities indicated that the prognosis for the population remained highly uncertain (Bradford et al. 2011).

ENHANCEMENT PROGRAM PLANNING

In January 2002, DFO SEP staff applied COSEWIC criteria in an analysis of available Cultus Lake sockeye stock assessment data. The results indicated that recovery planning should begin immediately. Thus, the recovery planning process for Cultus sockeye salmon was undertaken prior to both the COSEWIC listing and the ultimate decision to not list the population under SARA.

Sockeye salmon enhancement projects in Alaska (McDaniel et al. 1994) and Idaho (Kline & Willard 2001) provided baseline information from which to develop a multi-faceted recovery approach that included both capture and spawning of wild adults and collection of wild smolts. Sockeye salmon culture requirements had been well documented by the Alaska Department of Fish & Game, and the Alaska Sockeye Salmon Culture Manual (McDaniel et al. 1994) was used for technical guidance. The procedures in this document included both well-established general fish culture practices and sockeye-specific standards for water quality, disinfection, and compartmentalization, during egg takes, incubation, and rearing.

The captive brood program, involving rearing of Cultus Lake sockeye in captivity through the complete life cycle from egg fertilization until spawning, was developed as an emergency measure to provide a refuge for the population in the event of extirpation in the wild environment. Rosewall Creek Hatchery on Vancouver Island

and the Inch Creek Sockeye Satellite Facility near Mission were identified as suitable existing facilities to host the captive breeding and supplementation activities, respectively, for wild population restoration. Strong biosecurity measures were instituted at both sites to mitigate health risks associated with rearing sockeye. The endemic nature of infectious hematopoietic necrosis virus (IHNV) in BC necessitated special precautions for both safe sockeye culture and for protection of other susceptible aquatic species. The Cultus Lake Research Laboratory facility was deemed unsuitable for culture beyond eyed egg stage, as it did not have a fish-free source of water, and IHNV had been isolated from fish in the lake (Hsu et al. 1986).

An Enhancement working group (EG), composed of hatchery staff, SEP biologists, and DFO research scientists, met several times per year and provided oversight to the hatchery program. EG members also sat on the Recovery (later Conservation) Team to coordinate enhancement efforts with other recovery, conservation, and evaluation activities. Further background information on the Cultus Lake sockeye recovery planning process is provided in the following documents:

Bradford, M.J. et al. 2011. Status of Cultus Lake sockeye salmon. DFO Can. Sci. Advis. Sec. Doc. 2010/123. vi + 44p. Available from www.dfo-mpo.gc.ca/csas-sccs

Cultus Sockeye Recovery Team. 2005. Conservation strategy for sockeye salmon (*Oncorhynchus nerka*), Cultus Lake population, in British Columbia. Recovery of Nationally Endangered Wildlife (RENEW). Ottawa, Ontario, 48 p.

Cultus Sockeye Recovery Team. 2009. National conservation strategy for Cultus Lake sockeye salmon (*Oncorhynchus nerka*). Can. Tech. Rpt. Fish. Aquat. Sci. 2846: viii + 46 p.

Department of Fisheries and Oceans. 2003. Cultus Lake Sockeye. DFO Can. Sci. Advis. Sec. Doc. 2003/024 Available from www.dfo-mpo.gc.ca/csas-sccs

Schubert, N.D., et al. 2002. Status of Cultus Lake sockeye salmon (*Oncorhynchus nerka*). DFO Can. Sci. Advis. Sec. Doc. 2002/064. 109 p. Available from www.dfo-mpo.gc.ca/csas-sccs

FACILITIES

Three different facilities were employed to encompass the scope of the program. A primary facility was needed for broodstock collection, spawning, and incubation to eyed stage, but a second facility was necessary to undertake an isolated captive brood program. Although it would have been preferable to carry out all activities at the Cultus Lake site, it was necessary to divide juvenile rearing between two facilities to address risks associated with any unanticipated systems failure and an insufficient supply of pathogen free water for rearing. It was also considered prudent to maintain backup captive broodstock at a second facility for the same reason.

Following a detailed risk analysis of eight DFO and private facilities (CLSRPP 2002)*,* Rosewall Creek Hatchery was identified as the only facility in BC suitable for locating a complete captive brood program, and the Inch Creek Sockeye Satellite facility was considered to be an appropriate (partial) backup location. Considerations included IHN-free water, suitable water quality and abundance, emergency standby and security procedures, experienced fish culture staff, the ability to treat effluent water for disease control if necessary, and number and variety of available rearing ponds. Both sites provided discrete isolation that followed strict Alaskan sockeye protocols (McDaniel *et. al.* 1994) and met the required criteria.

Cultus Lake Salmon Research Laboratory

The Cultus Lake Salmon Research Laboratory provided the most practical location for adult holding and gamete collection programs due to its proximity to the Sweltzer Creek Fence. Water at the Cultus Lab is drawn from two intakes in Cultus Lake (both deep and shallow lake water) that are capable of providing sufficient capacity with adequate backup systems. A small incubation facility was installed for incubation to the eyed stage, at which point eggs were distributed between Rosewall Creek Hatchery and the Inch Creek sockeye facility.

Rosewall Creek Salmon Hatchery

The Rosewall Creek facility, which was proposed as the primary captive brood location, had a successful captive broodstock program already in place for the Puntledge River Summer-run Chinook, and its original design and staffing level allowed for application of proper captive sockeye broodstock protocols. When under full production, and with just 1,500 eggs seeding the program annually, the captive brood at Rosewall Creek could produce up to 1,000,000 eggs, and could rear about 300,000 fed fry to supplement capacity at Inch Creek.

Inch Creek Sockeye Satellite Facility

A production-scale sockeye enhancement program had been in place at the Upper Pitt River Hatchery since 1960 (Stobbart & Harding 1996) and the Inch Creek Sockeye Satellite facility had been built to replace incubation and juvenile rearing that had historically been carried out in this remote location. The Inch Creek facility was designed with sockeye biosecurity as a major consideration and was an ideal site for participating in the Cultus Lake program.

Inch Creek was considered suitable as the final incubation and primary rearing facility as well as a limited backup location for the captive brood program at Rosewall Creek. Captive fish could only be reared for one year, due to space and water limitations, after which they were released as yearlings to Sweltzer Creek. The Inch Creek facility could rear approximately 775,000 juvenile sockeye for release to Cultus Lake. All of the eggs taken at the Cultus Lake Lab and all (or most) of the eggs taken at Rosewall Creek were transferred to Inch Creek at the eyed stage. If Inch Creek met its capacity, then Rosewall Creek could accommodate up to 300,000 sockeye for final incubation and rearing.

PROCEDURES

This section outlines, in brief, procedures used at the three facilities (Cultus Lake, Rosewall and Inch Creek), which may differ from other enhancement programs.

Adult collection, holding and handling (Cultus Lake Laboratory)

Except where impractical, all juvenile fish released in the program were marked, thereby allowing differentiation of wild from hatchery progeny when adults were collected at the Sweltzer Creek fence (near the outlet of Cultus Lake). Where possible, wild fish were favoured as broodstock. At the Sweltzer Creek fence, operated by Stock Assessment Division staff, fish were counted in a trap and released to travel upstream to Cultus Lake or shunted aside and held overnight for brood stock collection. All possible measures to reduce stress during capture/handling were taken. The target for the captive brood program was the production of 500 genetically distinct families for each generation at Rosewall Creek. To achieve this, fish were collected over the duration of the return, with up to 250 adults collected.

In most years, collection began in August, and every attempt was made to ensure broodstock collection represented the natural run timing. During periods of high water temperature (>20^{o}C), all fish were passed through the fence to mitigate stress associated with holding.

Following capture at the Sweltzer Creek fence adults were placed into a transport tank containing cooler deep lake water, a mucus protectant, and a sedative. The transport vehicle was moved to the holding area where fish were removed individually, prophylactically treated with antibiotic, passive integrated transponder (PIT) tagged and placed into two secure, shaded concrete circular ponds inside the adjacent Cultus Lake Laboratory compound. The walled containers were covered with 70% shade cloth and the entire tank farm protected with a security fence and lockable gate. The dual tanks provided redundancy in event of failure of one pond. Water drawn from the Cultus Lake deep intake (10^{o}C) was aerated and degassed of excess nitrogen prior to fish contact.

Stress reduction

The broodstock were left undisturbed in holding ponds until mid-November to minimize stress, and sorting/spawning was conducted on a weekly schedule to avoid excess handling. Aquacalm™ was used (0.5 mg/L) to sedate fish for transport and PIT tagging. Vidalife™ (1 ml/15L of transport water) was also used as a mucus protectant.

Disease prevention

As fish were transferred to holding containers, a single treatment of oxytetracycline (20/mg/kg) was administered prophylactically to reduce pre-spawn mortality and vertical disease transmission. A weekly drip treatment of Parasite-S™ (formalin) was administered at a dose of 160ppm for one-hour 3X weekly, to keep external fungus infections under control.

Tagging

Initially, surface applied tags (e.g. Floy tags) were used to identify individual fish. The use of these tags proved problematic because they tended to tear off when fish were dip-netted for sorting / spawning. Their use was discontinued after the first year of the program. Because of their ease of application and durability, PIT tags were used in subsequent years. PIT tags provide each fish with a unique code that enables recording of tag data for each handling event from capture through to spawning and/or mortality, and permitted parental DNA determination for each of the thousands of family groups produced throughout the captive brood program.

Tagging adults with an individual identifier was important as:

- A matrix spawning regime was required to maximize genotypic diversity and this matrix, in some cases, resulted in sperm from a single male used as many as 12 times to fertilize egg lots from a similar number of different females. Eggs from each resultant family (progeny of a particular male x female cross) were provided a distinct ID and incubated separately until captive pooling was complete.

- All females were screened for IHNV and BKD and if positive disease results were returned, affected eggs were segregated or destroyed.

- Adult arrival and collection timing vs. spawning or mortality could be tracked to increase knowledge of possible effects on a stock that were related to variables such as disease and temperature.

Gamete collection

The Alaska Sockeye Salmon Culture Manual (McDaniel et al. 1994) was adhered to and strict biosecurity protocols were followed during all stages of production, particularly gamete collection to mitigate potential transfer of disease causing organisms. All equipment and surfaces that came into contact with fish, including the egg taker's hands, were disinfected between each fish handled, and each adult salmon was surface disinfected prior to spawning. Disinfectant footbaths were in place at the entrance/exit to all sockeye components of the facilities to ensure that pathogens were not moved into or out of working areas.

Females: Ripe females were killed by a sharp blow to the head then fully immersed in a 250ppm solution of Ovadine, scanned for PIT tag ID, hung by the tail and bled from the gills for at least 10 min. The females were then held head up, wiped dry and cut open from the vent to the pectoral fins. Eggs were collected into a dry, disinfected metal pan, with the skeins gently massaged to remove loose eggs, before being transferred into individual containers with lids, and placed into a cool location.

Males: Males were checked for ripeness and, if ripe, the PIT tag identification number was recorded. The ventral surface of the fish was disinfected (250ppm Ovadine), prior to milt expression, to reduce risk of vertical transmission of disease. Care was taken to keep the fish in an upright position with the head above the tail to ensure that the disinfectant did not run into the gills.

After the ventral surface of each male was wiped dry, milt was collected into individual containers and kept cool to ensure viability. To reduce bias towards early maturing males, repeat donors were sometimes culled part way through the egg collection period, but this was dependent on the overall number and quality/health of males on hand.

Genetic practices

Cultus broodstock selection: Enhancement and captive breeding for Cultus Lake sockeye salmon were based entirely on adult (or smolt) wild Cultus sockeye salmon collected at the Sweltzer Creek fence. Small numbers of hatchery-reared, age four, fish first returned in 2006 and were included in adult brood collection in representative numbers. In 2008, the escapement was >90% hatchery origin, predominantly fish returning from the first large release of captive-bred fry from 2004 brood-year spawning at Rosewall Creek Hatchery. Since 2008, hatchery-origin sockeye (both supplemental and captive-bred) have dominated both the overall Cultus adult returns and broodstock collections in most years, although naturally-spawned fish have been selected preferentially for broodstock when possible. Up to 50% of the escapement was also comprised of age three fish (of both hatchery and natural origins) in some years; these fish (males and females) were included in broodstock collection.

The initial enhancement efforts in 2000 and 2001 were undertaken hastily because of the extremely poor adult returns observed. As a result, few adults were available for spawning in those years (five females in 2000, and nine females in 2001) and it was recognized that the broodstock contained only a small fraction of the biodiversity present in the pre-collapse Cultus population. In an attempt to increase the genetic diversity in the captive population, 2,014 wild smolts were collected at the Sweltzer fence in 2002 and an additional 796 were transferred into the captive brood stream in 2003 (progeny of brood years 2000 and 2001 wild sockeye). These fish were held temporarily at the Chilliwack River Hatchery in 2002 and Inch Creek Hatchery in 2003, before being transferred to Rosewall Creek hatchery following disease screening. They were reared to maturity at Rosewall Creek, to be used as captive spawners in 2004-2006. The smolts, infected with *Salmincola*, initially suffered high mortality in captivity but substantial numbers survived until maturity. Genetic analysis subsequently confirmed that inclusion of the surviving smolts in the captive broodstock as they matured increased the genetic diversity in adults that returned from early captive brood releases.

Standardization of parental contributions to fish reared in captive breeding program: Equal numbers of fertilized eggs from each full-sibling Cultus family were selected for transfer from incubation at Inch Creek Hatchery (Cultus Laboratory spawning) to Rosewall Creek Hatchery for captive rearing each year. In early 2005, the number of eggs transferred annually to Rosewall Creek for captive rearing was set to 1500. Each year, the appropriate number of eggs (typically between three and five) were selected from each full-sibling family at Inch Creek Hatchery and pooled for transfer to Rosewall Creek Hatchery. This ensured that all parents successful in egg fertilization contributed similar numbers of progeny to the captive program. However, parental contributions were somewhat variable within and among years because male and female broodstock were used to produce variable and unequal numbers of full-sibling matings.

DNA screening: DNA screening was employed where either straying concerns or concerns for genetic makeup of females arose. DNA testing occurred in 2004 on the returning 2000 brood year adults, and again in 2008 on the returning 2004 brood year adults.

Cryopreservation of sockeye milt: On several occasions prior to 2005, milt from small numbers of male sockeye salmon used in spawning at Cultus Lake was also cryopreserved using methods described by Alderson & MacNeil (1984), Cloud et al. (1990), and Wheeler & Thorgaard (1991). The milt was stored for use in future egg fertilization at either location if deemed useful for the transfer of genetic diversity across year classes. The cryopreserved milt was used in the fertilization of eggs from the ten females spawned at Cultus in 2004 (Withler et al. 2010). Cryopreserved milt was also used in 2004 at Rosewall Creek in the captive brood program. Storage of the milt was discontinued as storage costs increased, observed fertilization rates were low and success in transferring genetic information across year classes was achieved by other methods (see below).

Same-year use of milt collected from males spawned at Cultus Lake Laboratory in captive brood egg fertilization: After 2004, as adult abundances at Cultus Lake increased, fresh milt collected from some males used in spawning at Cultus Laboratory was transferred to the Rosewall Creek facility and used in egg fertilization of captive brood females. Generally, milt collection and transfer occurred on a single day, and involved 10-20 Cultus males. The milt was used to fertilize eggs of females spawned the following day at Rosewall Creek Hatchery. This occurred in 2006 and 2007.

Captive brood rearing and spawning at Rosewall Creek Hatchery: Pooled eggs were transferred from spawning at Cultus each year and reared to maturity at ages three and four at Rosewall Creek Hatchery. Captive broodstock spawned each year at Rosewall typically numbered between 500 and 900 adults, with females generally outnumbering males. Eggs from each female were divided into two or more batches, and each batch was fertilized with milt from a different male. Generally, each male and female spawned on a given day was mated with two individuals of the opposite gender. Females were spawned on one day only, whereas males (often in short supply, especially early in spawning season) were PIT tagged and retained for repeated use if necessary. Spawning was between fish from different age groups when possible to avoid the inbreeding associated with mating of close relatives (half- and full-siblings). All juveniles produced in the captive stream were released into Cultus Lake the year following spawning. They were either reared until 'fed fry' at Rosewall Creek and transferred directly to the lake, or moved as eyed eggs to Inch Creek Hatchery for additional rearing prior to release. No Cultus sockeye produced at Rosewall Creek Hatchery were retained in captivity; all juveniles were acquired from spawning at the Cultus Lake Laboratory each year.

<u>Fertilization – matrix spawning</u>: At the Cultus Lake Laboratory, between 25 and 300 male and female broodstock were spawned each year and matrix (semifactorial) spawning was used to produce approximately 500 full-sibling families. Both males and females were spawned with multiple mates (generally between four and eight, depending on overall broodstock number and the number of fish available for spawning each day). The eggs from each female were evenly distributed into a predetermined number of labeled cups, and milt from a different male was used to fertilize the eggs in each cup. Milt was dispensed evenly among egg batches with disposable pipettes. Females were spawned and killed on a single day, whereas males, retained throughout the spawning period (mid November to early January) each year, were identified by PIT tag number at each use.

Fertilization was initiated with disease-free well water (transported from Inch Creek in the case of Cultus Lake egg takes) and eggs were left for at least one minute before excess milt was washed away. Containers were topped up with 100ppm Ovadine and disinfected/water hardened for 60 minutes. Eggs were then decanted into individual egg tubes for incubation until eyed, when eggs were shocked and the dead removed. Each group of eggs was labeled with an assigned family ID providing male and female parent identity.

<u>Genetic sampling for evaluation and adaptive management of Cultus sockeye supplementation and captive breeding</u>: Genetic sampling of all Cultus sockeye broodstock spawned at Cultus Lake Laboratory and Rosewall Creek Hatchery was initiated in 2004, although sample analysis was not undertaken until 2007, when progeny of the 2004 hatchery spawning had matured and started to return at age three to the Sweltzer Creek fence. Tissue samples were stored individually in undenatured 95% ethanol and labelled for matching to field data (fence arrival date, length, estimated age, estimated gender, hatchery or natural origin). Fish selected as Cultus broodstock at the Sweltzer Creek fence were PIT-tagged to match them with their field data and transferred to holding tanks at Cultus Lake Laboratory. At the Cultus Lake Laboratory, DNA samples were identified by PIT tag number and taken at the time of spawning (females) or at time of death on or prior to final spawning (males).

From 2006 onwards, some fish entering Cultus Lake for natural spawning were also sampled for genetic analysis as they were transferred across the fence. Both adipose-clipped (of hatchery origin) and unclipped (naturally-spawned in Cultus Lake) adult fish were sampled (tissue samples were collected from fin or operculum clips). Between 200 and 2000 fish were sampled annually in a representative manner over the duration of adult migration.

Beginning in 2008, smolts from Cultus Lake were sampled for genetic analysis at Sweltzer Creek fence over the course of smolt migration (April-May). Tail clips of hatchery (adipose-clipped) and natural (unclipped) smolts were separately bulk sampled (20 per vial) in a representative manner throughout migration. Generally, between 500 and 1000 smolts of each type were sampled; except when low abundances of natural smolts reduced availability.

Routine genetic analysis of Cultus sockeye was initiated in 2007, with the return of age three adults from the first large release of captive-bred fry. Genetic data consisted of genotypes at 14 polymorphic microsatellite loci; analysis was conducted on fish for which at least 10 loci were scored. By 2008, analysis of Cultus genetic samples was up-to-date and real-time analysis of sample collections (smolts and adults) was undertaken.

Incubation

Eggs could not be moved between facilities until screened for IHNV and BKD; therefore all early incubation (to the eyed stage) took place at Cultus Lake or Rosewall, allowing necessary disease screening processes to be completed. Eggs from any fish that tested positive for IHNV, or that tested at a high positive level for *R. salmoninarum,* were destroyed before hatch. Egg lots in which *R. salmoninarum* had been detected at low levels were incubated separately from clean eggs.

Only a very small number of eggs were required to seed the captive brood program each year; annually, between 2002 and 2009, three eggs from each family (approximately 1,500 in total) were transported to Rosewall Creek for this purpose. The remaining eggs were transported to Inch Creek where they were hatched and reared, and ultimately released to Cultus Lake as fry or smolts to supplement the wild population. Supplementation and captive breeding were designed to work together.

Eggs collected from captive reared fish spawned at Rosewall Creek were all destined for release to Cultus Lake except in brood year 2004 (see annual program summary section). In most years, all of the eyed eggs produced at Rosewall were sent to Inch Creek. In years when the total eggs produced by Cultus and Rosewall egg takes exceeded the Inch Creek capacity, Rosewall was capable of incubating, rearing, and marking up to 300,000 fry. In 2010, due to increasing returns of adult fish and the genetic risks of long-term captive brood programs, no further eggs were allocated to the captive program.

Egg disinfection following transport to final incubation facilities: On arrival at the final incubation facility, egg tubes were given a 10 second bath treatment in 100 ppm Ovadine solution prior to entering the incubation room and final planting into Heath trays.

Egg allocation and family design

Two identical groups of three family pools were created for both the main captive rearing program at Rosewall Creek Hatchery, and for the captive back-up program at the Sockeye Satellite at Inch Creek; each group was composed of approximately 1500 eggs. Each pool contained a representative sample of females from each week of spawning at Cultus (i.e. females were assigned to pools in random rotation, not by spawn date). Only fish from separate pools were then crossed at Rosewall. This eliminated the possibility of crossing female siblings at Rosewall, but allowed for male half sibling crosses in captive brood stock. When possible, fish from separate brood years (3 X 4 year-old fish) were crossed to eliminate this problem.

The Inch Creek facility is space restricted and therefore could only function as a back-up for the first year's rearing of each captive brood. These "back-up" fish were released to Sweltzer Creek (below Cultus Lake) when space or water was required at Inch Creek.

Remaining eggs were pooled by egg take date and designated as supplementation. These eggs underwent typical hatchery production methods from this point until release.

Fish health

Disease screening: Following gamete collection, ovarian fluid and kidney tissue samples from each female were submitted for IHNV, *Parvicapsula*, and BKD screening by the Pathology Laboratory at the Pacific Biological Station.

Low BKD positive fry: Fry that were identified as low-BKD positive, by screening, were ponded in isolation of other groups and reared for as short a period as possible.

Egg fungal treatments: Prophylactic treatment, with Parasite-S, was used until eggs reached the eyed stage at >300 ATUs. At this point eggs were shocked, picked, and transferred to either the Sockeye Satellite Facility at Inch Creek or to the Rosewall Creek Hatchery for incubation to hatch.

Parasite treatments: *Salmincola,* a problematic parasite in wild smolts captured in 2002 and 2003, were effectively removed using a combination of parasiticide SLICE oral treatments and physical removal of parasites from fish during holding in preparation for the Captive Broodstock Program. Losses from treatment, handling and disease screening amounted to ~25% in 2002 and ~10% in 2003.

Fry production

Ponding: Fry were typically ponded when only a small amount of yolk was remaining, at approximately 850 ATUs.

Feeding: A small amount of feed was offered immediately on ponding, and fish were fed at approximately 125% manufacturer's recommended rations for the first two weeks of rearing. For the first two or three months fish were primarily fed using automatic belt feeders. Subsequently, fish were fed by hand.

Marking

Predominantly, fish produced in the program and released to the wild were marked with an adipose fin clip to ensure that enhanced origin stock was clearly identifiable in subsequent cycles. Exceptions occurred where capacity for rearing to the size conducive to marking (~1.0 g) was limited; in these cases a portion of fry were released unmarked.

Fish were anaesthetized with CO_2 and adipose fin clipped. Yearling smolts were both clipped and coded wire tagged. Summer fry (1-2 g) were marked with an adipose clip only, and from 2005 to 2007 were also calcein marked.

Fry that were low BKD-positive were marked and released as soon as possible.

To enable the assessment of survival to smolt of pre-smolt release strategies between brood year 2003 and 2009, a portion of fry received an additional mark using the fluorochrome dye calcein (SE-MARK™ – Western Chemical, Ferndale WA.). Calcein affixes to calcium and therefore predominantly attaches to bony tissue (Mohler 2003, Negus & Tureson 2004), and was used as an accessory mark, with an adipose clip indicating hatchery origin.

An annual Stock Assessment downstream trapping program is operated at the outlet of Cultus Lake over a three month period each spring, with peak sockeye smolt migration occurring in late April/early May. As all hatchery releases into the lake were adipose fin clipped, smolts were enumerated and checked for the presence/absence of marks in order to apportion numbers by strategy.

Acoustic tagging: Limited numbers of smolts were implanted with acoustic tags in 2004-2007 under the POST research program to monitor sockeye migration. Results can be reviewed in Welch et al. 2009.

Release strategies

Three release strategies were regularly employed.

1. Summer release of approximately 1.0 g fry
2. Fall release of approximately 4.0 g parr
3. Yearling release of approximately 20 g smolts

Fry and parr releases in the first years of the program were carried out directly from the shore. In 2003 program staff noted a lower than expected survival and in 2004 a shift was made to include mid-lake releases in an attempt to reduce losses. As of 2008 all fry and par releases were conducted mid-lake. The first brood year of smolts were released to the lake. Subsequent smolt releases were made directly to Sweltzer Creek below the counting fence. Where possible, releases were carried out at dusk to mitigate predator impacts.

<u>Annual release of 'off-cycle' fry from captive brood with 'on-cycle' fry from supplementation:</u> The tendency of captive fish to mature younger than naturally-spawned or released hatchery fish led to genetic differentiation each year between the captive-bred fry from Rosewall Creek Hatchery and the supplemental fry spawned at Cultus Lake Laboratory and released from Inch Creek Hatchery. Typically, the captive age three fish spawned at Rosewall Creek each year were siblings of age four supplemental fish that would return to Cultus Lake a year later. Thus, in many years, the release of both captive and supplemental fry from the two hatchery facilities increased genetic diversity in the release group and adults that returned from the release. Estimates of the 'genetic effective population size' from genetic data confirmed that the presence of fish released from Rosewall Creek increased the genetic diversity of the adult returns relative to that provided by the returning Cultus fish alone (including both those spawned in the lab and in the lake).

ANNUAL PROGRAM SUMMARIES

Note: Data are collated by brood year in the Appendices

2000

By October 2000 very few adult sockeye had returned to the fence at Sweltzer Creek; the estimated adult escapement was 1,242 (614 females were counted into the lake). Those fish that did return were in extremely poor condition, many displaying large body-surface lesions. As a result, an ad hoc effort by a small group of concerned DFO employees was undertaken to secure some sockeye production from the Cultus stock. The extremely low escapements and an expectation of very high pre-spawn mortality were later estimated at 93% (COSEWIC 2003).

<u>Cultus brood collection</u>

The fish for the initial project were collected from the counting fence on Sweltzer Creek. Fifteen fish were dip netted from the river and placed into a submerged holding pen where they could be inspected and tagged before being individually transferred into transport containers and carried a short distance (100m) to holding facilities located at the Cultus Lake Research Laboratory. The number of adults collected for broodstock represented 1.2% of the estimated escapement.

Gamete collection

Very few fish survived to maturation. Those that did survive - five females and ten males - were subsequently spawned, with all incubation and rearing over the following 18 months carried out at the Cultus Lake Laboratory. Under most circumstances adult mortalities are discarded, but eggs are known to be viable for at least 12 hours post-mortem (Rosenberg 1983) and, in an attempt to obtain as many gametes as possible, one female fish was spawned post-mortem with approximately 50% of the eggs surviving to hatch. Four of the males proved to be infertile and the final broodstock number – five females and six males – provided 13,385 fertilized eggs for the 2000 brood year.

Disease screening

In 2000, no disease screening was carried out and there were no observations of any parasite related mortality.

2001

Incubation and rearing

Eggs (13,385) from the 2000 brood were incubated at the Cultus Lake Laboratory in vertical tray incubators supplied with surface water, as no alternatives were available. The Cultus Lake Laboratory is a research facility and was not designed for production; water quality is unsuitable for rearing large numbers of fish. However, standard fish culture practices were implemented and equipment necessary for the project was secured from other facilities in order to carry out the ad hoc operation as best as possible under the circumstances.

Releases

Due to poor survival rates from 2000, no fry were released in the spring of 2001. Those juveniles that survived were retained for release as smolts in 2002.

Cultus brood collection

As in 2000, an extremely small adult run was observed; the total estimated escapement was 719 with 280 females counted into the lake. A second ad hoc intervention to collect and spawn a small group of adults was undertaken and 22 males and 22 females were collected. This represented 6.1% of the total estimated escapement.

Gamete collection

All males showed signs of maturity therefore hormonal treatment was not required. Female mortality was high and surviving females were injected with Ovaplant to increase the maturation process. Spawning procedures were identical to those used in 2000 and again, the limited number of adults available for spawning (nine females and 11 males) resulted in relatively few eggs collected. Six of the 11 males were jacks, and two adult females were spawned post-mortem. Estimated fecundity was 2,791 eggs per female and 24,458 eggs were collected.

Disease screening

In the first year of sample submissions to the Pathology Laboratory, no broodstock tested positive for IHN or BKD.

2002

Program formalization

In January 2002, the Enhancement Working Group was formed and DFO employees, including hatchery staff, HEB biologists, and PBS research scientists, were engaged in the process. At the initial meeting of the Enhancement Working Group it became evident that, without a change in escapement and pre-spawn mortality trends, standard enhancement techniques could not produce sufficient numbers of fry to rebuild the stock. Genetic concerns were investigated and the group prepared a report detailing requirements for a successful captive brood program. Accumulated knowledge, in addition to the report, served as the starting point for an official hatchery intervention and the Cultus sockeye captive brood program was set in motion with two guiding principles:

1. Preserve genetic diversity.
2. Produce 500 captive spawners annually, between brood years 2000 and 2007, to generate a genetically representative captive brood in numbers sufficient to sustain the stock.

Following a detailed risk analysis, Rosewall Creek Hatchery was determined as the only suitable location for the captive brood program, with the Sockeye Satellite facility at Inch Creek as a backup. Both of these were isolation facilities and followed the strict Alaskan sockeye culture protocols (see McDaniels 1994). Some of the considerations included an IHNV-free water supply, suitable water quality, emergency standby and security procedures, experienced fish culture staff, treatment of effluent for disease control if needed, and the number and variety of rearing ponds available.

Incubation and rearing

At the beginning of the year, 21,093 eggs from the 2001 brood year were incubating in vertical incubators; these were separated in Vibert boxes according to family until disease-screening results were available. To control fungus, eggs were treated with 1600ppm formalin twice weekly until eyed. Percent survival to eyed was 65.9%; 63.8% survived to ponding.

In April, 20,835 fry were ponded and reared on deep lake water (average temperature 6.7°C). Although automatic belt feeders were used when needed, fish were primarily hand fed to satiation.

Survivals were poor and in the spring of 2002, 3,891 pre-smolts from the 2000 brood year, and approximately 7,500 fry from the 2001 brood year were on hand at Cultus Lake Laboratory.

With little stock specific rearing and incubation data available, 2,400 eggs from the wild brood were included into each captive group as a measure to ensure that the target of 500 survived to maturation.

In the fall of 2002, 1070 captive two-year-old broodstock were present at Rosewall Creek Hatchery in the captive brood program.

Smolt migration and in-lake survival

As all of the smolts (3,891) being held from the 2000 brood year were released below the Sweltzer Creek fence; there was no enhanced migration from the lake in 2002. Wild spawners accounted for 3,666 1-yr smolts at the counting fence in 2002. In 2002, the fence was in operation from March 31 until June 5.

Releases

The limited broodstock from 2000 provided insufficient genetic diversity for inclusion in a captive brood program; therefore, the few progeny on hand from brood year 2000 (3,891 smolts ~26g) were adipose clipped and released to Sweltzer Creek during the wild smolt migration in April and May 2002. At the same time, 90% of the 2001 fry (0.5g or larger) on hand were marked by adipose fin clip only. Approximately 50% of the 2001 brood parr (3,715 released at 4.5g, 461 unmarked) were transported and released mid-lake, near Lyndel Beach in September. The remaining parr were held for release as smolts in 2003.

Cultus brood collection

Wild smolt collection: Due to concerns regarding limited genetic material for the planned captive brood program, the 2000 brood year pre-smolts rearing at Cultus Lake were replaced with wild out-migrants. It was proposed that a maximum of 50% of any wild smolts captured at the fence be retained for this purpose. In total, 2,014 wild smolts considered to be representative of the run timing (CLSRPP 2002a, 2002b) were collected for the captive broodstock program. Because of a lack of pathogen free water at Cultus Lake Laboratory, a temporary isolated compound was set up at the Chilliwack River Hatchery to hold smolts in quarantine while they could be screened for IHNV and *R. salmoninarum*. Feed containing a variety of both natural and commercial components (moist pellets, frozen euphausids, frozen mysis, and freeze dried cyclops) was used as transition diet, and over several weeks the fish were switched to a pelleted diet only. Results from disease screening permitted final disposition of approximately 1,500 fish to the Rosewall Creek Hatchery on Vancouver Island for rearing to maturity.

After arriving at Rosewall, the wild smolts experienced multiple infection cycles of *Salmincola*, which required repeated handling and manual removal of the dead parasites following oral treatment with emamectin benzoate (50mg/kg). Smolts were also treated with a regime of Parasite-S following transportation to mitigate fungal infections following the gill irritation brought on by the copepod infestation. The stresses associated with the parasites, treatments, and subsequent secondary fungal infection resulted in high mortality (approximately 50%).

Adult brood collection: In the fall of 2002, a total of 266 adults were collected at the Sweltzer Creek fence and moved to Cultus Lake Laboratory in a transport tank containing sedative and mucus protectant to reduce stress and abrasion. This number represented 5.2% percent of the estimated escapement (5,148 adults, 2,718 females). Each fish was prophylactically treated by antibiotic injection before being placed in holding into either a 5.5m diameter concrete holding pond or into one of 40 aluminum isolation boxes. Indoor six-foot circular containers were also tested, but a water supply interruption resulted in 100% mortality in these containers. A weekly flush treatment of formalin was applied to control fungus and external parasite infections.

Gamete collection

Use of photoperiod manipulation, spawning hormone injections, and mixed-sex holding of brood, were investigated as measures to improve holding and maturation, but difficulties with mortality and identifying tag loss confounded results. However, the overall pre-spawn mortality was lower (29%) than seen in the previous two years. Spawning included 70 males (of 89 captured), and 120 females (of 177 captured), producing 438,100 eggs that were matrix-fertilized to produce 480 distinct genetic crosses.

All eggs were incubated to eyed stage at Cultus Lake Laboratory. Ten eggs from each wild brood mating were transferred to the captive brood program. Five eggs from each mating were transferred to each of the two satellite locations (Rosewall Creek and Inch Creek) for duplication in the event of a catastrophic loss. Those eggs not destined for the captive brood program were deemed “supplementation” and transferred for final incubation, rearing, and adipose fin clipping at the Sockeye Satellite at Inch Creek. These were later released in 2003.

During the 2002 season it was noted that there was no apparent relationship between adult arrival and spawn timing. Eggs were collected once weekly, over six weeks, beginning November 13 and concluding December 16.

Cryopreservation

Cryopreservation of Cultus sockeye milt had taken place in the past to create a gene bank for the stock. Because of the low out-migration in 2002 an extremely low adult migration was anticipated in 2004 and gametes in storage were supplemented with milt samples from the 2002 brood. Over six weeks of spawning, 86 samples were preserved and stored at WestGen, a genetics preservation centre in Langley, BC. It was anticipated that this additional genetic material would provide an opportunity for cross-brood year DNA transfer to increase genetic variability.

Disease Screening

Samples for BKD and IHN screening were submitted for all adults spawned. One fish tested low positive for BKD. No fish were found to be positive for IHN. A sample of wild caught smolts was submitted for IHNV screening prior to transfer to Rosewall Creek for the captive program; none tested positive.

The parasite *Parvicapsula minibicornus* is present in the sockeye populations of the Fraser River and is thought to play a role in pre-spawn mortality, particularly in the early freshwater entrants from the late run stocks. Although reducing water temperature and minimizing handling and stress were expected to help the fish combat infection, an off label use of Albendazole was delivered twice via oral gavage during the holding period to some of the broodstock. The treatment was deemed to be ineffective as fish that were treated still had very high levels of the parasite in their glomerulus (25/25 glomeruli examined were heavily infested) at spawning time, and many untreated fish with the same level of infestation also survived to spawn. Eggs resulting from the treated fish were tracked to determine if the use of the medication would result in any detrimental impacts on egg survival. No discernible effect on survival was observed and the treatment was not repeated.

2003

Incubation and rearing

In the summer of 2003 there were approximately 2,075 brood year 2002 hatchery fry (< 1g) on site at the sockeye satellite facility, as a backup group to the Rosewall captive brood. An additional 262,000 brood year 2002 hatchery fry represented surplus progeny of the captive brood egg take, were ponded at the Inch Satellite facility, and were scheduled for release to Cultus Lake at 5g in early October, 2003.

Egg survival to the eyed stage was 86.6%. Egg mortality was presumed to be related to a combination of factors including extra handling of fish and eggs to satisfy Alaska Sockeye Salmon Culture Manual protocols, broodstock treatment effects, and small volumes of milt available for some matrix spawnings. Because the objective was maximum diversity not maximum production, no changes to procedures were recommended.

One group of Cultus Lake wild stock 2002 brood fry, reared at Inch Creek Hatchery were fed an unrestricted diet, resulting in much larger fish over the same growth period. Since an extremely limited adult return was expected in 2004, three hundred were retained for the captive brood program and the remaining 1,620 were transported to Cultus Lake for release in 2004. To distinguish these fish from normal smolts they were designated as super-smolts (SS) in release reports.

As at June 2003, Rosewall Creek Hatchery maintained 1,061 wild spawned juveniles (brood year 2000) of approximately 250-300g, 989 hatchery juveniles (brood year 2001) that ranged between 150-200g, 796 wild juveniles (brood year 2001) between 12-20g, and 1,986 hatchery fry (brood year 2002) of less than 1g.

Smolt Migration and In-lake Survival

In 2003 the fence operated between March 24 and May 28. During this period, a total of 11,260 smolts (one and two year olds) migrated through the fence. Half of the hatchery smolts (1,598) were released below the Sweltzer Creek fence and the remaining fish (1,568) were released at Maple Bay. Of those released to the lake, 562 were enumerated past the fence for a survival of 11.7%. A further 3,715 parr were released to the lake in the fall of 2002, but survival to migration of these fish is unknown. The wild contribution to the migration in 2003 consisted of 10,698 1-yr smolts.

Releases

A number of release strategies and timings were employed during 2003. The captive excess remaining on hand from 2001 were differentially clipped and released into the lake (Ad/RV – 1,568) and to Sweltzer Creek (1,568 - Ad/LV).

Releases were conducted from shore rather than mid-lake as done in 2001, predominantly because the much larger release number of fry was logistically more difficult to move safely to the center of the lake, and they were carried out at dusk to reduce predation.

Fall parr (227,029) from the 2002 brood were released from shore at dusk in late September, 2003.

Cultus brood collection

Wild smolt collection: Wild smolts (881 from the 2001 brood year) were captured at the Sweltzer Creek fence in the spring of 2003 to supplement the genetic makeup of captive brood reared from egg. Smolts were collected across the entire run period, transferred to the Sockeye Satellite at Inch Creek Hatchery for disease screening and parasite removal. In the summer of 2003 approximately 796 of these (12 to 20g) were transferred into captive brood. An equal number of brood year 2001 hatchery-produced fish were retained to ensure 1,500 captive brood would represent the year.

Adult collection: In the fall of 2003, 246 adult fish were collected at the Sweltzer Creek fence; approximately 5% were lost to pre-spawn mortality during the holding period (60-90 days post-capture). The adults collected for spawning represented 11.3% percent of the estimated total adult escapement (2,185 total; 864 females).

Gamete collection

Spawning of wild caught fish spanned from November 18th until December 22nd with 132 females and 100 males successfully used: 464,038 eggs were collected and 640 distinct matings were produced, of which 592 were assigned to the captive brood program. Of the 100 males spawned some were used for fertilization only, some for fertilization and cryopreservation, some for cryopreservation only, and some were discarded for quality or volume reasons. Eggs were collected once weekly, over six weeks, beginning November 18 and concluding December 22.

The use of PIT tags made it possible to record the date of capture at the fence and related that information to h individual spawn timing. It had been assumed that the earliest arriving fish would also be the earliest spawners, and that late arrivals would be the last fish to spawn. However, no relationship between time of arrival and time of spawning was found; late arrivals might spawn immediately and early arrivals might be the last to spawn.

Eggs were incubated at Cultus Lake Laboratory until eyed and picked of dead. Eggs assigned to the captive brood program were distributed between Rosewall Creek and Inch Creek Hatchery facilities with roughly equal numbers transported to each facility, 1,734 to Rosewall Creek and 1,731 to Inch Creek. The remaining eggs were transported to Inch Creek for secondary incubation and rearing.

In the captive brood program, approximately 62,000 eggs were collected from maturing two and three-year old stock. Of the 2001 brood wild smolts, 184 matured as age-2 fish, however these were predominantly males and the eggs (16,000) from the two-year-old females proved infertile. The production from 22 captive three-year-old females and 67 males resulted in 46,000 eggs for incubation.

Disease screening

Tissues and ovarian fluid were collected from all adult females and were submitted to the Pathology Laboratory for BKD and IHN screening. Of the 132 females screened, 121 tested negative for *R. salmoninarum* and all tested negative for IHNV; these eggs were assigned to captive brood and production use. An additional eight females were found to have low detectable levels of *R. salmoninarum*; these eggs were assigned to production only and reared in isolation. Three females were untested for IHN due to insufficient ovarian fluid, therefore these eggs were assigned to production only and reared in isolation. One female was spawned late and was not screened for disease; these eggs were assigned to unfed fry release.

2004

Incubation and rearing

Following primary incubation at the Cultus Lake Laboratory, 402,000 eggs were transferred from Cultus Lake Laboratory to Inch Creek for the remainder of incubation and rearing to release. The 46,000 eggs produced from captive brood at Rosewall were transferred to Inch Creek for rearing to release.

Smolt migration and in-lake survival

Stock Assessment counted 115,400 smolts through the fence in the spring of 2004. Of these, 109,843 were 1-yr wild smolts, 6 were 2-yr wild origin, 5,542 were enhanced origin from brood year 2002, and 9 were 2-yr smolts of enhanced origin. The fence was operated between March 30 and June 3 in 2004.

Survival to smolt through May 2004 of the 2002 brood year adipose clipped fall parr release group was just 2.44% and compared poorly to the 11.55% survival from the small release group the previous year. Acoustic sampling conducted indicated wild summer fry to smolt survival was within normal range (10-15%).

Releases

The 2002 brood year back-up super-smolts at the satellite facility had reached a size of approximately 75g by spring 2004. These excess-to-captive fish were marked with a combination of adipose and ventral fin clips to differentiate between the two groups. A total of 515 fish were marked with adipose/left ventral clips and released to Cultus Lake. The remaining 540 super-smolts were marked with adipose clip and right ventral fin clips and released to Sweltzer Creek. None of these fish were recovered and in subsequent years smolts were placed into the creek to avoid residualization. Mortality related to ventral fin clipping has been estimated to be high, up to 41-46% (SEP-HEB 1995) therefore, to reduce risk of lowered survival; this was the final use of this mark.

A total of 1,080 super-smolts were adipose only clipped and released below the fence on Sweltzer Creek in May. Some (120) of these were also implanted with acoustic radio tags for the POST program.

Eggs from the 2003 brood year for those fish that screened low-detectable for BKD were released as unfed fry (32,740 @ ~ 0.15g) to Jade Bay and Maple Bay in May and June. These groups of fry, because of their small size at release, were not marked.

A summer release of 148,448 took place from shore at Maple Bay in July. These fry were adipose clipped and calcein marked.

Fall releases were carried out at Jade Bay and Maple Bay in October and November. A total of 164,814 captive brood parr (4.5 g) were adipose clipped and released from shore. The remaining 48,913 fish (reared to various smolt + sizes), were held for release in 2005.

Cultus brood collection

In the fall of 2004, only 89 of an expected 300 - 500 spawners returned to Cultus Lake. Only an estimated 77 survived to spawn, 33 of these were females. This was the second lowest escapement on record (85 in 1997). A risk avoidance strategy was in place that limited the captive program to 50% or less of the return, therefore only 37 adults were captured for the enhancement program representing 41.6% of estimated escapement.

Seventeen males and 20 females were captured at the fence on Sweltzer Creek, of which three males and three females were hatchery adipose clipped fish. Many of the adults were in very poor physical condition, displaying recent scarring and fungal infections. During handling (capture, tagging, drug injection etc.) a number of these fish were noted to have abnormal morphological characteristics and advanced spawning coloration.

DNA screening

Because a number of fish collected at the fence displayed characteristics unusual to the stock, it was hypothesized that there were some non-Cultus origin fish in holding. Tissue samples were removed by opercular punch from each adult and forwarded to the Genetics Laboratory at PBS for analysis. DNA analysis confirmed observations that two males and four females, among the 37 total fish collected, were strays from other systems however, these died prior to spawning. All fish that were spawned, both wild and marked, were confirmed as Cultus origin by DNA analysis.

Gamete collection

Ten females and 15 males of returning adults were matrix spawned, In addition, the females were crossed with 10 captive 2002 brood year males from Inch Creek and cryopreserved milt from 2002 brood yearthe (Forty-six samples of brood year 2002 cryopreserved milt from 39 wild males were used to generate 89 crosses). Fertilization rates were considerably lower in crosses using cryopreserved milt (48%) compared to those that used milt from the returning adults or from the captive brood fish from the Sockeye Satellite (91%). In total, 198 distinct matings were accomplished using adult fence return females, and 40,000 eggs were collected. Eggs were collected once weekly, over five weeks, beginning November 16 and concluding December 14.

Disease screening

Standard disease screening was undertaken in 2004. Tissues and ovarian fluid from all females spawned, both wild and captive reared, were submitted for IHN and BKD screening; none tested positive for either disease.

An ongoing low-level disorder, termed "side-swimmer disorder", was investigated and National Marine Fisheries Service staff in Washington State working with Redfish Lake sockeye, were consulted on the condition. Unfortunately, no conclusions were reached on the issue. A small percentage of fish, especially after age two, appear to quickly develop the disorder that results in a horizontal swimming orientation. Fish survive for varying lengths of time (6 months or more) following onset of the condition, but eventually cease feeding and expire. Although the condition was not rare, captive brood losses were generally less that 1%.

2005

Incubation and rearing

Eggs collected from 2004 returning fish were incubated at the Cultus Lab until eyed stage, when they were surface disinfected and allocated to captive or supplementation production streams. Three eggs from each mating were removed for inclusion into each of the captive programs at Rosewall Creek Hatchery and the Sockeye Satellite Facility at Inch Creek. (~1,600 to each facility - 860 were captive derived and 830 originated from Cultus returns). Eggs derived from Cultus returns not required for the captive program were designated for supplementation and 40,000 were pooled and transported to the Inch Creek facility for hatching, rearing, and release.

Rosewall Creek produced 1,325,735 fertilized eggs in brood year 2004, with survival to release approximately 50%. Inch Creek was allocated 507,000 of the surviving eggs, and the remaining 254,000 eggs were incubated and reared at Rosewall Creek.

Smolt migration and in-lake survival

Fence enumerations saw 81,453 1-yr and 287 2-yr enhanced origin smolts, and 17,156 1-yr and sixteen 2-yr wild origin smolts migrate out of the lake for a total out-migration of 98,912 fish leaving Cultus Lake in 2005. The fence was operated from March 14 until May 27 in 2005.

Releases

An April pre-smolt release was planned to provide hatchery fish with an acclimation period prior to the natural wild smolt outmigration. In mid-March, due to unexpectedly low well water levels, water needs at the Inch Creek sockeye satellite exceeded availability for production. As a result, 47,269 pre-smolts were adipose clipped and coded wire tagged before being released at 12g. These fish were released from Jade Bay and Maple Bay in approximately equal numbers.

Unmarked, captive-bred supplementation fish (263,618) were released in April as fed fry (mean weight 0.28g) to Cultus Lake at Spring Bay. The unmarked release was necessitated by lack of rearing space and represented the only large-scale release of unmarked fry.

In May and June, 1,109 POST tagged super-smolts (~70g) were released at the Sweltzer Creek fence.

Poor results from the 2004 smolt release prompted release strategy changes and through July and August, 297,085 adipose clipped juveniles were calcein marked and released as fed fry (~1.25g) mid lake near Jade Bay. Adipose clipped parr (131,743 at ~6g) were released near Jade Bay in Cultus Lake over a period of nine days in October. These were released mid-lake as a predator avoidance tactic.

Cultus brood collection

In keeping with measures set out in departmental genetics guidelines, and as an additional risk avoidance measure to help protect the small 2005 return (375 adults), 50% of returning females were captured for holding and the remaining fish were allowed to pass into Cultus Lake to spawn naturally. A total of 148 fish (63 females and 85 males) were collected as brood, representing 39.7% of the estimated escapement.

Pre-spawn mortality of held fish was minimal at 5.4% whereas the pre-spawn mortality of fish passed into the lake was estimated at 18%. It is thought that prophylactic antibiotic injections may have provided a survival benefit.

Gamete collection

In October, approximately 300 two-year-old fish (~1.0 kg) were on site at Inch Creek; they had been retained for possible use in the captive program. The 50 largest of these were taken off feed, to promote maturation, and ten males matured through November and December. These were used for matrix fertilizations at both Cultus and Rosewall Creek, and also provided milt for cryopreservation for supplementing future years. These 50 fish, and the remaining 249, were then released, unmarked, from shore at Spring Bay.

From the Sweltzer Creek collection, 60 females and 78 males were successfully spawned and more than 185,000 eggs were collected. Twenty of the males were jacks and these were randomly utilized for spawning throughout the season. The targeted number of crosses was achieved using wild or unmarked females and, of 518 crosses, 3% were fertilized with 3-yr old males of hatchery origin. Eggs were collected once weekly, over six weeks, beginning November 16 and concluding December 20.

More than 400 captive-reared females from the 2000 (wild smolt) and 2001 (wild smolt/hatchery) broods matured and were spawned at Rosewall Creek. Some wild smolt origin females from both brood years were also fertilized with the growth advanced males and cryopreserved sperm. In excess of 720,000 eggs were collected from the captive program.

Disease screening

Ovarian fluid and kidney tissue from all spawned females, both Sweltzer and captive brood, were submitted for IHN and BKD screening. One captive female tested positive at a low level for BKD; this small egg lot was subsequently incubated and reared at Rosewall, Creek in isolation of other groups, and the short-term fed fry were released unmarked to Spring Bay in 2006.

2006

Incubation and rearing

The supplementation eggs (185,273) from the wild spawning were incubated at Cultus until eyed. Following pick, the eyed eggs were transported to the Inch Creek Sockeye Satellite for final incubation and rearing through to release.

Incubation at Rosewall Creek Hatchery comprised 721,052 eggs from captive brood at the beginning of 2006.

The captive brood component of the program retained 1,574 fry. These fry had a mean weight of 2.25g as at August 2006, and their survival from ponding was approximately 70%.

Smolt migration and survival

During the outmigration in 2006, 40,562 1-yr and 50 2-yr hatchery origin smolts passed through the fence during the period of operation (March 15 to May 31). The survivals from brood year 2004 were estimated at 4.95% for the spring release, 6.65% from the summer release, and 15.5% from those released in the fall.

The unmarked component of the migration consisted of 13,742 1-yr and 22 2-yr smolts. Otolith analysis provided an estimate that of the 13,742 1-yr old smolts, 3,104 were wild and 10,638 were unclipped hatchery smolts.

Releases

An allocation of 2,495 surplus smolts (~ 40g) retained for the POST program was unused; a transplant approval was received for their release to Cultus Lake. These fish were adipose clipped and released at Spring Bay in February.

In April, 51,388 supplementation smolts (mean weight 22g) marked with adipose clips and coded wire tags were released below the fence in Sweltzer Creek. Captive surplus/excess super-smolts (mean weight 65g) from the Inch Creek facility were adipose clipped and released to Sweltzer Creek in April; this group numbered 2,372 and included 200 POST tagged fish.

The isolated group of fry from the low BKD positive female was released as unmarked fed fry (1,584 fry) at an average weight of 0.39g. They were released to Spring Bay in late April.

In mid-June, 56,411 adipose clipped, fed fry (1.2 g) were released near Jade Bay into Cultus Lake; release was mid-lake for predator avoidance. Captive progeny were generally kept separate whenever possible to allow for earlier release in hopes of challenging them to natural selection processes for a longer period of time. However, limited rearing space had necessitated that fry from both captive and wild egg takes be ponded together in the same container, therefore this release comprised both Cultus and Rosewall progeny combined.

In late July, 133,615 fry (1.3 g) were adipose clipped, calcein marked, and released mid-lake from the south end of Maple Bay, where surveys indicated the fewest pike-minnow were present. These fry were also of mixed composition (wild and captive).

In October 2006, 98,813 mixed composition, adipose clipped, parr (4g) were released at Jade Bay, by hose, approximately 200m offshore. Additionally, 56,982 separately reared supplemental fish were released mid-lake from Jade Bay as fall parr (adipose clip only, 4.5g).

Cultus brood collection

Of an estimated of 3,797, 276 fish were retained (168 females and 107 males) representing 7.3% of the run. All were unmarked. Stock assessment recorded 2,083 females passed into the lake. Pre-spawn mortality in the captured fish was 29% during holding (33 males and 48 females); a water flow problem was responsible for 21 of the mortalities. Pre-spawn mortality was substantially lower than that estimated for fish allowed to pass into the lake. When the water flow related mortalities were removed from the total, the pre-spawn mortality rate of held fish was less than 25%. This compares with estimates of 40-70% for those in the lake.

Gamete collection

A total of 430,674 eggs were taken from 121 returning females. From these eggs, and the milt of 76 wild origin males, 568 distinct crosses were produced. Once the low BKD lots were removed (52 crosses from 10 females screened low BKD positive and were removed from the captive stream), 516 crosses were assigned to captive brood. Eggs were collected once weekly, over seven weeks, beginning November 14 and concluding January 2.

Due to operational complexities that arise from the long (up to 150 days) maturation windows experienced with captive broodstock at Rosewall Creek, a study was conducted during the 2006 collection. All age-5 & 6 (2000 & 2001) brood were food deprived to promote maturation, and the age-3 & age-4 broods were divided into fed and unfed groups. Pre-spawn mortality in the food deprived groups (August to November) was 5.5%. Mortality in the fed groups averaged 11.8% over the same period. Starved fish displayed a more compressed spawning window and spawn timing was nearer that seen in the wild. Eight age-5 females matured (predominately from collected wild smolts) but the 20,000 eggs spawned were 100% infertile. No age-6 females (wild smolts) matured. Given these results, and after wider consultation - the team decided the program would be best served by euthanizing all age-4+ fish that had not matured by January 31st (previously chosen as latest day for inclusion into any particular brood production).

Fecundities of age-3 females were adequate for the needs of the program, and the reduction of age-4 biomass improved rearing conditions by reducing densities and load rates. Over the course of the 2006 egg take, 49 of the 2002 brood (age-4) and 395 of the 2003 brood (age-3) females were spawned.

The captive program produced 980,268 eggs from three and four-year-old broodfish.

Disease screening

All spawned females were tested for IHNV and BKD. Of the 121 returning females disease screened, 111 tested negative for BKD and IHNV, and 10 females tested low level detectable for BKD. From the captive brood samples, 5 females tested low level of detection, and four returned low positive results. Eggs from low BKD positive fish were incubated and reared in isolation. There were no IHN positive results.

2007

Incubation and rearing

Each of the Rosewall and Inch Creek programs received 1,509 eyed-eggs for the captive program. Survival to eyed at Cultus was 85% and 363,264 supplementation eggs from the spawning were transferred to the sockeye satellite facility at Inch Creek.
Following eyed egg pick, 808,175 eggs remained on hand at Rosewall Creek. There was insufficient incubation and rearing space available at the Inch Creek Sockeye Satellite for more than 750,000 Cultus eggs in total, therefore 360,000 eggs were transferred to the Inch Creek facility and the remaining captive brood progeny were incubated, reared, and marked at Rosewall Creek prior to transport and release to Cultus Lake. In all, 640,000 fry were reared to release.

Smolt migration and survival

The wild component of the smolt migration consisted of 9,606 1-yr and three 2-yr smolts. Enhanced contribution to the migration was 35,476 1-yr and 20 2-yr smolts. The fence was in operation between March 29 and May 31, and the total migration from the lake was 45,105. Additionally, 52,029 hatchery smolts and 1,137 super smolts were released below the fence in 2007 for a total estimated system out-migration of 98,200.

The enhanced contribution to the smolts migrating out of the lake in 2007 consisted of two groups: one group that had an adipose clip and calcein mark and a second group with only an adipose clip. The adipose/calcein group consisted of fry released July 25-26, 2006 with a mean weight of 1.32 g and the survival to migration of these fish was 8.7%. The adipose only group contained a mix of release dates and weights, but the overall mean weight was 3.4 g, and the survival to migration was higher at 11.2%. Also included in the adipose only marked group were 14,505 fry that were produced from adults spawned at RWC on Jan. 31st or later in 2006. These fry were kept at Rosewall Creek on warmer water and released in Oct. 2006 as parr.

Sampling conducted at the fence once again indicated a similar size at migration of hatchery and wild smolts with ~10% size variation between the two (wild larger in 2007), averaging ~12-13g.

Releases

Due to difficulties with supply and permits from Health Canada, calcein marking was applied to the fall instead of the summer release group.

From a risk avoidance perspective, marking the fall release instead of the summer group reduced the numbers of handled fish by up to 80%, thereby reducing exposure to possible mark complications. The quality of the calcein mark was excellent through to release (fish were shaded immediately following marking to negate the destructive effect ultra violet light has upon the compound) and no problems were apparent with marking the larger sized fish.

Spring releases (April - May) consisted of the planned supplementation release of 52,029 smolts. These were adipose clipped and tagged with agency tags (tags that include the simple, etched DFO code, but not the full binary that would denote a distinctive ID within DFO coding parameters) before being released in two batches in late April. Two adipose-clipped surplus super smolt releases (697 and 440 fish at an average mass of ~80g) took place below the fence at Sweltzer Creek. Of these, 320 were POST tagged.

A total of 569,861 summer fry from Rosewall Creek were released to Cultus Lake from Jade Bay between June and August. These ranged between 0.92 - 1.63g and were all adipose fin clipped. A mixed composition group of 113,638 summer fry and a wild Cultus group of 123,201 were also released, in late July, as adipose clipped, fed fry.

Of the summer fry from Rosewall Creek, 38,264 originating from females that were screened at a low level of detection for BKD and reared in isolation were adipose clipped and released as summer fry in June and July. Of the mixed composition fry released in late July, 17,228 originated from low BKD positive females.

Two groups of parr were released in October after being adipose clipped. 71,005 of these were also calcein marked while the remaining 67,150 were adipose clipped only.

Releases of juveniles from eggs produced at Rosewall totaled 702,000 adipose clips. Of these, 664,800 were released as summer fry, and 37,000 were released as the remaining component (~25%) of the 150,500 Calcein marked fall parr group. Survivals from fry stage through to release were comparable to those from the adult collection program.

248,528 adipose clipped juveniles were released from the broodstock collection program and included; ~84,000 summer fry, ~113,000 fall parr (75% of the total 150,000 calcein marks,) and ~50,400 smolt (CWT) release.

All of the summer-released fish were released mid-lake from Jade Bay at dusk as a predator avoidance measure.

Cultus brood collection

Escapement was only 25% of that predicted, and the attempt to retain fish from all timing portions of the run required passing fish into the lake earlier in the migration in hopes of retaining later fish. As in 2006, there was not a prolonged migration and numbers abruptly decreased near the end of October with the latest arriving fish suffering the greatest mortality. The final escapement was estimated at 800 adults (282 females), and 151 were collected as broodstock (18.9% of the run). Of the final 16 fish captured (between October 10th and November 7th) twelve perished prior to spawning. Only one of the first 75 females captured between early September and mid-October succumbed prior to spawning.

In total, 61 wild males and 90 females were collected and pre-spawn mortality was low at 12% (18 fish). The pre-spawn mortality of fish passed into the lake was estimated at 30-70%. Given that adults spawn at depth in Cultus Lake, pre-spawn mortality estimates may be inaccurate due to the difficulty of recovering carcasses.

Gamete collection

In total, 282,261 eggs were taken at the Cultus Lab from the 74 females that matured. The fertilization matrix used 59 males. Eggs were collected once weekly, over seven weeks, beginning November 13 and concluding January 2.

The captive program produced 935,247 eggs from three-year old fish (126 males and 440 females), and 183,218 from four-year old fish (100 males and 85 females) for a total of 1,118,465 eggs.

Disease screening

All captive brood females were screened for IHN and BKD, 12 screened positive at a low level of detection for BKD. Although cross-contamination was suspected for 5 of 6 sequential samples, all were incubated and reared in isolation and assigned to supplementation production. No wild origin females tested positive.

2008

Incubation and rearing

Since there were no positive screening results from the wild-origin females, representative eggs from all 594 families were included in the captive brood program. Following eyed stage pick and disinfection, 1,654 eggs were transported to Rosewall Creek, and 1,654 captive backup and 257,915 supplementation eggs were transferred to the Inch Creek Satellite facility. Survival from green to eyed stage for the 2007 brood was 91.5%.

The 525 females spawned at Rosewall in 2007 produced 1,118,465 eggs. Following eyed pick there was insufficient incubation and rearing space available for the remaining 841,285 eggs at the Inch Creek Sockeye. Therefore, after surface disinfection, ~537,000 eggs were transferred to the Inch Creek facility for rearing, marking, and release, and the ~304,000 in excess of available space remained at Rosewall Creek for full incubation, rearing, and marking prior to transport and release to Cultus Lake as summer fry. Survival from green to eyed egg stage was 75%.

Smolt migration and survival

The fence was in operation from March 18 until May 18 in 2008. The hatchery out-migration resulted in 201,648 1-yr and 40 2-yr smolts passing through the fence. This included adipose clipped fish from a summer release of 806,690 (20% survival) and a fall adipose clip/calcein release (28% survival). The wild migration numbered 135,607 1-yr and seven 2-yr smolts.

Releases

50,503 adipose clipped and coded wire tagged smolts (mean weight ~ 22g), and 1,400 adipose clipped only surplus super smolts (~60g) were released to Swelzer Creek in April and May.

Summer releases of captive brood origin fry totaled 557,793 between June and August. All releases were fed fry (mean weight ~1g) and all were adipose clipped. Releases were conducted mid-lake at dusk from Jade Bay; 190,837 mixed composition, adipose clipped fry (~1g) were also released mid-lake at dusk in August.

All fall parr released (150,572) were adipose clipped and calcein marked in August at 1.5g and released at 4g in October.

Cultus brood collection

A total of 161 wild adults were collected at the Sweltzer Creek fence, 83 males and 78 females. This represented 31% of the estimated escapement (521 total, 164 females passed through to the lake). Fifteen of the collected males were jacks and 54 were 4 year olds males. It was estimated that only 5% of the returning adults were of wild origin, the remainder of hatchery origin.

Pre-spawn mortality in held fish was 21% (34 adults). Late arriving adults formed the majority of this – approximately 16 of the last 20 fish that were collected and transferred into holding died. There were no unusual results from diagnostics and it was contrary to the results from previous years where *Parvicapsula* infected fish saw high mortalities in the early arriving adults.

Gamete collection

Eggs were collected once weekly, over five weeks, beginning November 18 and concluding December 22. A total of 69 returning females were spawned and, to fulfil fertilization matrix requirements, each female's eggs were distributed into either 10 or 8 lots of equal proportion. Ten lots were chosen early in the spawning window and were reduced to eight lots mid-season as the likelihood of obtaining targeted number of crosses increased. Milt from 59 different males was used in a fertilization matrix with 1-15 crosses from each male. A total of 257,915 eggs were collected and 586 genetically distinct families were produced using matrix spawning. All females were successfully outbred with crosses conducted between genetic groups as shown in Table 1. Ranking of male groups for producing the least genetically similar crosses with female groups is shown in Table 2. The 1st ranking for all crosses was group 2 unmarked wild fish (highest priority cross). The 2nd rank were group 3 jack unmarked or marked (alternate brood years) except for group 3 (jack) females.

Following disease screening, a total of 1,662 eggs (three from each of the remaining 554 families), were retained for inclusion in the captive brood program.

At Rosewall Creek, all age three & four fish were fed a reduced ration during June and starved beginning in July. In early November, fish showing no visible signs of maturation were sorted and reintroduced to food. Unfortunately, fungal infections caused high mortality and an estimated 60-70% loss of age-four fish for the 2008 brood year. Only three and four-year old fish were utilized for spawning and none of the remaining 2004 adults were held for future seasons.

Disease screening

All wild-origin females were disease screened and all fish were negative for IHNV. Four females tested positive at a low level of detection for BKD and the 32 crosses involving these females were removed from the captive program. Eggs from these fish were reared in isolation at Inch Creek, but were marked and released as a part of the regular supplementation release.

In the captive program, six females returned low level of detection, 5 were low positive, four were moderately positive, and four were high positives for BKD. The moderate and high positives were destroyed. However, eggs from more than 25% of these females were immediately discarded at spawning as they were visibly of poor quality. The remaining low positives and low level detection eggs were incubated and reared in isolation of other groups.

2009

Incubation and rearing

At the start of 2009, approximately 250,000 eggs from Cultus fence females were incubating at Inch Creek. The captive brood program provided 879,918 eggs to incubation; approximately 587,000 of these were transferred to Inch Creek for rearing, and roughly 91,000 were reared at Rosewall Creek. 1,566 eggs were transferred to Rosewall Creek for the captive brood program. This was the final group of eggs into the captive brood program.

Smolt migration and survival

The Cultus Fence was operated from March 23 until May 18, when high water flow and associated debris forced removal of panels. The total number of smolts enumerated in 2009 was 288,832. Of these, 70,106 (70,073 1-yr, 33 2-yr) were unmarked wild fish and 218,726 (218,429 1-yr, 297 2-yr) were of hatchery origin.

Hatchery survival from lake release to migration of the adipose clipped-only group was 26.8% (173,825 from the summer release total of 648,269) and the adipose clipped calcein group had a survival rate of 29.6% (44,605 from the fall release total of 150,572).

Releases

Three hundred captive (backup fish raised at Inch Creek) super-smolts (62g) were transported to Rosewall Creek to top up the three captive pools at that location. The remaining 1,250 super-smolts were adipose clipped and released to Sweltzer Creek in April.

50,395 adipose clipped and coded wire tagged smolts (22g) were released below the fence on Sweltzer Creek in May.

All summer releases (677,868 - July-August) were adipose clipped and were of captive Rosewall supplementation origin (1.2 – 2.2 g). All summer release fry were released mid-lake at dusk to Cultus Lake from Jade Bay.

The fall release consisted of 142,248 adipose clipped and calcein marked parr (~5.25g) that were released mid-lake at dusk, from Jade Bay.

Cultus brood collection

Of the 1,722 adults that returned to the fence, 282 were collected with the remainder passed through to the lake, representing 16.3% of the estimated escapement. Of the broodstock collected, 162 were male and 120 were female. Jacks comprised a significant portion of the return.

As first noted in 2008, late arriving fish had a lower survival rate than did early returns and, of the last 34 fish captured between mid-October and early November, 44% (15 fish) succumbed prior to successful spawning. Pre-spawn mortality for the fish captured prior to October 15th was approximately 7% and includes more than 50 fish that were captured when water temperatures were greater than 20°C

Although the 2009 adult return was lower than the number anticipated, the escapement of 1,661 represented a 442% increase over the 376 counted in the 2005 brood year. Cultus was the only Fraser River sockeye stock, other than the Harrison, to see such an increase in numbers that fall.

Gamete collection

Of the 282 returning adults collected, 117 males and 92 females matured successfully and 320,209 eggs were collected. Eggs were collected once weekly, over six weeks, beginning November 17 and concluding December 22.

The captive brood program produced 437,887 eggs. Three-year-old broodstock (304 females and 195 males) provided 432,537 eggs and 5,350 eggs were collected from four-year-olds (six females and 18 males).

Disease screening

Five females from the first egg take screened low-level positive for BKD. None of the 87 remaining female broodstock tested positive from any other egg take. The five low level BKD positive females were excluded from the captive broodstock program (30 crosses) and resultant fry were reared in isolation.

Losses to side-swimming in captive reared fish were lower compared to previous years, as the season progressed, other mortality increased and post mortem samples from both the 2005 and 2006 brood year fish tested positive for BKD. In late May, the 2005 brood year (three-year old) fish were being held in a single container. These fish had suffered 40% mortality since January and received an injection of OxyVet. Mortality in the 2006 brood year (two-year old) fish was 4% between January and May and these fish received erythromycin treatment via medicated feed. Mortality continued through the fall and during the captive brood spawning, 304 females were tested for BKD with 71 screening positive. Fifteen screened at a low level of detection, and another 22 were low positive. Eggs from these females were reared in isolation. An additional 34 females screened at moderate or high level positive for BKD and their eggs were culled from the program.

2010

Incubation and rearing

In January 2010, 285,200 eggs were incubating at Inch Creek. No unusual conditions were observed during incubation of Cultus fence-returning origin and, following eyed egg pick, the survival to this stage was estimated at 85% (252,453). The captive brood at Rosewall contributed 432,630 eggs to incubation.

Smolt migration and survival

The fence was operated between March 15 and May 21 in 2010. Only 365 1-yr and four 2-yr smolts were of wild origin in 2010. Hatchery releases resulted in an outmigration of 88,089 1-yr and 119 2-yr smolts. The 1-yr hatchery releases represented a 10% survival to out-migration. Given that no secondary mark was applied, this is the first brood year that separation of summer vs fall survival is not possible.

Releases

In May, 55,568 adipose clipped and coded wire tagged smolts (~22g) were released below the Sweltzer Creek fence. In April, 1,260 adipose clipped super-smolts (82g) were released at the same location.

In July, 103,149 captive reared fish were released as adipose clipped fed fry (1.4g) from Jade Bay. A further 132,957 adipose clipped fed fry (1.23g), of mixed captive and Cultus return origin, were released in August.

In October, 148,532 parr, originating from wild returns, were released. All of these were adipose clipped, and 93,052 were calcein marked.

Cultus brood collection

Broodstock collection resulted in 357 adults into holding (153 males and 204 females). The total number of adults counted through the fence and collected for broodstock provided an escapement estimate of 10,654 with 5,541 females counted into the lake. Broodstock collected for enhancement represented 3.3% of the returning escapement.

Gamete collection

Of the 357 adults collected from wild returning brood, 105 males and 184 females were spawned, producing 719,624 eggs. Eggs were collected once weekly, over six weeks, beginning November 16 and concluding December 14.

The captive brood program spawned 343 females and 176 males from the three-year-old brood for a total of 901,654 eggs. As a result of high mortality from BKD, it was decided that the age-four year class would be culled.

Disease screening

Of the 184 Cultus return samples tested for BKD, 127 tested negative, 43 were low level detection, and 14 tested low positive. All were negative for viral testing. Rosewall captive screening resulted in 335 negatives, one low level detection – these eggs were discarded.

2011

Incubation and rearing

In early 2011, 719,624 eggs were incubating at the Inch Creek Satellite facility. Due to rearing space constraints and concerns over density, 54,754 eyed eggs from low-level detection females were culled. Following picking, survival to eyed was estimated at 81.5% and 564,153 eggs were taken through rearing at Inch Creek.

The captive brood at Rosewall contributed 664,778 eyed eggs to incubation (survival to eyed 73.7%). Due to space constraints, 462,391 eggs were moved to Inch Creek and 202,387 remained at Rosewall Creek.

Smolt migration and survival

Between March 11 and May 26, a total of 57,624 1-yr unmarked smolts and four 2-yr unmarked smolts passed through the counting fence during the spring 2011 out-migration. The enhanced component of the out migration included 64,681 2-yr and 23 age-3 smolts.

Releases

During the spring of 2011, 50,425 adipose clipped and coded wire tagged smolts (~22g), and 1,260 adipose clipped super-smolts (82g) were released below the Sweltzer Creek fence.

Between early June and mid-August, 650,653 fed fry were released to the lake at Jade Bay. Of these, 257,670 were released in June and originated from the Rosewall Creek captive program, 4,395 of this group were considered too small for marking and released unclipped. The wild/supplemental component of the release accounted for 104,225 fed fry, and a further 298,758 were of mixed captive and returning origin.

In the fall, 104,255 returning origin parr, and 150,173 parr of mixed wild returning and captive origin, were released in early and mid-October to Maple Bay and Sunnyside.

All releases were to mid-lake and occurred at dusk.

Cultus brood collection

The escapement for 2011 was estimated at 7,464 adults, with 3,908 females being passed through to the lake. Broodstock collection accounted for 3.3% of the escapement with 94 males and 159 females being taken as brood. Pre-spawn mortality was (8.6%) and 21 fish were lost (2 males, 29 females).

Gamete collection

Eggs were collected once weekly, over six weeks, beginning November 15 and concluding December 20. Successful spawning of 92 males and 130 females resulted in 463,072 fertilized eggs placed into incubation. Following a formal public consultation process with user groups, no eggs were transferred to Rosewall Creek as the captive brood program was in the first stages of discontinuation.

The Rosewall Creek captive program spawned 342 males (249 age-3 and 93 age-4) and 613 females (527 age-3 and 86 age-4) for a total egg production of 1,533,835.

Disease screening

A total of 130 Cultus adult return samples were submitted for BKD testing with 71 testing negative, 29 with a low level of detection, and 30 low positive. These were reared in isolation and marked and released early. All ovarian fluid samples tested negative, by cell culture, for IHNV. Of 343 Rosewall captive brood fish screened for disease, 340 were negative for *Renibacterium salmoninarum* and three tested positive at a low level of detection; eggs from these females were destroyed.

2012

Incubation and rearing

In 2011, the Rosewall Creek captive brood program produced a greater number of eggs than the program could safely rear at the facility. Survival from green to eyed was 72% (1,106,219) and, due to greater than anticipated survival, and following multi-sector discussions, 272,000 eggs from the 2011 brood year were culled, resulting in 834,219 eyed eggs for production. Survival to ponding from the green egg stage was 53%.

At Inch Creek, green egg to eyed egg survival was 90.7% for a total of 420,143 eggs in incubation at the beginning of 2012.

Smolt migration and survival

Of the 1-yr smolts that were counted through the fence, 187,654 were of wild origin and 76,541 of hatchery origin. In the spring of 2012, no 2-yr smolts from either hatchery or wild origin were seen to pass through the counting fence.

Releases

During the spring of 2012, 54,252 adipose clipped and coded wire tagged smolts (~20g were released below the Sweltzer Creek fence.

Between late June and late August, 505,599 fed fry were released to the lake at Jade Bay. Of these, 437,311 originated from the Rosewall Creek captive program.

The wild/supplemental component of the release accounted for 183,850 fed fry, and a further 378,418 were of mixed captive and returning origin.

In the fall, 149,828 wild origin parr were released to Jade Bay.

All releases were to mid-lake and occurred at dusk.

Cultus brood collection

Adult escapement for 2012 was estimated at 1,155, with 512 females being passed through to the lake. Broodstock collection accounted for 13.9% of the estimated escapement with, 105 males and 159 females being taken as brood. Pre-spawn mortality was 19% with a loss of 48 adults (27 males, 21 females).

Gamete collection

A total of 482,120 eggs were collected from Cultus returns. Eggs were taken once weekly, over six weeks, beginning November 14 and concluding December 18. The Rosewall Creek captive brood program produced 1,258,557 eggs.

Disease screening

Disease screening was performed on 139 samples submitted from the Cultus adult returns. Sixty-one samples tested negative, 54 screened positive at a low level of detection, and 24 were determined to be low level positive. The eggs from low positive fish were reared in isolation and marked and released as soon as possible. In 2012 the Pathology Laboratory performed only a prevalence assessment on the captive brood held at Rosewall Creek as lifelong captivity was being discontinued. Since fish would not be held through a life cycle, and instead released as fry, the risk of disease incidence was low. Of the 60 samples submitted for testing; 57 tested negative and 3 tested at a low level of detection.

2013

Incubation and rearing

A greater allocation of rearing space was available at Rosewall Creek Hatchery compared to previous years as less space was necessary for a concurrent program (Sakinaw sockeye), therefore no eggs were culled. Survival from green egg to eyed egg stage was 75.4%; 550,839 eyed eggs were transferred from Rosewall Creek to Inch Creek for final incubation and ponding.

482,120 green eggs were collected at Cultus Lake and the green to eyed survival for these eggs was 81.5%; 392,796 eggs were taken through rearing at Inch Creek.

Smolt migration and survival

In 2013, 70,067 smolts were enumerated as they migrated out through the Sweltzer Creek fence. Marked fish accounted for 60,017, and the unmarked component was 10,051. Three of the out-migrating fish were 2-yr smolts and only one was marked.

Releases

During the spring of 2013, 49,438 smolts (~22g) were released. Between early June and late August, 998,643 fed fry were released into the lake at Jade Bay. Of these fed fry, 829,731 originated from the Rosewall Creek Hatchery captive brood program. In October, 151,154 returning origin parr were released mid-lake at Jade Bay.

Gamete collection

2013 was the final year for collection of eggs from the Rosewall Creek captive brood program; 62,494 green eggs were taken from 39 females spawned between April 24 and July 9, 2013. Of these green eggs, 41,748 survived to the eyed stage; the resulting fry were transferred to Inch Creek on January 29, 2014 for rearing and release in October as parr.

Disease screening

Disease screening was carried out for 101 samples submitted from the Cultus adult returns; 11 returned negative results, 43 screened at a low level of detection, and 47 were low positive. No eggs exceeded limits where destruction was recommended, and these are to be reared in isolation and released as fry. Of interest in the 2013 brood; one female tested positive. Since the disease is considered endemic, and no females had tested positive at any point in the duration of the program to date, these eggs were felt to pose little risk and were retained.

The few remaining captive brood fish at Rosewall Creek spawned earlier than expected but, since no further captive rearing was planned, no screening was performed on these fish.

BREEDING PROGRAM - GENETIC ANALYSES

Beginning in 2004, all broodstock spawned at Cultus Lake Laboratory and Rosewall Creek Hatchery were genetically sampled. The resulting data provided the ability to identify hatchery-spawned individuals back to their parents at the Cultus Lake Laboratory or Rosewall Creek Hatchery. This enabled the success of captive and supplemental breeding programs to be evaluated, allowed fish from different spawning dates to be tracked, and provided the ability to assess different release groups. Additionally, the data enabled the estimation of genetic relatedness of brood animals and the genetically effective size of Cultus sockeye spawning groups (including Cultus brood fish, Rosewall brood fish and natural spawners in Cultus Lake). From 2008, genetic data were used by both the enhancement working group and the recovery/conservation team in assessing the success of enhancement actions and adaptive management of hatchery efforts to most effectively increase abundance and maintain genetic diversity in the natural spawning population. Some results from the genetic analyses for fish from the 2004-2008 hatchery brood years are provided in Table 1; which presents the number of fish for which genotypes were successfully obtained on an annual basis between 2004 and 2012. Analyses for subsequent brood years are ongoing but incomplete.

Table 1. Numbers of Cultus Lake sockeye salmon successfully genotyped in genetic analysis each year between 2004 and 2012. Sampling included naturally-spawned (unmarked) and hatchery-produced (adipose-clipped) smolts and returning adult fish at Sweltzer Creek fence, and adults used as broodstock at both the Cultus Lake Laboratory and Rosewall Creek Hatchery.

Sample year	Age 2 Smolts		Age 3-5 Fence Adults		Age 3-5 Brood Adults			Total
	Unmark	Ad-Clip	Unmark	Ad-Clip	Cultus		RW	
					Unmark	Ad-Clip		
2004	0	0	0	0	28	0	752	780
2005	0	0	0	2	149	0	480	631
2006	0	0	240	72	173	0	712	1197
2007	0	0	46	56	87	74	750	1013
2008	1255	1452	44	107	21	131	582	3592
2009	972	1180	186	437	70	208	470	3523
2010	21	1021	718	1314	219	135	522	3950
2011	751	1002	321	1015	181	73	862	4205
2012	970	899	16	722	9	231	909	3756

Genetic analysis of brood year 2004

The first large release of captive-bred sockeye from Rosewall Creek Hatchery was in 2004, when the unexpectedly high number of juvenile fish produced (due to increased maturation at age three in captivity) meant that it was not possible to adipose-clip them all as planned. As a result, initial releases of unfed fry to Cultus Lake consisted of unclipped Rosewall fish, released in a year in which wild juveniles were the progeny of fewer than 50 fish that entered Cultus Lake in 2004 to spawn. In the spring of 2006, 40,582 marked and 13,742 unmarked 1 yr old smolts migrated out from the lake, with the unmarked smolts consisting of both hatchery and wild juveniles. In 2006 a large number of brood year 2004 Rosewall origin fry had been released unmarked due to capacity issues. Based on otolith analysis, it was estimated that the composition of the brood year 2004 out-migrating smolts was 3,104 wild fish and 10,638 hatchery origin. No smolt samples were collected for genetic analysis in 2006, but genetic identification of adult returns from brood year 2004 supported the otolith analysis, indicating that most unmarked smolts were of hatchery origin and providing evidence that the estimate of 417 smolts per wild female spawner for brood year 2004 (Table 8) was a substantial overestimate, likely by at least 100%.

The fish spawned at Rosewall Creek Hatchery in 2004 were derived from two groups. Almost two thirds of the brood fish were progeny of a small number of wild adult fish spawned at Cultus in 2001. Most of the 44 adults collected for broodstock use in 2001 (Table 2) contributed few or no progeny to the group subsequently transferred to, and reared at, Rosewall Creek Hatchery. In fact, genetic analysis indicated that only 16 parents in 2001 contributed to the fish that matured at age three in 2004 at Rosewall from this group. Moreover, a majority of Rosewall spawners in this group were progeny from only six 2001 brood year parents; two females each crossed with two different males (Withler et al. 2011). The remaining Rosewall 2004 brood fish were more genetically diverse (primarily female) and matured at age four from a Cultus wild smolt collection in 2002.

Analysis of 62 age three fish (56 marked and six unmarked) from the 2007 adult return revealed that all were hatchery fish, whose parentage was dominated by fish reared at Rosewall from the 2001 crosses at Cultus. The very restricted number of parents that produced these Rosewall spawners was evident in the genetically effective size of 35, estimated from genetic data on age three returns (Withler et al. 2011). The resulting limited genetic variation present in age three hatchery fish that returned to Cultus Lake in 2007 raised concern about the level of genetic diversity that would be present in the 2008 return, expected to consist of predominantly hatchery-produced age four fish also from brood year 2004. A crossing design was developed and implemented for 2008 to avoid a large increase in inbreeding that would result from the mating of related fish arising from the six highly successful ‘dominant’ grandparents spawned at Cultus in 2001.

In 2008, brood collection at Cultus was directed toward unmarked fish in an effort to maximize the number of wild fish included. Brood fish were genotyped prior to spawning and assigned to one of three groups, 1) marked and unmarked age four hatchery fish with two or four of the ‘dominant’ grandparents, 2) other marked and unmarked age four hatchery fish with no dominant grandparents and 3) other fish (a few wild age four and five fish, but primarily age three wild and hatchery fish). All spawning was conducted between mates selected from different groups. Ultimately, the crossing plan was easier to implement than expected because, although age four hatchery fish did comprise 91% of fish that returned to Cultus Lake in 2008 (based on genetic analysis), they were predominantly progeny of wild smolts that matured and were spawned at Rosewall in 2004, not descendants of the 16 grandparents spawned at Cultus in 2001 (Withler et al. 2011).

Genetic analysis of brood year 2005

The 2005 brood year was the first year from which significant numbers of hatchery-produced fish originated from the spawning of fish at both Rosewall Creek

Hatchery and Cultus Lake Laboratory. No genetic analysis of smolts was conducted; analysis of returning adult hatchery fish in 2008-2010 revealed that Rosewall origin fish displayed substantially lower survival compared to those from Cultus. Rosewall fish constituted approximately 60% of hatchery releases but only 10% of adult returns. Cultus hatchery fish constituted 90% of hatchery returns from this brood year, and of those, 90% were the progeny of 27 females spawned on the last two spawning days at Cultus Lake Laboratory (December 13 and 20, 2005). Only 10% of returning Cultus origin fish were the progeny of 33 females spawned between November 16 and December 6 on the first four spawning days at Cultus. This was the first indication that survival of Rosewall and Cultus fish could differ considerably and that, even within the Cultus fish, survival among spawning dates could vary significantly. In the absence of smolt sampling, it was not possible to determine at which life history stage after release (freshwater or marine) mortality occurred. However, since Rosewall fish survived most poorly and the last-spawned Cultus fish survived much better than all others, it seemed likely that differences in survival were at least partly due to differences among release groups. Rosewall fry predominate in early releases (summer/fall) and Cultus fish from the final spawning dates predominate in late fall and spring smolt releases each year.

The large variance in parental contributions to adult returns in brood year 2005 led to concern about the ‘genetically effective size (Nb)’ of the annual Cultus hatchery fish production. Estimation of Nb based on variance of adult progeny returns provided a value of 59 for the brood year, from a total census size of 139 adult brood fish (60 females, 79 males). In a typical wild salmon population, the expected genetic effective size usually falls between 10 and 30% of the census size when calculated as a long-term harmonic mean over generations. Thus, the value of 42% (59/139) for a single year-class of hatchery production was not unusually low in comparison to values observed in wild populations. Although few fish from Rosewall’s hatchery production returned from brood year 2005, their presence increased the Nb of the age four hatchery fish that returned to 103. Moreover, over half the hatchery fish that returned in 2009 were age three fish from brood year 2006; their presence further increased the Nb of the total hatchery return to 183.

The Nb of the naturally-spawned (i.e. wild) age three and four fish that returned in 2009 was 478. The value for the combined return of hatchery- and naturally-spawned fish was 333; but 2009 was the last return year in which the presence of hatchery fish from a restricted number of families decreased the overall Nb of the adult return. Thereafter, the presence of diverse groups of fish from both hatchery sources has resulted in combined Nb estimates that exceed values obtained for the naturally-spawned adults alone.

Genetic analysis of brood year 2006

In the 2006 brood year, milt from live males spawned at Cultus lab was also used to fertilize eggs from some females at Rosewall hatchery. Thus, approximately 24% of the Rosewall juvenile releases from this brood year were from Rosewall mothers crossed with Cultus fathers (RWxC). These fish comprised about 15% of the total release of 996,748 juveniles (including RWxRW, RWxC and CxC juveniles). The proportion of RWxC juveniles was lower (11%) in the marked smolt sample from this year but then stayed relatively constant at about 12% in adult returns. In contrast, proportions of both the RWxRW and CxC increased from release proportions by about 2% in the marked smolt samples, but then the two types of hatchery fish performed very differently during ocean migration. RWxRW fish decreased from 52% of the smolts to 37% of the adult returns whereas CxC fish increased from 37% of the smolts to 50% of the adult returns. The 40% increase in the proportion of CxC fish from release to adult return for this brood year was in the same direction but less than the doubling observed for the 2004 and 2005 brood years, in which CxC fish increased from 4% at release to 10% at return, and from 39% to 89%, respectively. CxC fish from smolt releases below the fence each year were responsible for some of the apparently increased proportion of CxC in returning adults compared to the proportion going through the fence during smolt migration. However, in brood year 2006 adult returns, a relatively high survival of RW origin fish in both freshwater (Table 6; survival to migration) and ocean migration was observed.

In 2006, low levels of BKD infection were detected in 11 of 121 females spawned at Cultus. The females were present on three of seven spawning days. Progeny from these were segregated and included in early fry releases to Cultus Lake in 2007. The average adult returns from brood year 2006 Cultus females in fish sampled for genetic analysis between 2009 and 2011 varied by spawning day, but averaged six per female overall. BKD positive females produced 1.4 fewer adult returning progeny, on average, than did other females from the same spawning day.

Genetic analysis of brood year 2007

In brood year 2007, RWxC fish were also produced at Rosewall and again represented approximately 15% of total hatchery releases. Both freshwater and marine survival of RWxC were high; they comprised 24% of marked smolt samples and 20% of adult returns. In contrast, CxC fish constituted 26% of lake releases, only 12% of marked smolts, and 37% of adult returns. The increased proportion of Cultus fish in adult returns was due to a very high survival in this brood year of fish released in the CWT-tagged smolt group. Removing adult fish that returned from the smolt release, adult returns from Cultus would constitute 22% of marked adult returns. Thus in adult returns, CxC fish released to the lake represented only a slightly smaller proportion of fish than they did at release, almost completely recovering from their low freshwater survival and smolt contribution through relatively high marine survival (compared to RWxRW and RWxC fish).

Genetic analysis for brood year 2007 revealed that the smolt releases of Cultus fish were comprised entirely of progeny from 12 females spawned on the last two spawning days (Dec. 18 and Jan. 2) at Cultus. Their absence from smolt samples indicated that none of these fish had been included in juvenile releases to Cultus Lake, they had all been included in the smolt release below the fence. Analysis of returning adults indicated that they comprised over 50% of the age four return of Cultus fish in 2011, although they were progeny of only 16% (12/74) of the Cultus brood females. The genetic analysis indicated that marine survival of the smolt release from this brood year was high and underestimated from the monitoring of CWTs in adult fish at the Sweltzer fence. It was known from previous years that CWT detection in live adults being passed into Cultus Lake for spawning was problematic (CWTs were frequently not detected), as there had consistently been a higher detection rate in fish collected for broodstock. Broodstock scanning was more thorough and conducted at closer range to the tag because it was done on carcasses after death. The underestimation in brood year 2007 was large. Based on CWT detection in adipose-clipped fish, 5.67% (53/935) of adult (non-jack) hatchery returns were from the smolt release. Based on genetic assignment to the parents of progeny included in the smolt release, 18.9% (175/928) of the hatchery adult return was from the smolt release.

The results for this brood year were similar to those of 2005 in that females spawned on the last two days at Cultus produced an average of about ten times as many returning adult progeny than did females spawned at Cultus on other days. It may be that the high survival of the late-spawned progeny in 2005 was also due to the fact that they also were predominantly or exclusively included in the smolt release for that year. Since no smolts were analyzed from brood year 2005, we cannot confirm that no progeny from late crosses in 2005 were included in lake releases, as we did for 2007.

Genetic analysis of brood year 2008

The adult return of sockeye to Cultus Lake in 2008 was dominated (≥90%) by hatchery fish because of the very low escapement into Cultus Lake in 2004. Of the hatchery fish, 90% were of Rosewall origin and 10% were of Cultus origin (a doubling of the Cultus contribution relative to its proportion at release). Therefore, in 2008, a vast majority of the spawning fish, both in the hatchery and among the 360 adults passed through the Sweltzer fence into Cultus Lake for natural spawning, were of hatchery origin. These fish were productive and contributed well as hatchery fish at Cultus Lab/Inch hatchery but failed to spawn successfully (as measured by smolt production) in Cultus Lake.

The Cultus lab juveniles produced in 2008 constituted 22% of hatchery releases into Cultus Lake, a third of the 88,000 hatchery smolt migration through Sweltzer fence and an additional 50,000 smolts in the smolt release below the fence. Among adult returns three to five years later, Cultus hatchery fish (from the in-lake and smolt releases combined) represented almost 60% of hatchery adult returns. In contrast, natural spawning of the 360 adult fish that entered Cultus Lake to spawn in 2008 was a virtually complete failure in terms of smolt production. Only 369 unmarked smolts were counted at the fence in 2010 (Table 13), and 231 of these were sampled for genetic analysis. The genetic analysis revealed that 91% of ‘unmarked smolts’ were, in fact, hatchery fish with incomplete or missing fin clips, or clips that were misread during sampling. Some level of misidentification during smolt sampling is not surprising given that sampling is conducted on the fence at night often with thousands of smolts being screened and subsampled over the course of an evening. However, genetic analysis revealed that of 369 ‘unmarked’ smolts, fewer than 50 were actually produced by natural spawning in the lake.

Thus, 335 of the smolts classified as unmarked were, in fact, hatchery fish. If these are included with the count of 88,112 marked smolts, they represent approximately 0.4% of the total number of hatchery fish. Analysis of smolts from other years has indicated that this is a consistent result, between one-half and five percent of hatchery smolts are ‘misread’ as unmarked each year during smolt migration. During years in which large numbers of smolts are produced by natural spawning, misidentified hatchery fish generally comprise a small proportion (≤10%) of the unmarked smolt sample. In years of low natural smolt production, such as 2008, the misidentified hatchery fish may represent the majority of unmarked fish.

In 2008, four of the 69 females spawned at Cultus were BKD positive. Their progeny were again included in an early-release group. No progeny from any of the four females was detected in genetic sampling of smolts or adult returns from this brood year. Only two of the remaining 65 BKD-negative females at Cultus produced no progeny among the returning adult samples.

SUMMARY

The Cultus Lake program has been successful at preventing the extirpation of this unique sockeye stock. Through a captive brood program, genetic diversity in a threatened stock has been enriched to the point where the captive component is no longer required. Through the efforts of a great many individuals, the recovery navigated many technical and environmental hurdles. During the thirteen years of enhancement that the program has spanned, a great deal of valuable information has been added to the base of knowledge on this stock, and this information has assisted, and will continue to inform, other salmon enhancement programs.

The data provide some interesting information pertaining to survival as related to release stage and size at release. Beyond minor variation in pin-heading, there appears to be little difference year to year in survival to release stage, from ~0.25g to final 20.0g smolt release, aside from the 2010 brood, which saw high mortality due to gas bubble disease. Although the relationship between size at release and survival appears to be strong, daily mortality seems to remain relatively constant and this is independent of fish release size; the longer fish are in the hatchery, the better the apparent survival to smolt migration is.

A number of release strategies have been used over the course of the program. Release of fed-fry in summer resulted in favourable in-lake survival rates as measured by smolt out-migration. Although the fall parr releases resulted in an apparently slightly greater survival compared to summer releases (average 15.9% vs. 11.8%), when both cost of production (total labour, feed, water pumping, etc.) and extended exposure to wild/natural selective pressures are considered, continued fall releases are difficult to rationalize.

Early river entry of late-run Fraser sockeye stocks has been linked to elevated pre-spawn mortalities. It has been suggested that this may be tied to the presence of the parasite *Parvicapsula*, and may impact the rate of rebuilding, although uncertainty exists as to both the rate of pre-spawn mortality and spawning success of enhanced origin returning adults. However, PIT tag data has revealed trends in broodstock survival that contradict assumptions made for late-run sockeye stocks in general.

Although migration timing of the Cultus Lake stock has advanced over the short duration of the Enhancement Program (from 50% migration by September 30th between 1996 to 2001, to 50% migration by September 20th between 2002-2012) spawn timing has not changed. There is no apparent relationship between migration timing and spawn timing – both late and early arrivals may spawn early or late. In seven out of nine years, from brood year 2004 to 2012, fish that arrived early (e.g. before September 16) had much lower pre-spawn mortality than later arrivals. It is possible that early migration may be a successful adaptation to current environmental conditions in the watershed.

In addition to sporadic in-lake fry production given fluctuating/uncertain levels of adult pre-spawn mortality, widely varying historic smolt per spawner rates (for years prior to early river entry of late run stocks phenomenon) show that freshwater productivity within Cultus Lake is highly variable.

Although the recovery program can be considered successful when considering that it has resulted in both an increased number of returning adults and an improvement in the overall genetic makeup of those animals, the long-term success in the wild is still unknown and continued enhancement and monitoring of this stock will be necessary for the foreseeable future.

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REFERENCES CITED

Alderson, R. and A.J. MacNeil. 1984. Preliminary investigations of cryopreservation of milt of Atlantic salmon (*Salmo salar*) and its application to commercial farming. Aquaculture. 43 (1-3): 351-354.

Beamish, R.J., C. Mahnken, and Neville, C.M. 1997. Hatchery and wild production of Pacific salmon in relation to large-scale, natural shifts in the productivity of the marine environment. ICES J. Mar. Sci. 54: 1200-1215.

Bradford, M.J., J.M.B. Hume, R.E. Withler, D. Lofthouse, S. Barnetson, S. Grant, M. Folkes, N. Schubert, and A-M. Huang. 2011. Status of Cultus Lake Sockeye Salmon. Can. Sci. Advis. Sec. Doc. 2010/123. vi + 44p. Available from www.dfo-mpo.gc.ca/csas-sccs

Cloud, J.G., W.H. Miller, and M.J. Levenduski. 1990. Cryopreservation of sperm as a means to store salmonid germ plasm and to transfer genes from wild fish to hatchery populations. Prog. Fish Cult. 52:51-53.

(COSEWIC) Canadian Endangered Species Conservation Council 2003. COSEWIC assessment and status report on the sockeye salmon *Oncorhynchus nerka* (Cultus population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. ix + 57 pp.

(CLSRPP) Cultus Lake Sockeye Recovery Planning Process. 2002a. Draft Report of the Enhancement Work Group.

(CLSRPP) Cultus Lake Sockeye Recovery Planning Process. 2002b. Report of the Stock Assessment and Fisheries Management Work Group.

Cultus Sockeye Recovery Team. 2005. Conservation strategy for sockeye salmon (*Oncorhynchus nerka*), Cultus Lake population, in British Columbia. Recovery of Nationally Endangered Wildlife (RENEW). Ottawa, Ontario, 48 pp.

(DFO) Department of Fisheries and Oceans. 2003. Cultus Lake Sockeye Salmon. DFO Can. Sci. Advis. Sec. Doc. 2003/024. 6 p.

Hsu, Y.L., H.M. Engelking, and J.C. Leong. 1986. Occurrence of different types of infectious hematopoietic necrosis virus in fish. Appl. Environ. Microbiol. 52:1353-1361.

Johnson, M. and N. Schubert. 2001. Memorandum to the Area Director dated December 7, 2001 titled: 'Late Run of Cultus Sockeye Salmon - A Critical Conservation Concern'. 3p.

Jones, S.R.M., G. Prosperi-Porta, S.C. Dawe, and D.P. Barnes. 2003. Distribution, prevalence and severity of *Parvicapsula minibicornis* infections among anadromous salmonids in the Fraser River, British Columbia, Canada. Dis. Aquat. Org. 54:49-54.

Kline, P.A., and C. Willard. 2001. Snake River sockeye salmon captive broodstock hatchery element annual progress report. IDGF Report #01-24.

McDaniel, T., K.M. Pratt, T.R. Meyers, T.D. Ellison, J.E. Follett, and J.A. Burke. 1994. Alaska sockeye salmon culture manual. Alaska Department of Fish and Game. 31 pp.

Mohler, J. 2003. Producing fluorescent marks on Atlantic salmon fin rays and scales with calcein via osmotic induction. N. Amer. J. Fish. Manage. 23: 1108–1113.

Negus, M.T. and F.T. Tureson. 2004. Retention and Nonlethal External Detection of Calcein Marks in Rainbow Trout and Chinook Salmon. N. Amer. J. Fish. Manage. 24:741–747.

Ricker, W. E. 1937. The food and food supply of sockeye salmon (*Oncorhynchus nerka* Walbaum) in Cultus Lake, British Columbia. J. Biol. Bd. Can. 3:450- 68.

Rosenberg, D.L. 1983. Fertilization success of coho salmon gametes: Effects of storage under various atmospheric conditions, temperature acclimation, and temperature variations. Prog. Fish Cult. 45: 84-87.

Schubert, N.D., Beacham, T. D., Cass, A.J., Cone, T.E., Fanos, B.P., Foy, M., Gable, J.H., Grout, J.A., Hume, J.M.B., Johnson, M., Morton, K.F., Shortreed, K.S., and Staley, M.J. 2002. Status of Cultus Lake sockeye salmon (*Oncorhynchus nerka*). Can. Sci. Advis. Sec. Doc. 2002/064: 109 p. Available from www.dfo-mpo.gc.ca/csas-sccs

(SEP-HEB) Salmonid Enhancement Program Habitat Enhancement Branch. 1995. Differential survival of Chinook and coho marked with an AdCWT ventral clip compared to AdCWT only mark. Government of Canada Memorandum. June 22, 1995.

St-Hilaire, S., M. Boichuk, D. Barnes, M. Higgins, R. Devlin, R. Withler, J. Khattra, S. Jones, and D, Kieser. 2002. Epizootiology of *Parvicapsula minibicornis* in Fraser River sockeye salmon, *Oncorhynchus nerka* (Walbaum). J. Fish Dis. 25: 107-120.

Stobbart, A.R. and D.R. Harding. 1996. Pitt River Sockeye Hatchery Update – 1995. Can. Manuscr. Rep. Fish. Aquat. Sci. 2353. 38 p. Available from: http://waves-vagues.dfo-mpo.gc.ca/waves-vagues/

Welch, D.W., M.C. Melnychuk, E.R. Rechisky, A.D. Porter, M.C. Jacobs, A. Ladouceur, R.S. McKinlay, and G.D. Jackson. 1009. Freshwater and marine migration and survival of endangered Cultus Lake sockeye salmon (*Oncorhynchus nerka*) smolts using POST, a large-scale acoustic telemetry array. Can. J. Fish. Aquat. Sci. 66:736-750.

Wheeler, P.A., and G.A. Thorgaard. 1991. Cryopreservation of rainbow trout semen in large straws. Aquaculture. 93:95-100.

Withler, R.E., R.H. Devlin, S. Latham, C.C. Wood and K. J. Supernault. 2011.

Analysis of gene origin in the first adult returns to the Cultus sockeye salmon captive breeding program. Conserv. Genet. 12:1469–1483. doi: 10.1007/s10592-011-0246-5.

APPENDIX - DATA SUMMARIES BY BROOD YEAR[1]

Table 2. Broodstock collection, adults passed through the Sweltzer Creek fence, and total escapement & spawning estimates[2]

	Adults removed for broodstock use		Adults passed through the fence		Total escapement
Year	Marked	Unmarked	Marked	Unmarked	
2000	0	15	0	1,227	1,242
2001	0	44	0	675	719
2002	0	266	0	4,882	5,148
2003	0	246	0	1,939	2,185
2004[3]	0	37	0	52	89
2005	2	147	5	221	375
2006[4]	1	275	125	3,396	3,797
2007	50	101	174	475	800
2008[5]	129	32	301	59	521
2009	198	83	933	508	1,722
2010	130	227	6,350	3,947	10,654
2011	64	189	5,074	2,137	7,464
2012	250	14	62	829	1,155
	824	1,676	13,024	20,347	35,871

[1] Due to the difficulties inherent to collating data collected by different programs and many different individuals over the span of the program, minor discrepancies may exist between the data presented here and that obtained from other DFO sources.
[2] Values include pre-spawn mortalities and jacks
[3] Cryopreserved sperm from 39 brood year 2002 males was used in 2004
[4] Due to an abundant adult run in 2006, broodstock collection attempted to avoid all hatchery marks
[5] 2008 broodstock hatchery/wild ratio was calculated from both observed hatchery marks and DNA analysis of unmarked fish

Table 3. Broodstock and egg data by year[1]

	2000[2]	2001[3]	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
Females captured	Nr	22	177	141	20	63	168	90	78	120	204	159	159	122
Females spawned	5	9	120	132	10	60	121	74	69	92	184	130	138	88
Female survival to spawn	Nr	40.9%	67.8%[1]	93.6%	50.0%[1]	95.2%	72.0%	82.2%	88.5%	84.4%	90.1%	81.8%	86.8%	81.6%
Females screened out	-	-	1	11	0	0	11	0	5	5	0	0	0	4
Effective females	5	9	119	121	10	60	110	74	64	87	184	130	138	84
Males captured	10	22	89	105	17	85	103	61	83	162	153	94	105	77
Males used	5	11	70	100	15	78	76	52	59	117	105	92	78	66
Male survival to spawn	50%	50%	78.7%	95.2%	88.2%	91.8%	73.8%	85.2%	71.1%	72.2	68.6%	97.9%	74.3%	77%
Number taken	13,385	24,458	438,100	464,038	39,976	185,273	430,674	282,261	257,915	320,209	719,624[4]	463,072	482,120	312,796
Eyed egg mean weight (g)	Nr	Nr	0.090	0.088	0.081	0.075	0.083	0.084	0.090	0.082	0.094	0.092	0.091	0.086
Fecundity (realised)	2,677	2,718	3,682	3,529	3,998	3,088	3,559	3,814	3,738	3,100	3,911	3,562	3,468	3,446
Number dead	Nr	3,365	14,9571	60,633	11,445	16,668	67,419	24,052	32,897	40,491	128,010	42,929	89,325	55,567
Number live	Nr	21,093	288,529	403,406	28,531	168,605	363,254	258,209	225,018	279,718	564,153	420,143	392,796	284,455
Survival to eyed	Nr	86.2%	65.9%[1]	86.6%	71.4%[1]	91.0%	84.4%	91.5%	87.2%	87.4%	81.5%	90.7%	81.5%	86.8%
Rosewall captive brood	-	-	2,279	1,734	828	1,554	1,512	1,654	1,620	1,566	0	0	0	1,593
Inch captive brood	-	-	2,259	1,731	819	1,554	1,512	1,654	1,620	1,566	0	0	0	1,589
Inch rearing	3,891[5]	20,835[5]	283,991	399,941	26,884	165,497	360,230	254,901	221,778	276,680	564,153	420,143	392,796	260,902

[1] In brood years 2005 and 2009, small irreconcilable discrepancies, with respect to adult numbers collected, exist between SEP data and StAD data.
[2] Ad hoc data and 2004 survival data are not included in calculations. In 2002 holding trials were underway and 2004 was an extremely low return, with strays comprising a significant proportion of mortalities
[3] Two females were spawned post-mortem – rearing occurred at Cultus Lake
[4] For the 2010 brood year, 54,754 eggs testing low positive for BKD were culled at the eyed stage because of rearing space/ density concerns.
[5] Progeny from BY2000, and 2001 reared at Cultus Lake

Table 4. Total captive program egg production by brood and calendar years

Brood year \ Calendar year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total brood year egg representation
2000	46,000	631,677	230,902	-	-	-	-	-	-	-	-	908,579
2001	16,000[1]	694,058	233,638	20,380[5]	-	-	-	-	-	-	-	911,712[2]
2002	-	-	256,512	146,597	-	-	-	-	-	-	-	403,109
2003	-	-	-	813,291	183,218	-	-	-	-	-	-	996,509
2004	-	-	-	-	935,247	0	-	-	-	-	-	935,247
2005	-	-	-	-	-	879,918	5,350	-	-	-	-	885,268
2006	-	-	-	-	-	-	427,280	0	-	-	-	427,280
2007	-	-	-	-	-	-	-	901,654	250,327	-	-	1,151,981
2008	-	-	-	-	-	-	-	-	1,283,508	87,693	-	1,371,201
2009	-	-	-	-	-	-	-	-	-	1,170,864	62,494	1,234,358
Total	62,000	1,325,735	721,052	980,286	1,118,465	879,918	432,630	901,654	1,533, 835	1,258,557	62,494	9,276,626
Total adjusted	46,000	1,325,735	721,052	959,888	1,118,465	879,918	432,630	901,654	699,616	1,258,557	62,494	8,406,009

[1] Non-viable eggs
[2] Adjusted for non-viable eggs

Table 5. Rosewall Creek captive brood spawning

Calendar year	Age of fish (Brood Year +)	Number spawned		
		Males	Females	Eggs collected
2003	1	-	-	-
	2	184[1]		16,000[2]
	3	67	22	46,000
	4	-	-	-
	5	-	-	-
		Total 2003 captive egg production		62,000[3]
2004	1	-	-	-
	2	23	0	0
	3	207	285	694,058
	4	9	196	631,677
	5	-	-	-
		Total 2004 captive egg production		1,325,735
2005	1	-	-	-
	2	-	-	-
	3	43	135	256,512
	4	35	103	233,638
	5	96	60	230,902
		Total 2005 captive egg production		721,052
2006	1	-	-	-
	2	-	-	-
	3	166	395	813,291
	4	34	49	146,597
	5	15	8	20,380[4]
		Total 2006 captive egg production		980,286
2007	1	-	-	-
	2	-	-	-
	3	126	440	935,247
	4	100	85	183,218
	5	-	-	-
		Total 2007 captive egg production		1,118,465
2008	1	-	-	-
	2	-	-	-
	3	204	366	879,918
	4	-	-	-
	5	-	-	-
		Total 2008 captive egg production		879,918
2009	1	-	-	-
	2	-	-	-
	3	191	304	432,537
	4	19	6	5,350
	5	-	-	-
		Total 2009 captive egg production		432,630

[1] Two year olds from the wild smolt capture. A total of 184 fish were spawned, records not available for numbers of males and females.
[2] Fertilization proved unsuccessful, no production from these eggs.
[3] 16,000 eggs produced by 2001BY wild caught smolts proved infertile
[4] Non-viable therefore a decision was made to hold no captive adults beyond age-4 spawning season

Table 5. *cont'd*. Rosewall Creek captive brood spawning

Calendar year	Age of fish (Brood Year +)	Number spawned		
		Males	**Females**	**Eggs collected**
	1	-	-	-
	2	-	-	-
2010	3	176	343	901,654
	4	-	-	-
	5	-	-	-
		Total 2010 captive egg production		901,654
2011	1	-	-	-
	2	-	-	-
	3	249	527	1,283,508
	4	93	86	250,327
	5	-	-	-
		Total 2011 captive egg production		1,533,835
2012	1	-	-	-
	2	-	-	-
	3	244	549	1,170,864
	4	58	32	87,693
	5	-	-	-
		Total 2012 captive egg production		1,258,557
2013	1	-	-	-
	2	-	-	-
	3	59	39	62,494
	4	-	-	-
	5	-	-	-
		Total 2013 captive egg production		62,494
		Total captive egg production		**9,276,626**

Table 6. Cultus Lake enhanced fry survival to smolt, by brood year

Brood year	Migration year	Number released	Release type	Mean release wt. (g)	Release mark	# smolts migrated	Survival to migration
2000	2002	3,891	Smolt	25.7	Ad Only	3891	100.0%
2001	2003	3,254	Parr	4.5	Ad Only	Unknown	Unknown
		461	Parr	4.5	Unmarked	Unknown	Unknown
		1,568	Smolt	19.3	Ad+RV	562	11.7%[1]
		1,598	Smolt	19.3	Ad+LV	1598	100.0%
2002	2004	227,029	Parr	4.0	Ad Only	5,542	2.4%
		814	SS/subA/A	73/983	Ad+LV/UM	92[2]	Unknown
		1,620	SS	74.0	Ad/Ad-RV	1,620	100.0%
2003	2005	32,740[3]	Unfed Fry	0.2	Unmarked	819	2.5%[4]
		148,448	Fed Fry	1.1	Ad+Calcein	4,550	3.1%
		164,418	Parr	4.5	Ad Only	6,902	4.2%[5]
		47,804	Pre Smolt	12.0	Ad+CWT/UM	5,698	11.9%
		1,109	SS	70.1	POST/UM	1,109	100.0%[6]
2004	2006	263,618[7]	Fed Fry	0.3	Unmarked	13,055	5.0%[8]
		297,085	Fed Fry	1.2	Ad+Calcein	19,759	6.7%
		131,743	Parr	6.4	Ad Only	20,804	15.5%
		51,388	Smolt	22.4	Ad+CWT	51,388	100.0%
		2,495	Pre Smolt	41.0	Ad Only	2372	100.0%
		2,372	SS	65.0	POST	2,372	100.0%
2005	2007	1,584[9]	Fed Fry	0.4	Unmarked	40	2.5%[10]
		133,615	Fed Fry	1.3	Ad+Calcein	11,624	8.7%
		212,206	FF/Parr	3.4	Ad Only	23,720	11.2%[11]
		52,029	Smolt	20.5	Ad+CWT	52,029	100.0%
		1,137	SS	78.6	Ad+POST	1,137	100.0%

[1] Only recorded as marked/unmarked at fence, all lake release marks included in one calculation
[2] Unmarked since not expected to migrate
[3] Progeny of low positive BKD females; released early as unfed fry
[4] Estimated minimum survival
[5] Value includes 535 "no pin" estimated from 47,269 Ad/CWT released
[6] Super-smolts from captive back-up. Not production fish
[7] Unmarked release resulting from space constraints; fry too small to mark at time of release
[8] Short-term fed release due to insufficient rearing capacity
[9] Unmarked release of fry originating from females tested low positive for BKD
[10] Short-term rearing due to low BKD – estimated minimum survival
[11] 56,400 fed fry at 1.15g & 155,800 parr at 4.15g

Table 6. *cont'd*. Cultus Lake enhanced fry survival to smolt, by brood year

Brood year	Migration year	Number released	Release type	Mean wt. (g)	Release mark	# smolts migrated	Survival to migration
2006	2008	806,690[1]	Fed Fry	1.2	Ad Only	163,107	20.2%
		138,155	Parr	4.4	Ad+Calcein	38,303	27.7%[2]
		50,503	Smolt	22.4	Ad Only	50,503	100.0%
		1,400	SS	59.8	Ad+POST	1,400	100.0%
2007	2009	748,630[3]	Fed Fry	1.0	Ad Only	173,825	23.2%
		150,572	Parr	4.5	Ad+Calcein	44,605	29.6%
		50,395	Smolt	22.3	Ad+CWT	50,395	100.0%
		1,250	SS	61.7	Ad Only	1,250	100.0%
2008	2010	677,868[4]	Fed Fry	1.7	Ad Only	60,358	9.0%
		142,228	Parr	5.25	Ad+Calcein	27,745	20.0%
		55,568	Smolt	21.8	Ad+CWT	55,568	100.0%
		1,260	SS	81.9	Ad Only	1,260	100.0%
2009	2011	236,106[5]	Fed Fry	1.3	Ad Only	49,327	16.9%[6]
		55,480	Parr	4.4	Ad Only		
		93,052	Parr	4.5	Ad+Calcein	15,355	16.5%
		50,425	Smolt	20.0	Ad+CWT	50,425	100.0%
		1,372	SS	47.9	Ad Only	1,372	100.0%
2010	2012	4,395[7]	Fed Fry	0.6	Unmarked	Unknown	Unknown
		646,258	Fed Fry	1.2	Ad Only	76,541	9.6%[8]
		150,173	Parr	4.3	Ad Only		
		54,252	Smolt	20.2	Ad+CWT	54,252	100%
2011	2013	899,579[9]	Fed Fry	0.9	Ad Only	60,246	5.7%[10]
		149,828	Parr	4.5	Ad Only		
		49,438	Smolt	22.2	Ad+CWT	49,438	100%

[1] Includes 55,492 fry originating from low BKD positive females
[2] Includes 71,000 Ad Calcein and 67,150 Ad Only
[3] Includes progeny of low negative females
[4] Includes progeny of low negative females
[5] Includes progeny of wild and captive brood low positive females
[6] Includes fed-fry and parr as not mark distinguished
[7] Fry insufficient size for marking
[8] Includes fed-fry and parr as not mark distinguished
[9] Includes fry from 29 low negative and 30 low positive females that were reared in isolation, marked, and released early
[10] Includes fed-fry and parr as not mark distinguihsed

Table 7. Cultus Lake survival by stage[1]

Brood year	Cultus Egg Take							
	Female broodstock			# Eggs		Fry ponded	Green	
	Held	Spawned	Survival	Taken	Eyed		to eyed	to pond
2000	N/R	5	N/A	13,385	N/A	N/A	N/A	N/A
2001	22	9	40.9%	24,458	21,093	20,835	86.2%	85.2%
2002	177	120	67.8%	438,100	288,529	279,322	65.9%	63.8%
2003	143	132	92.3%	464,038	403,406	384,979	86.6%	83.0%
2004	16	10	62.5%	39,976	28,531	22,689	71.4%	56.8%
2005	63	60	95.2%	185,273	168,605	154,099	91.0%	83.2%
2006	169	121	71.6%	430,674	363,254	364,158	84.4%	84.6%
2007	90	74	82.2%	282,261	258,209	213,571	91.5%	75.7%
2008	78	69	88.5%	257,915	225,018	193,401	87.2%	75.9%
2009	109	92	84.4%	320,209	279,718	229,463	87.4%	80.5%
2010	204	184	90.0%	664,870	564,153	470,522	78.4%	65.4%
2011	159	130	81.8%	463,072	420,143	414,324	90.7%	89.5%
2012	159	138	86.8%	482,120	392,796	379,654	81.5%	78.7%

Table 8. Cultus Lake wild-origin smolts per spawner

Wild			
Brood year	Females to lake	Smolts migrated	Smolts/ female
2000	614	3,666	6
2001	258	11,266	44
2002	2,718	109,859	40
2003	864	17,156	20
2004	33	13,742[2]	417[2]
2005	64	9,613	150
2006	2,083	135,670	65
2007	249	70,073	281
2008	174	365	2
2009	349	57,628	165
2010	5,541	187,654	34
2011	3,908	10,095	3
2012	511	N/A	N/A

[1] 54,754 eggs were culled from BY2010 and approximately 272,000 eggs were culled from BY2011 because of rearing space/density concerns. Enhanced green to ponding survivals appear low due to these culls.
[2] In 2005 a large number of BY2004 Rosewall origin fry were released unmarked due to capacity issues. Based on otolith analysis, it was estimated that the composition of the BY2004 out-migrating smolts was 3,104 wild fish and 10,638 hatchery origin.

Table 9. Captive brood survival by stage[1]

	Rosewall (Captive Brood) egg take				
Brood year	**Eggs taken**	**Eggs eyed**	**Fry ponded**	**Green to eyed survival**	**Green to pond survival**
2000	0	- -	-	-	-
2001	0	-	-	-	-
2002	0	-	-	-	-
2003	62,000	N/A	30,938	N/A	49.9%
2004	1,339,185	850,575	767,855	63.5%	57.3%
2005	721,051	310,681	272,780	43.1%	37.8%
2006	980,268	808,176	745,426	82.4%	76.0%
2007	1,118,465	841,286	775,398	75.2%	69.3%
2008	879,918	751,405	687,615	85.4%	78.2%
2009	438,000	320,000	288,000	73.1%	65.8%
2010	901,654	664,778	658,181	73.7%	73.0%
2011	1,533,835	1,106,219	817,533[2]	72.1%	53.3%
2012	1,258,557	889,480	801,058	70.7%	63.6%
2013	62,494	41,748	38,621	66.8%	61.8%

[1] Beyond minor variation in pinheading, there was little difference, year to year, in survival to release stage from ~0.25g to final 20.0g smolt release, except for BY2010, which saw high mortality due to gas bubble disease.

[2] Approximately 272,000 BY2011 eggs were culled due to concerns over the number that could be safely reared.

Table 10. Cultus sockeye in-lake release percent survival

Brood year	Migration year	Release location	Pike minnow predator removal	Spring fed fry 0.14-0.4g	Summer fed fry 1.0-1.3g	Fall parr 3.4-6.4g	Spring pre-smolt 12-19g	Annual lake release mean survival
2001	2003	Mid-lake	N	None	None	N/A[1]	N/A[1]	11.7
2002	2004	On shore	N	None	None	2.4	None	2.4
2003	2005	On shore	N	2.5[2]	3.1	4.2	12.05[3]	4.6
2004	2006	Mid-lake	Y	5.0	6.7	15.5	None	7.7
2005	2007	Mid-lake	Y	3.5	8.7	11.2	None	10.2
2006	2008	Mid-lake	Y	None	20.2	27.7	None	21.3
2007	2009	Mid-lake	Y	None	23.2	29.6	None	24.0
2008	2010	Mid-lake	Y	None	9.0	20.0	None	10.7
2009	2011	Mid-lake	Y	None	16.9[4]		None	16.9
2010	2012	Mid-lake	Y	None	9.6		None	9.6
2011	2013	Mid-lake	Y	None	5.7		None	5.7

[1] Small-numbered parr & in-lake smolt release mark types were not distinguished at fence count
[2] Estimate only as these fish were released unmarked due to: 2003 - low BKD levels and no marking as stress/disease reduction measure, 2005 - lack of available rearing space
[3] The 2005 Pre-smolt release group appears in the average range for all releases but, this was the total migration following just ~60 days lake residence and this "pre-smolt" release "strategy" was not repeated (prompted by low water table and insufficient well water available to continue rearing at Inch Creek)
[4] Small-numbered parr & in-lake smolt release mark types were not distinguished at fence count

Table 11. Releases by brood and calendar year

Calendar year / Brood year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	
2000	-	-	3,891	-	-	-	-	-	-	-	-	-	-	-	3,891
2001	-	-	3,715	3,166	-	-	-	-	-	-	-	-	-	-	6,881
2002	-	-	-	227,029	2,434	-	-	-	-	-	-	-	-	-	229,463
2003	-	-	-	-	346,002	48,913	-	-	-	-	-	-	-	-	394,915
2004	-	-	-	-	-	692,446	56,255	-	-	-	-	-	-	-	748,701
2005	-	-	-	-	-	-	347,405	53,166	-	-	-	-	-	-	400,571
2006	-	-	-	-	-	-	-	944,845	51,903	-	-	-	-	-	996,748
2007	-	-	-	-	-	-	-	-	899,202	51,645	-	-	-	-	950,847
2008	-	-	-	-	-	-	-	-	-	820,096	56,828	-	-	-	876,924
2009	-	-	-	-	-	-	-	-	-	-	384,638	51,797	-	-	436,435
2010	-	-	-	-	-	-	-	-	-	-	-	800,826	54,252	-	855,078
2011	-	-	-	-	-	-	-	-	-	-	-	-	1,049,407	49,438	1,098,845
2012	-	-	-	-	-	-	-	-	-	-	-	-	-	1,149,797	1,149,797
	-	-	7,606	230,195	348,436	741,359	403,660	998,011	951,105	871,741	441,466	852,623	1,103,659	1,199,235	**8,149,096**

Table 12. Releases by brood year

Brood year	Source[1]	Type[2]	Release year	Release season	Release stage[3]	Number marked	Mark types used[4]	Number unmarked	Total release
2000	W	S	2002	Spring	S	3,891	-	-	3,891
2001	W	S	2002	Fall	P	3,254	-	461	6,881
		CE	2003	Spring	S	3,166	-	-	
2002	W	S	2003	Fall	P	227,029	Ad	-	229,463
		CE	2004	Spring	SS	2,135	Ad/RV/LV/P	-	
				Fall/ Winter	sA/A	-	-	299	
2003	W	S	2004	Spring	UFF	-	-	32,740	394,915
				Summer	FF	148,448	Ad+CM	-	
				Fall	P	147,053	Ad	-	
	C	S	2004	Fall/ Winter	P	17,761	Ad	-	
	W	S	2005	Spring	S	47,269	Ad/CWT	535	
		CE			SS	466	P	643	
2004	C	S	2005	Spring	FF	-	-	263,618	748,701
	C+W			Summer	FF	297,085	Ad+CM	-	
				Fall	P	131,743	Ad	-	
	C+W	S	2006	Spring	PS	2,495	Ad	-	
		CE			SS	2,372	Ad	-	
		S			S	51,388	Ad+CWT	-	
2005	C+W	S	2006	Spring/ Summer	FF	190,026	Ad/Ad+CM	1,584	400,571
				Fall	P	155,795	Ad	-	
	W	CE	2007	Spring	SS	1,137	Ad/P	-	
		S			S	52,029	Ad/A	-	
2006	C	S	2007	Spring	FF	158,400	Ad	-	996,748
	C+W			Summer	FF	648,290	Ad	-	
	W			Fall	P	138,155	Ad/Ad+CM	-	
		CE	2008	Spring	S	50,503	Ad+CWT	-	
					SS	1,400	Ad	-	

[1] W=wild egg take, C=captive egg take from Rosewall Creek Hatchery
[2] CE= Excess to captive brood program S= Enhancement supplementation
[3] PS=pre-smolt, S= smolt, P=parr, SS=super smolt, UFF=unfed fry, FF=fed fry, s/A = smolt held to adult, A=adult
[4] Marks include adipose clips (Ad), ventral fin clips (right or left – RV/LV), calcein marking (CM), coded wire tags (CWT), POST acoustic tags (P), agency tags (A), or a combination thereof, to denote different release times and locations. Annual brood summaries may be requested from the program documents for individual marks on distinct groups of fish

Table 12. *cont'd*. Releases by brood year

Brood year	Source[1]	Type[2]	Release year	Release season	Release stage[3]	Number marked	Mark types used[4]	Number unmarked	Total release
2007	C	S	2008	Spring	FF	92,000	Ad	-	950,847
				Summer	FF	465,793	Ad	-	
	C+W				FF	190,837	Ad	-	
				Fall	P	150,572	Ad+CM	-	
	W	CE	2009	Spring	SS	1,250	Ad	-	
		S			S	50,395	Ad+CWT	-	
2008	C	S	2009	Summer	FF	677,868	Ad	-	876,924
	C+W			Fall	P	142,228	Ad+CM	-	
	W	S	2010	Spring	S	55,556	Ad+CWT	-	
		CE			SS	1,260	Ad	-	
2009	C	S	2010	Summer	FF	103,149	Ad	-	436,435
	C+W					132,957	Ad	-	
	W	S		Fall	P	93,052	Ad+CM	-	
						55,480	Ad	-	
	W	CE	2011	Spring	SS	1,372	Ad	-	
		S			S	50,425	Ad+CWT	-	
2010	C	S	2011	Summer	FF	243,275	Ad	4395	855,078
	C+W					298,758	Ad	-	
	W					104,225	Ad	-	
	C+W	S		Fall	P	150,173	Ad	-	
	W		2012	Spring	S	54,252	Ad+CWT	-	
2011	C	S	2012	Summer	FF	437,311	Ad	-	1,098, 845
	W					83,850	Ad	-	
	C+W					378,418	Ad	-	
	W			Fall	P	149,828	Ad	-	
			2013	Spring	S	49,438	Ad+CWT	-	
2012	C	S	2013	Summer	FF	356,215	Ad	-	1,189,470
	W					67,657	Ad	-	
	C+W					574,771	Ad	-	
	W			Fall	P	151,154	Ad	-	
			2014	Spring	S	39,673[5]	Ad+CWT	-	

[1] W=wild egg take, C=captive egg take from Rosewall Creek Hatchery
[2] CE= Excess to captive brood program S= Enhancement supplementation
[3] PS=pre-smolt, S= smolt, P=parr, SS=super smolt, UFF=unfed fry, FF=fed fry, s/A = smolt held to adult, A=adult
[4] Marks include adipose clips (Ad), ventral fin clips (right or left – RV/LV), calcein marking (CM), coded wire tags (CWT), POST acoustic tags (P), agency tags (A)or a combination thereof to denote different release times and locations. Annual brood summaries may be requested from the program documents for individual marks on distinct groups of fish
[5] Estimate based on smolts in holding at time of publication

Table 13. Sweltzer Creek Fence - Cultus sockeye smolt counts by brood year

Brood year	Unmarked	Marked	Hatchery smolts released below fence	Total smolts outmigrating	Fence operation
2000	3,666	-	3,891	7,557	Mar 31 - Jun 5, 2002
2001	10,794	571	1,598	12,963	Mar 24 - May 28, 2003
2002	110,130	5,558	1,620	117,308	Mar 30 - Jun 3, 2004
2003	81,475	17,206	1,109	99,790	Mar 14 - May 27, 2005
2004	13,742[1]	40,582	51,388	105,715	Mar 15 - May 31, 2006
2005	9,613	35,516	53,166	98,295	Mar 29 - May 31, 2007
2006	135,640	201,945	51,903	389,488	Mar 18 - May 18, 2008
2007	70,077	218,548	51,645	340,270	Mar 23 - May 20, 2009
2008	369	88,112	56,828	145,309	Mar 15 - May 21, 2010
2009	57,628	64,704	51,797	174,129	Mar 11 - May 26, 2011
2010[2]	187,654	76,541	54,252	318,447	Mar 11 – May 29, 2012
2011	10,051	60,017	49,438	70,067	Mar 14 – May 21, 2013

[1] In 2005 a large number of BY2004 Rosewall origin fry were released unmarked due to capacity issues. Based on otolith analysis, it was estimated that the composition of the BY2004 out-migrating smolts was 3,104 wild fish and 10,638 hatchery origin.
[2] 2-yr old smolts not included

Table 14. Adult collection periods at the Sweltzer Creek fence

Brood year	First adult collection date	Last adult collection date
2000	N/A	N/A
2001	Oct. 5, 2001	Nov. 23, 2001
2002	Aug. 13, 2002	Oct. 21, 2002
2003	Sept. 16, 2003	Nov. 14, 2003
2004	Sept. 8, 2004	Nov. 15, 2004
2005	Sept. 13, 2005	Nov. 17, 2005
2006	Aug. 25, 2006	Nov. 21, 2006
2007	Sept. 6, 2007	Nov. 6, 2007
2008	Aug. 12, 2008	Oct. 15, 2008
2009	Aug. 18, 2009	Nov. 6, 2009
2010	Aug. 16, 2010	Nov. 1, 2010
2011	Aug. 18, 2011	Oct. 12, 2011
2012	Aug. 22, 2012	Oct. 16, 2012
2013	Aug. 26, 2013	Oct. 2, 2013