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Scientific Information in Support of Recovery Potential Analysis for Chinook Salmon Okanagan Population, *Oncorhynchus tshawytscha*

Analyse du potentiel de rétablissement de la population de saumons quinnats de l'Okanagan, *Oncorhynchus tshawytscha*

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Abstract

The Okanagan chinook population is the last remaining Columbia basin stock that resides within Canada and it is geographically and genetically distinct from chinook populations elsewhere in Canada. The Canadian Okanagan population consists of anadromous salmon that migrate to and from the Pacific Ocean through the Columbia River, to the area bounded by McIntyre Dam at the outlet of Vaseux Lake. Ancestral Columbia River Chinook salmon population have been estimated at 2-4 million fish with the historic abundance in the Upper Columbia in the hundreds of thousands. Historically the Okanagan Chinook population was large enough to support an important food and commercial/economic trade fishery prior to non-native human settlement. However, downstream fishing combined with high inter-dam mortalities for migrating salmon has led to reduced numbers.   Rapid human development in the river basin has led to wide spread degradation of habitat. Loss of habitat has also been attributed to irrigation and water withdrawal, logging, mining, transportation corridors, and other human activities, which have reduced the quantity, quality, and capacity of spawning and rearing areas. The annual number of chinook spawning in Canada is less than 50 adults.

There is a high degree of interrelatedness for chinook found within the Okanagan River. A close familial relationship among Okanagan Chinook presents strong evidence for the successful out migration, return and survival of a few families of Okanagan Chinook. Yet the level of genetic diversity in the small population and recovery of a few tagged fish indicates that it is currently receiving strays from a larger population. The lack of significant differentiation in allele frequency between the Similkameen and Okanagan River samples indicates that the Similkameen population is likely the source of strays.

The amount of spawning and rearing habitat available within the Canadian portion of the Okanagan River was estimated to be 16km^2. Anadromous species may use the Columbia River for rearing, and must use it as a migration corridor. Juveniles rear and grow to adults in the Pacific Ocean. Adults spawn over a patchy range of habitat. Total spawning capacity estimates range from 2,440 to 8,680 fish with a defensible estimate of 1460 spawning pairs. These estimates are based on watershed areas, known habitats, and behavioural characteristics of Okanagan Chinook. The most northern accessible portion of the Okanagan River contains reaches that are suitable for spawning and rearing. The naturalised upper sections contain a variety of complex habitats, while the lower channelized section lacks habitat complexity. It has no backwater pools, primary pools, undercut banks, pool tail-out glides, and has little groundwater influence. Following their emergence in April or May, the exact rearing locations of Okanagan Chinook fry are unknown. We suspect they rear in the Okanagan River for a short time and in Osoyoos Lake, but they may also rear downstream in the mainstem Columbia River.

The life history of the Canadian portion of the Okanagan Chinook population has never been examined as a unique entity. We suspect their life history is similar to the life history of other Upper Columbia River summer stocks that have been examined in more detail. Juvenile Chinook move downstream through the Columbia River throughout the year and pass through the estuary to the ocean. Fish may remain in the estuary for periods ranging from weeks to months.

Chinook in Canada have been adversely impacted by human induced changes in the environment. These threats include; water withdrawals, construction of dams that limit and exclude passage or entrain/harm migrating fish, channel modification and introduction of non-native fish species. American Columbia River habitat impacts can be

severe. These alterations have resulted in reductions in habitat complexity, slower water velocities and higher water temperatures with the Columbia and Okanagan Rivers. Chinook salmon populations are also impacted by fisheries and large scale hatchery supplementation.

We employed a parameter estimation and sensitivity analysis, using stochastic and deterministic elements to evaluate population trajectories under baseline conditions and explored the potential impacts of multiple management alternatives (Appendix C). Our population viability analysis (PVA) model indicates that juvenile survival downstream through the hydro-power system limits population persistence. The same is true for adult survival, which is likewise constrained by upstream passage mortality through the hydro-power system. Ocean survival is another influential parameter, but values used in our simulations were derived from a period when ocean survivals were among the highest recorded (i.e., the late 1990's). Thus, it is likely that observed rates of decline would exceed those observed in our simulations. While fishing mortality also contributes to the decline, even complete cessation of harvest and corresponding reduction in mortality was found to be insufficient to recover the stock.

Given the uncertainty that managers can dramatically improve juvenile and adult survival through the gauntlet of American hydro dams and reservoirs, it appears that the only alternative that can feasibly forestall extirpation in the near-term is via hatchery production. However, the magnitude of artificial production required to meet escapement goals is immense and would require a large program (approximately 1.75 million smolts annually). A program of that magnitude would be accompanied by its own array of risks.

The long-term recovery objective should be a secure and viable Canadian chinook population within the Okanagan Basin. The short-term objective should be to maintain this run of chinook through hatchery supplementation. The longer-term objective would require a viable naturally spawning Canadian chinook population. The minimum population size of this spawning population based on a scenario from the population viability analysis was an average of 295 individuals over four brood years. It was speculated that this could be achieved by 2050.

Immediate action needs to be taken to prevent the Canadian population from being extirpated. First and foremost would be the implementation of a hatchery program to supplement the current population. Second would be investigation into provisions for fish passage at facilities currently limiting access. Third is determining and mitigating the impacts of predation/competition with exotics fish species is required. Fourth, reducing fisheries impacts should be investigated. Lastly, investigation into how Canada can contribute to improve downstream survival through mainstem hydroelectric dams should be conducted. To support the existing wild population, measures should be taken to ensure that the required habitat features are maintained, enhanced, or restored in the Canadian portion of the Okanagan.

A high degree of uncertainty exists in establishing recovery goals, recovery targets, and in defining critical habitats. A clear understanding of the life-cycle characteristics of the Canadian Okanagan population is required. Three biological scenarios exist based on possible differences in degree of isolation and degree of uniqueness of the population. Each of these scenarios has different implications for recovery time, recovery goals, and delineation of critical habitats. Continuation of studies to clarify these uncertainties is recommended.

Résumé

La population de saumons quinnats de l'Okanagan est le dernier stock du bassin du fleuve Columbia qui réside encore au Canada. Cette population est en outre géographiquement et génétiquement distincte des autres populations de saumons quinnats. La population canadienne de l'Okanagan est composée de saumons anadromes qui migrent dans le Pacifique et qui retournent dans le fleuve Columbia, jusqu'à une région bornée par le barrage McIntyre, à la décharge du lac Vaseux. Selon les estimations, la population de saumons quinnats du Columbia aurait déjà atteint de 2 à 4 millions d'individus, l'abondance historique dans le cours supérieur du Columbia atteignant quant à elle des centaines de milliers de poissons. Avant l'établissement de l'homme blanc dans la région, la population de saumons quinnats de l'Okanagan était suffisamment importante pour soutenir une importante pêche commerciale et de subsistance. Toutefois, la pêche en aval, combinée à une mortalité élevée chez les saumons en migration entre les barrages, a entraîné une diminution de l'abondance. De plus, le développement humain rapide survenu dans le bassin du fleuve a été l'une des causes de la détérioration à grande échelle de l'habitat. La perte d'habitat est également attribuable à l'irrigation et aux prélèvements d'eau, à l'exploitation forestière et minière, aux voies de transport et à d'autres activités humaines qui ont réduit la disponibilité, la qualité et la capacité des frayères et des aires de croissance. Aujourd'hui, le nombre de saumons quinnats qui frayent chaque année au Canada est inférieur à 50 individus.

On note un haut degré de consanguinité chez les saumons quinnats de la rivière Okanagan. Les liens familiaux étroits témoignent du succès de l'émigration, du retour et de la survie des quelques familles de saumons quinnats de cette rivière. Pourtant, le degré de diversité génétique de la petite population et le rétablissement de quelques poissons marqués montrent qu'elle accueille actuellement des poissons égarés d'une plus grande population. Le manque de différenciation significative quant à la fréquence allélique entre les échantillons des rivières Similkameen et Okanagan indique que la population de la Similkameen est probablement le point d'origine des poissons égarés.

La disponibilité d'un habitat favorable à la reproduction et à la croissance dans la partie canadienne de la rivière Okanagan est estimée à 16 km^2. L'espèce anadrome peut utiliser le fleuve Columbia pour sa croissance et doit l'emprunter comme couloir de migration. Les jeunes grandissent et deviennent des adultes dans l'océan Pacifique, bien qu'il puisse exister une petite population résidente qui reste en eau douce pendant toute la durée de son cycle biologique. Les adultes frayent dans des habitat discontinus dans la partie nord la plus accessible de la rivière Okanagan. L'estimation de la capacité totale de reproduction varie entre 2 440 et 8 680 poissons, avec une estimation justifiable de 1 460 paires de reproducteurs. Ces estimations sont fondées sur la superficie des bassins, les habitats connus et les caractéristiques de comportement des saumons quinnats de l'Okanagan. On observe, dans les tronçons naturalisés du cours supérieur, une variété d'habitats complexes, tandis que l'habitat des tronçons du cours inférieur canalisé manque de complexité. On n'y trouve pas de bras-morts, de bassins primaires, de rives sapées, de rapides, et le mouvement attribuable aux eaux souterraines est limité. On ne connaît pas l'emplacement exact des aires de croissance des alevins des populations de l'Okanagan après leur émergence, en avril ou en mai. Nous soupçonnons qu'ils grandissent dans l'Okanagan pendant une courte période et dans le lac Osoyoos, mais ils pourraient aussi passer une partie de leur période de croissance dans le cours supérieur du Columbia.

Le cycle biologique des saumons quinnats de la portion canadienne de la population de l'Okanagan n'a jamais été étudié en tant qu'entité unique. Nous supposons que son cycle est semblable à celui d'autres stocks d'été du cours supérieur

du Columbia qui ont été étudiés en détail. Les jeunes saumons quinnats descendent vers l'aval en empruntant le fleuve Columbia pendant toute l'année et arrivent dans l'océan après avoir traversé l'estuaire. Les poissons peuvent rester dans l'estuaire pendant des périodes variant de quelques semaines à quelques mois.

Au Canada, les saumons quinnats ont subi les effets négatifs des changements apportés par l'homme à l'environnement, notamment : les prélèvements d'eau, la construction de barrages qui limitent ou obstruent le passage ou entraînent/blessent les poissons migrateurs, les modifications de chenal et l'introduction d'espèces de poisson exotiques. Les effets sur l'habitat dans la portion américaine du fleuve Columbia sont parfois graves. Ces modifications ont entraîné une réduction de la complexité de l'habitat, une diminution de la vitesse du courant et une hausse des températures de l'eau du Columbia et de l'Okanagan. Les populations de saumons quinnats ont aussi souffert de la pêche et des lâchers à grande échelle de poissons d'élevage.

Nous avons utilisé une estimation des paramètres et une analyse de sensibilité ainsi que des éléments stochastiques et déterministes afin d'évaluer la trajectoire de la population dans les conditions de base et avons examiné les effets possibles de multiples scénarios de gestion (annexe C). Notre modèle d'analyse de la viabilité de la population (AVP) révèle que le taux de survie des jeunes en aval, au niveau de la centrale hydroélectrique, limite la longévité de la population. Il en est de même pour la survie des adultes, qui est aussi restreinte par la mortalité en amont, au passage de la centrale hydroélectrique. La survie en mer est un autre paramètre d'influence, mais les valeurs utilisées pour nos simulations provenaient d'une période au cours de laquelle le taux de survie en mer était parmi les plus élevés jamais observés (fin des années 1990). Ainsi, il est probable que les taux de déclin observés dépassent ceux que nous avons obtenus dans nos simulations. Même si la mortalité par pêche contribue au déclin, un arrêt complet des captures et la réduction correspondante du taux de mortalité seraient insuffisants pour assurer le rétablissement du stock.

Étant donné l'incertitude entourant la capacité des gestionnaires d'améliorer considérablement le taux de survie des juvéniles et des adultes dans le dédale des barrages et des réservoirs hydroélectriques américains, il semble que la seule solution susceptible de repousser le moment de la disparition locale à court terme soit la production en écloserie. Toutefois, l'ampleur de la production artificielle requise pour atteindre les objectifs d'échappée est considérable et exigerait un vaste programme (environ 1,75 million de saumoneaux par année). Un programme de cette ampleur amènerait lui aussi son propre éventail de risques.

L'objectif de rétablissement à long terme devrait être une population canadienne assurée et viable de saumons quinnats dans le bassin de l'Okanagan. L'objectif à court terme serait de maintenir la remonte de saumons quinnats par des apports artificiels. L'objectif à long terme nécessiterait une population viable de saumons quinnats canadiens capables de se reproduire naturellement. La taille minimale de cette population de géniteurs, selon un scénario découlant de l'analyse de viabilité de la population, serait de 295 individus en moyenne sur quatre années de génération. On présume que cet objectif pourrait être atteint d'ici 2050.

Des mesures immédiates doivent être prises pour empêcher la population canadienne de disparaître localement. Premièrement, il faudrait mettre en œuvre un programme d'élevage pour soutenir la population actuelle. Deuxièmement, il faudrait vérifier s'il est possible de faciliter le passage aux installations qui limitent actuellement l'accès. Troisièmement, il faut déterminer et atténuer les effets de la prédation ou de la compétition des espèces de poissons exotiques. Quatrièmement, il faudrait examiner s'il est possible de réduire les répercussions de la pêche. Enfin, il faut entreprendre une étude afin de déterminer de quelle façon le Canada peut contribuer à améliorer la survie en aval à travers les barrages hydroélectriques du cours principal. Afin d'appuyer la population sauvage actuelle, des mesures devraient être prises pour faire en sorte que les caractéristiques requises de l'habitat soient maintenues, améliorées ou rétablies dans la portion canadienne de l'Okanagan.

Le choix des objectifs et des cibles de rétablissement et la définition des habitats essentiels sont empreints d'une grande incertitude. Il est impératif d'obtenir une bonne compréhension des caractéristiques du cycle de vie de la population de la portion canadienne de l'Okanagan. Il existe trois scénarios biologiques fondés sur des différences possibles dans le degré d'isolement et le caractère unique de la population. Chacun de ces scénarios a des répercussions différentes pour ce qui est du délai et des objectifs de rétablissement, ainsi que de la délimitation des habitats essentiels. La poursuite d'études visant à dissiper ces incertitudes est recommandée.

1.0 Context

Chinook salmon (*Oncorhyncus tshawytscha* Walbaum), *Canadian* Okanagan population (Figure 1), was designated as endangered in an emergency assessment on May 4th, 2005 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Okanagan Chinook were designated as a result of having a population of less than 50 spawners making it susceptible to extinction/extirpation from habitat loss, exploitation and stochastic factors. The status was re-examined by COSEWIC in April 2006 and Okanagan Chinook were designated as threatened. This more recent assessment was based on genetic data indicating there was the potential of rescue from populations in adjacent areas of the Columbia River basin. A final decision on whether this species will be legally listed under SARA is pending. If listed, activities that would harm the species would be prohibited and a recovery plan would be required. Until such a plan is available, section 73(2) of SARA authorises competent Ministers to permit otherwise prohibited activities affecting listed wildlife species, any part of its critical habitat, or the residences of its individuals. An activity can also be authorized if it is scientific research related to the conservation of the species and conducted by qualified persons, or benefits the species, or is required to enhance its chances of survival in the wild, or affecting the species is incidental to the carrying out of the activity. The analysis provided herein will allow the Minister of Fisheries and Oceans to determine the basis under which permits are to be issued in the Okanagan River.

One of the documents that will be used in the decision to list Okanagan Chinook under SARA is a Recovery Potential Analysis (RPA). This RPA defines the current biological status of the species and its habitats and the feasibility of survival and recovery. On a biological basis it will set recovery targets in population size and range and will estimate the time needed to achieve these targets. It will describe current sources and levels of human and natural induced mortality. The RPA will also outline the uncertainties associated with various management actions and the potential of future studies to clarify unknowns.

The Canadian population of Okanagan Chinook is found within the Okanagan River and is the last remaining Canadian population using the Columbia River. This population is geographically and reproductively isolated from other Canadian Chinook populations, with the nearest coastal population being 1400 km away (COSEWIC 2006). Within the Columbia River Basin prior to the construction of the Grand Coulee Dam in 1939, other populations of Chinook occurred as far upstream as the outlet of Lake Windermere, British Columbia (Fulton 1968; Scholz et al. 1985; Chapman et al. 1995.

To reach the Okanagan River adult Chinook must move through nine mainstem hydroelectric Columbia River dams (Figure 2). Once they have entered the Okanagan River, the Canadian destined Chinook must pass over the American Zosel Dam to reach spawning habitat located below the McIntyre Dam. Currently, Chinook cannot reach either Okanagan Falls or any lakes upstream of Osoyoos Lake due to the presence of McIntyre Dam at the outlet of Vaseux Lake (Figure 2). Okanagan Chinook have been historically persistent, but with such low numbers their future is uncertain.

Figure 1. Okanagan Chinook (2006 spawning season).

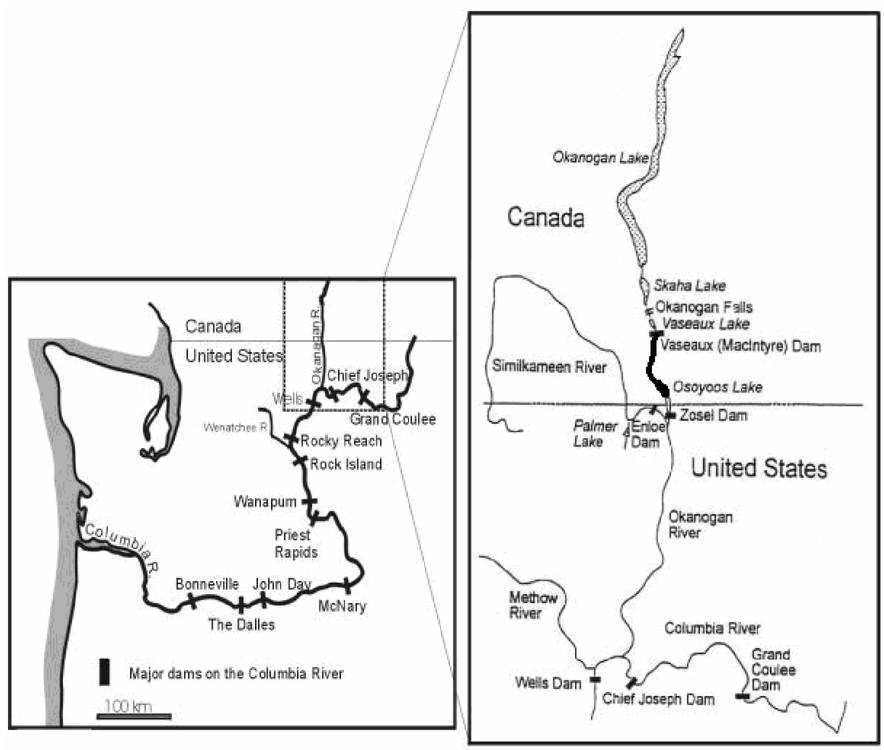

Figure 2. Distribution map for Okanagan Chinook.

2.0 Population Assessment and Analysis

2.1 Information sources

The information specific to Okanagan Chinook was obtained from studies completed by the Okanagan Nation Alliance within the Okanagan River since 2002.

This data was collected as part of the enumeration studies for sockeye and Chinook. Visual surveys were conducted throughout September and October to count the numbers of Chinook. Biological samples were collected and live fish were tagged and returned to the river. These samples were analysed by Fisheries and Oceans Canada (DFO) for genetic information. Pair-wise F_{st} values between the Okanagan River 2005 and 2006 samples and the combined 1993 and 2005 Similkameen River samples were calculated. Genetic relationships among Chinook salmon samples from different spawning locations were examined using the Cavalli Sforza Edward chord distance and were depicted in a neighbour-joining dendrogram.

Spawning redd surveys were completed and the physical characteristics of these redds was determined. Methodologies are described in the brood year reports completed by Wright *et al.* (2006). A further source of information was from the Ecosystem Diagnosis and Treatment (EDT) system for the Okanagan Subbasin Plan (NPCC 2004). This system divides the watersheds into reaches and rates 48 channel and habitat attributes within each reach. Data for this analysis was obtained from historical studies and from subjective values input by various experts. Where specific information was lacking some surrogate values could be obtained from literature pertaining to other Columbia River stocks. The Okanagan population is believed to be most related to the Upper Columbia River summer Chinook stocks.

Washington Department of Fish and Wildlife (WDFW) have been conducting spawning ground surveys in the US portion of the Okanagan River since 1956 (Miller 2005). Since 1990, spawning survey methods have included aerial peak counts and ground counts by raft or foot within survey reaches. Other monitoring programs that are used to enumerate the stocks include recording commercial harvest and enumerating adult summer chinook at four mainstem mid Columbia hydroelectric facilities (Evenson and Talbot 2003).

Chinook have been formally counted during the sockeye enumeration program in the Canadian portion of the Okanagan River each year since 2001 and adults have been seined, tagged, and released since 2003 (Wright and Long 2006). There are few records of Okanagan Chinook before this time. The best evidence of population abundance are historic accounts of the major Chinook fishery at Okanagan Falls (Ernst 1999; Ernst and Vedan 2000), and gill netting in Osoyoos Lake in 1971 (Northcote *et al.* 1972). The presence of Chinook was recorded in DFO correspondence files (Kamloops and Salmon Arm offices) for a few years from the 1920's to 1999, and there were observations of spawning Chinook within the river during sockeye enumeration surveys from 1968-1999 (COSEWIC 2006).

2.2 Genetic Description

The basis for comparisons of genetic relatedness between Okanagan Chinook and other populations in the Columbia basin were initiated in 2000 and continued into 2007. In total 68 Chinook have been captured in the Okanagan River and Osoyoos Lake but not all of these were sampled for DNA. A single sample was taken in each of 2000, 2002 and 2003, while three fish were sampled in 2004 and 28 in 2005 (COSEWIC

2006). In 2006, 32 samples were collected, of which 31 provided results for genetic analysis.

Okanagan chinook are characterized by having a summer/fall adult migration and ocean-type juvenile life-history (Waples et al. 2004) similar to the behaviour of other upper Columbia summer/fall run fish. Okanagan Chinook are genetically different from other Canadian stocks (COSEWIC 2006). This population is genetically distinct from other ESUs or equivalents within the Fraser basin due to distinct regional glacial histories and geographic isolation (Myers et al. 1998). Within Canada, the Okanagan population is the last of the Upper Columbia summer/fall run chinook.

The Canadian Okanagan Chinook population is genetically affiliated with other upper Columbia River summer/fall run chinook. Okanagan River Chinook were most closely related to two other Upper Columbia fall/summer run fish populations (Figure 1, Appendix B). These are the Similkammeen and Wenatchee river chinook. The genetic differentiation (F_{ST} value) between the 2005 Okanagan River and a multi-year (1993, 2005, 2006) Similkameen River sample was low (0.011) but significantly different from zero. The difference between the 2006 Okanagan and Similkameen River samples (0.002) was not significantly different from zero (Appendix B).

There is evidence for successful reproduction of Chinook in the Canadian Okanagan River. Immature fry/juveniles of more than one age have been captured, and fish of greater than one year of age were discovered "residualizing" in Osoyoos Lake. Genetic analysis (Appendix B) confirmed that the juveniles sampled were the result of two different spawning events, as sibling relationships were not apparent between two age classes of juveniles.

A few Chinook have contributed most of the genetic material to the population. In total, 33 fish belonging to three families accounted for 40% of the Chinook salmon sampled between 2000 and 2006 in the Okanagan River and Osoyoos Lake. They included all nine of the residualized yearlings sampled in 2003, two out of three adults sampled in 2004, 18 out of 28 adults sampled in 2005 and four out of 31 adults sampled in 2006. The most reasonable explanation for the large numbers of fish from these families returning to the Okanagan River between 2004 and 2006 is that they arose from a spawning event that took place in the Okanagan River, perhaps in 2001 (Appendix B). Some of the juveniles produced residualized and stayed in Osoyoos Lake rather than migrating to the ocean in the spring of 2002. They constituted the fish caught in the Lake as yearlings in 2003 and contributed to those that returned to the River for spawning in 2004, 2005 and 2006.

Okanagan Chinook clustered with upper Columbia summer and fall run Chinook populations (Anonymous 2006). The longer dendrogram branch length associated with the Okanagan River samples reflects the larger Cavalli-Sforza Edward chord distances between it and other samples in the group (Figure 3) (Appendix B). The distinctiveness is attributable to the close familial relationship between the sampled fish. In 2005, 21 of the 28 fish were either full or half siblings to at least one other fish. The small size of the population may result in interbreeding depression. The entire population is derived from 11 fish of one sex and 28 fish of the other. It is likely that several of the Chinook salmon that returned in 2006 originated from the families that produced the 2005 returns. Nine of the 31 fish sampled in 2006 may have also originated from the families that returned in large numbers in 2005, but the remaining 2006 fish tended to be unrelated to each other.

Okanagan River fish in 2005 were the result of a few families that experienced high survival (Anonymous 2006a). A small population would be expected to have a low level of genetic diversity if it is based exclusively on a few families for a number of generations. However, the level of genetic diversity in Okanagan Chinook was considered high as measured by allelic richness and genetic diversity. This high level of diversity in a small population indicated that it has received genetic input from a larger population or is newly formed. The Okanagan population is unlikely to be a long-standing remnant population that is independent from nearby populations in the Okanagan drainage. The low level of genetic differentiation of the Okanagan River fish from nearby upper Columbia summer/fall Chinook populations make these neighbouring populations the most likely source of gene flow into the Okanagan River (Anonymous 2006b). Nevertheless, the large numbers of adults returning from a few families in 2005-2006 indicates that successful spawning (in terms of producing returning adults) has occurred recently in the Okanagan River.

The possibility that the successful spawners and their progeny were part of an isolated remnant population was examined through family analysis (Appendix B). Three hypotheses were addressed using a set of ten genotypes that represented successful spawners in the Okanagan River. First, if the Okanagan River fish represented a remnant population they would have a different allele frequency when compared to neighbouring populations. The allele frequencies of the ten successful Okanagan River spawners/progeny were not significantly different from allele frequencies in the nearby Similkameen and Wenatchee rivers (both $P > 0.05$). Second, a small sized remnant population would have lost alleles due to genetic drift and inbreeding. Neither the successful Okanagan River spawners nor the 2006 Okanagan sample of adult fish showed a reduced level of allelic diversity. Third, the loss of alleles in the remnant population would have reduced the level of heterozygosity of individual Chinook salmon in the remnant population relative to fish from a larger population. Reduced levels of heterozygosity were not noted.

The genetic analysis presented in Appendix B, indicated that few if any of the Chinook salmon sampled between 2000 and 2006 in the Canadian portion of the Okanagan River, were members of an isolated remnant population of Chinook salmon. The Chinook sampled included successful spawners and their progeny. The fish present in the Canadian portion of the River were considered to be part of a much larger metapopulation and are currently receiving, or have recently received, gene flow from a larger nearby population. This nearby population is likely the Similkameen River population.

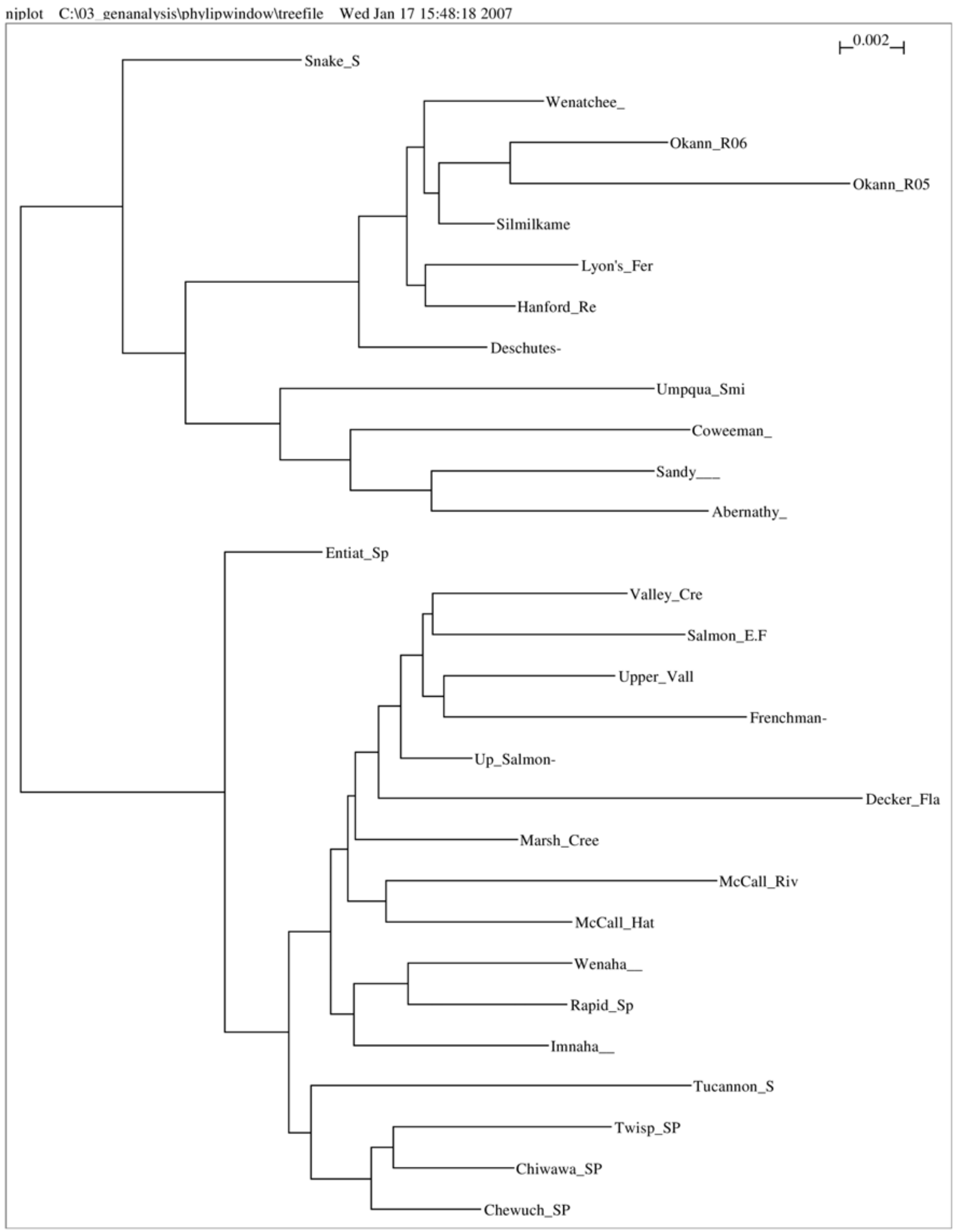

Figure 3. Dendogram of Cavalli-Sforza and Edwards (1967) cord distances (12 loci) among Chinook salmon populations in the Columbia River. Sp (spring), Su (summer), and F (fall) denote spawner migration timing (PBS Genetics Lab, *unpublished data* 2007).

2.3 Current Species Status and Trends

Chinook salmon populations are effected by both natural and anthropogenic factors. Prior to 1900, Columbia River Chinook estimates were indirectly measured. Annual escapement fluctuated and would have been influenced by natural phenomenon and annual variation in climatic conditions.

The Canadian Okanagan Chinook population is most closely related to the much larger Upper Columbia River summer/fall chinook population. The upper Columbia chinook summer/fall population was classified as "depressed" by state fisheries agencies in 1992 but was subsequently upgraded to "healthy" in a 2002 assessment (http://wdfw.wa.gov/fish/sasi/stock_descriptions_30dec04.xls). The American federal government has concluded that the Upper Columbia River summer Chinook is not in danger of extinction as a metapopulation, nor will it be in the near future (Moore *et al.* 2004). Recent counts have significantly surpassed 1956-1999 returns. Upper Columbia summer/fall chinook is a challenging stock to manage because it has highly variable annual escapement, it lacks a productive population within the Canadian portion of the Okanagan River, and there is a desire to increase the proportion of the stock considered to be wild. The number of returning adults has declined dramatically from historic levels (Evenson and Talbot 2003). The decline has been attributed to over fishing and habitat loss due to hydropower and storage dams.

The Upper Columbia summer Chinook stocks were considered to be part of the prolific salmon runs associated with the Columbia River Basin (Evenson and Talbot 2003). The total historic Columbia River Chinook salmon population has been estimated at 2-4 million fish with the Upper Columbian runs estimated in the hundreds of thousands (Waknitz *et al.* 1995; Mullan 1987). Based on rough estimates of habitat availability, 250,000 Chinook may have once been produced in the mid-Columbia River between the McNary and Chief Joseph Dams (NRC 1996). These late spring and summer runs supported the largest fishery in the Columbia basin.

Periodic fluctuations in abundance of Columbia River salmon were common. Episodes of starvation among Native American tribes were recorded in 1811, from 1826 to 1829 and in 1831 (Mullan 1987). These fluctuations may have been the result of variations in ocean conditions. Settlement within the basin has resulted in significant alterations to both habitat and stream community composition and abundance (Moore *et al.* 2004).

Human encroachment throughout the basin resulted in a significant decline in Columbia River salmon numbers. In the late 1800's a general decline was apparent in the Upper Columbia Chinook populations (Waknitz *et al.* 1995). The fishery at Kettle Falls just upstream of Grand Coulee Dam reported millions of Chinook salmon with a peak in June and a major peak in August (Mullan 1987). This was the site of an extensive native fishery with summer chinook being the dominant component of the catch. Its importance continued with non-native settlement. Following completion of the Rock Island dam in 1932, only 400 Chinook salmon were harvested at Kettle Falls. A third fish-way was installed at Rock Island Dam as a result of declining catches and no further passage problems were noted for adult Chinook. There was a further reduction in catch from 84% to 47% in the mid 1940's resulting in a corresponding increase in escapement. The catch peaked in 1957, and then declined after the mid 1960's. Escapement remained stable from 1953-1984.

The Canadian Okanagan Chinook population, prior to non-native settlement, was numerous enough to support an important food and commercial/economic trade fishery (Ernst and Vedan 2000). First Nations have reported that Chinook were heavily fished at the outlet of Skaha Lake and that Chinook were able to reach both Skaha and Okanagan Lake (Ernst 1999; Ernst and Vedan 2000). Traditionally six runs of salmon including steelhead would ascend the Okanagan River into Okanagan Lake (Vedan 2002). Spring Chinook were also thought to be present in the Okanagan River and tributaries associated with the watersheds lakes. If they once existed they have since been extirpated. Sockeye salmon, due to their abundance, was the primary salmon species harvested within the traditional fishery (Mullan 1987).

Commercial fisheries were established within decades of de Heccate arriving at the mouth of the Columbia River (Bottom *et al.* 2005). Commercial harvest began in 1818 with pickling and salting of salmon. An Intensive fishery began in the Columbia River following the development of cannery technology (Williams *et al.* 2006). By 1874, it was estimated that over one-half of the salmon run attempting to return to the Upper Columbia was harvested in the downstream commercial fishery (Waknitz *et al.* 1995; NRC 1996). Prior to 1933 the mean commercial harvest catch rate was 2.1×10^6 Chinook salmon and a peak harvest of 2.3×10^6 fish (19.5 million kilograms) was recorded in 1883 (Evenson and Talbot 2003). Catches ranged from 7.7 to 16.8 million kg between 1890 and 1920 (Fulton 1968). During this period the spring and summer races of Chinook were principally targeted. As they declined, there was a shift to the fall population (Williams *et al.* 2006). After 1923 the harvest of all populations of Chinook declined. This decline continued until the river fisheries were closed. The summer fishery was closed in 1965 and the spring fishery was closed in 1977.

Historical accounts of Chinook in the U.S. portion of the Okanogan Basin do not include run size or escapement estimates, but from the 1880's to the 1930's local newspapers regularly mentioned active food fisheries (Smith 2003 a, b). In the Okanogan River aerial redd surveys have been conducted since 1956 (Figure 4) (Miller 2006). A redd expansion factor of 2.27 in 2004 was used to estimate adult escapement. Between 1956 and 1998 redd estimates have fluctuated. However, since 1999 redd estimates have been increasing. This may be linked to improved ocean survival in recent years and to improved smolt survival associated with high run-off conditions during downstream migration (PSC 2007). Hatchery contributions during the period of 1999-2002 have been estimated to represent 56% of the escapement with a range of 20-70% (COSEWIC 2006).

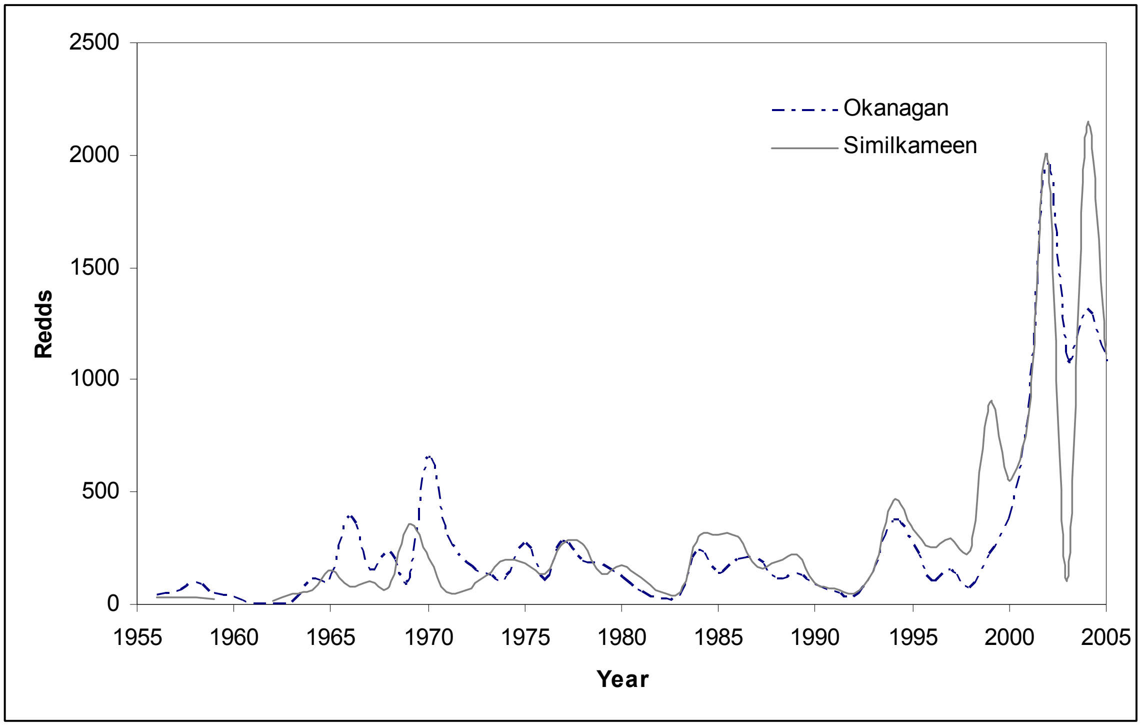

Figure 4. Summary of aerial redd surveys for Okanogan (US portion below Osoyoos Lake) and Similkameen Rivers from 1956-2005 (data adapted from Miller 2006).

Within the Canadian portion of the Okanagan Basin, Chinook have been intermittently documented since 1965 (Figure 5) (COSEWIC 2006). Most of the Chinook observations occurred in conjunction with sockeye salmon enumeration as counts of Chinook were not specifically conducted. Escapement has been estimated from the live and dead counts. In the past decade, Okanagan Chinook escapement estimates have been very low, ranged from 5 to 25 adults per year, for those years in which salmon were known to be present. However, in 2006, a video counter was installed at the Zosel Dam fish-ways, and documented 565 Chinook passing into Osoyoos Lake as opposed to a peak count of less than 30 observed on the spawning grounds (Rayton, M., personal communication 2007). It is unknown if the Chinook passing over Zosel Dam spawned in the Canadian portion of the Okanagan River or migrated back downstream to spawn. Research should be conducted to clarify the apparent discrepancy between dam counts and spawning surveys as this has a bearing on status and PVA modeling. Spawning adults may have been supplemented by residual/resident Okanagan Chinook, although there is no conclusive evidence (COSEWIC 2006; Wright and Long 2005).

Okanagan Chinook have been consistently found within the basin, although, they were notably absent from gillnetting samples in Osoyoos Lake in 1972 (Allen and Meekin 1980). By contrast, Okanagan Chinook were captured in gillnet sampling of Osoyoos Lake in 1971 (Northcote *et al.* 1972). Also, Chinook were gill netted in Osoyoos Lake in 2003 (6) and 2004 (1-genetics only) (Okanagan Nation Alliance Fisheries Department unpublished files). All six Chinook in 2003 were aged 1+, were all males, had evidence of fry in their stomachs (presumably sockeye), and showed evidence of spawning maturity.

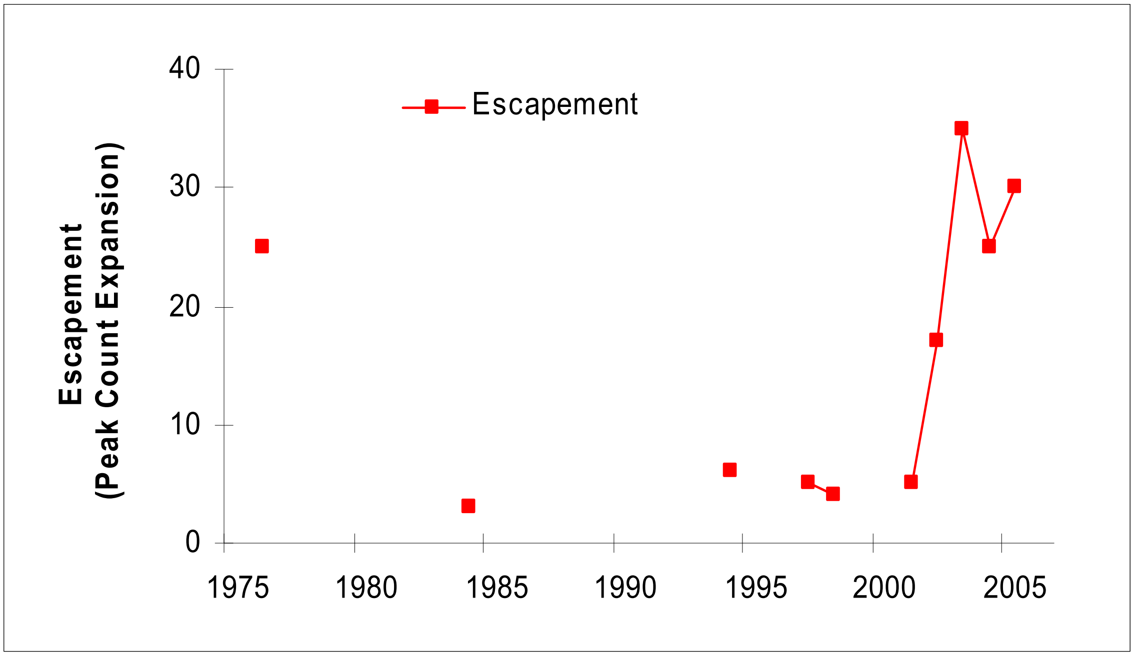

Figure 5. The escapement of Chinook to the Canadian Okanagan River (1975-2005).

American hatcheries have played a major role in the management of Chinook since the declines of the spring run in the late 1800's. Chinook salmon were the first fish to be artificially propagated in the Columbia Basin (Williams *et al.* 2006). The primary goal was to increase numbers for harvest (Fulton 1968; Mullan 1987). In the Upper Columbia, hatchery programs began with the Methow and Wenatchee Rivers. The hatchery programs for Chinook in the Columbia expanded from releasing 61 million juveniles in 1960 to 160 million in 1988 (Williams *et al.* 2006).

In 1939 the Grand Coulee Dam blocked access to 1,835 km of the upper Columbia River (Mullan 1987). To preserve the runs above this point many salmon were trapped and transported from Rock Island Dam to Wenatchee and Entiat Rivers and released. In addition, salmon were transported to the Leavenworth, Entiat and Winthrop National Fish hatcheries (Mullan 1987; Myers *et al.* 1998). There was an attempt to shift salmon production from the upper river to the lower river. To maintain production, lower river stocks would be enhanced through stocking of hatchery fish and upper river stocks would be transferred to the lower rivers. The fish transported were a mixture of up river stocks captured at Rock Island Dam, as well as fish taken from the Lower Columbia. The Grand Coulee Maintenance Project ran from 1939-1943 and tended to homogenize population diversity above Rock Island Dam (Mullan 1987). Lastly, no Chinook were released into the Canadian portion of the Okanagan River, which, other than six year old returns, wiped out any returns during this period.

Summer Chinook were managed primarily to maintain natural levels of production in the Wenatchee, Methow, Okanogan and Similkameen River (Mullan 1987). They were released annually from Wells Dam Hatchery and intermittently at Rocky Reach and Winthrop Hatcheries before 1985. The summer Chinook that have been out-planted were the progeny of broodstock collected either in the U.S. Okanogan River or at Wells Dam. The broodstock collected at Wells Dam is a mix of Okanogan and Methow River Chinook.

In the past decade, between 300,000 and 1 million yearlings and sub-yearlings have been stocked annually in the U.S. portion of the Okanogan Basin (FPC 2007). Recent releases of summer Chinook were derived from the Methow-Okanogan and Wells stocks. A total of about 860,000 spring Chinook were planted between 2001 and 2006 in the U.S. portion of the Okanogan River and its tributaries (FPC 2007).

During enumeration of Chinook on the Okanagan River, marked American hatchery fish have been caught. The contribution of hatchery fish to the total spawning population has varied. In 2003, half of the Chinook that were captured (six in total) on the Canadian Okanagan River spawning grounds were of hatchery origin (Wright and Long 2006). Thus a significant portion of the Canadian Okanagan population can be comprised of strays from U.S. hatcheries. However, none of the Chinook observed spawning in 2004, 1 of 29 adults in 2005, and 1 of 35 adults in 2006 showed evidence of hatchery origin (i.e. an adipose clip). All fish are clipped when released from the hatchery (i.e. mass marking). The hatchery-origin fish observed in 2003 were likely summer (ocean-type) Chinook, as no spring (stream-type) Chinook were stocked in the Okanagan basin during the corresponding brood years (COSEWIC 2006).

The goal of a proposed hatchery located at the base of Chief Joseph Dam is to increase the abundance of Okanagan Chinook (COSEWIC 2006). The numbers of returning adults are to be increased to levels sufficient to sustain a food and sustenance harvest for the Colville Confederated Tribes. This hatchery could also potentially be used for recovery of the Canadian population of Okanagan Chinook. However, since the interrelatedness between the Canadian and American Chinook populations is relatively unknown, further work is required to determine how hatchery supplementation can be used to for recovery.

Hatchery reared fish can have profound effects on wild populations (Hedrick *et al.* 2000). Artificial supplementation may have negative ecological impacts such as introduction of diseases from captive fish or reduced survival of wild juvenile Chinook due to increased competition with hatchery juveniles Hatchery reared fish may introduce deleterious genetic effects such that the life history traits propagated may be inappropriate for the environmental conditions and mortality is increased. Thus it is important to maintain a wild spawning population as well.

2.4 Habitat Summary

Canadian Chinook habitat extends from the McIntyre Dam to the American border. Their historic range in the Okanagan Basin likely included some of the major tributaries of the river and mainstem lakes as far upstream as Okanagan Lake (Ernst 1999; Ernst and Vedan 2000). Chinook currently cannot pass McIntyre Dam at the outlet to Vaseux Lake. Chinook in the Canadian portion of the Okanagan Basin can access 16 km^2 of lake and river with varying degrees of habitat suitability for spawning and rearing. The total accessible length above the US border is approximately 32 km of which 10.5 km is lake and 21.5km is river. The lower river from 1.6 km above Oliver to Osoyoos Lake was channelized in 1957.

An 8.5 km non-engineered section remains below the McIntyre Dam and this includes a 4.5 km “natural” segment immediately below the dam and another 4.0 km dyked but still “semi-natural segment” (Stockwell and Hyatt 2003). Chinook spawning has been observed in 3.5 km of this upper river section (Davis et al. 2007). The 8.5 km of natural and semi-natural channel below the McIntyre dam can be considered to be critical spawning habitat for the Canadian portion of the population. Although approximately 3.5 km is currently utilized for spawning, the remaining length is required to support a recovering population. At present spawning habitat does not appear to be a limiting factor for the few adults returning and current spawning capacity is likely above any recovery targets.

Three measures were used to predict the availability of Chinook spawning habitat in Okanagan River and the lowest estimate of spawning capacity is likely the most defensible. The "cells method" (Phillips et al 2005) estimated the number of potential spawning pairs based on water levels for 2002 and 2003 at 4,340 and 3,760 respectively however, this was considered by Davis et al (2007) to be an over-estimate. The "channel intersection method" estimated 1,460 spawning pairs based on the association between redd locations and specific hydrological features. A "watershed-area-based" model developed by Parken et al. (2006), estimated a maximum sustainable yield of 1700 pairs. Thus, enough spawning habitat is currently available to support between 1,460 and 4,340 naturally spawning pairs between the McIntyre Dam and the Oliver Bridge.

The initial productive capacity estimate for the accessible portion of Okanagan River in Canada as developed by Parken et al (2006) was 10,000 spawners (Appendix A). However, considering the dry climate (i.e. reduced flows in the river) and modified condition of the river, we have reduced this estimate by 50%, to 5,000 spawners or 2,500 spawning pairs. This modified estimate of productive capacity (i.e. replacement point) is still higher than the estimated availability of Chinook spawning habitat, but leads to the conclusion that the river can support many times more Chinook than currently spawn there.

Water temperatures in most of Okanagan River are seasonally too high for rearing Chinook. Year-round rearing in the river is dependent on the availability of areas with suitable water temperatures, especially in July when the river is hottest. Thermal imagery taken in December 2006 indicates that there are numerous areas in the river that are affected by groundwater, possibly creating the necessary rearing conditions. Year-round availability for Okanagan Chinook may only be critical during the first 3-6 months after emergence as this population exhibits ocean type life history.

Unlike spawning habitat we are unable to establish the extent of Chinook rearing habitat. The distribution of rearing fish, their numbers, residency time, and densities are unknown. Our understanding of the movements of Chinook fry and juveniles following emergence is vague. Okanagan Chinook may use portions of the American Columbia River basin. This area is used as a migration corridor for both juveniles and adults and may serve as potential juvenile rearing habitat. Thus, we can not estimate rearing habitat availability, capacity, or identify the rearing habitats important for survival or recovery. Ongoing research activities conducted by the Okanagan Nation Alliance are designed to characterize spawning habitat (especially the role of groundwater) and establish the locations of Chinook rearing.

2.5 Threats to Habitat

Chinook in Canada have been adversely impacted by significant human induced changes to the ecosystem. The impact of human change to Chinook habitat is difficult to assess. However habitat trends can be inferred by changes in salmon population numbers and changes in distribution. The main threats to Okanagan Chinook habitat include; water withdrawals, construction and operation of dams (for power generation or water diversion), channel modification, and introduction of non-native fish species (Raymond 1988; Myers *et al*. 1998).

Water Withdrawal

Within the Okanagan basin both surface water and groundwater is withdrawn. The withdrawal of water and resulting reduction in water levels, increased water temperatures, and lowered oxygen concentrations; can ultimately reduce the amount of fish habitat (NRC 2004). The two aquifers within the Okanagan Basin are classified as 1A (BC Water Resources Atlas 2007). They have undergone considerable development and are vulnerable to contamination. Thus they have a high priority rating for management purposes.

The current system of water control limits fish access, alters hydrological features including water velocities and volumes, and increases water temperatures (NRC 2004). McIntyre Dam at the outlet of Vaseux Lake blocks upstream passage to the rest of the basin including 35,000 hectares of Okanagan Lake and its tributaries (Symonds 2000). No estimates of habitat lost due this blockage in upstream passage have been made.

Okanagan River discharge and Okanagan Lake levels are currently managed under a Canada-BC agreement (www.obtwg.ca). A web-based tool called Fish Water Management Tools (FWMT) is used by water and fish managers to make 'fish friendly' decisions. However, decisions are made primarily for the benefit of sockeye salmon in the Okanagan River and shore spawning kokanee in Okanagan Lake and the benefits/costs to Okanagan Chinook are unknown.

Hydro Dams

The spring freshet is stored by the upper Columbia hydroelectric dams in both Canada and the USA and is released for power production in winter. This reduces the magnitude of spring flows; required to transport fish downstream, clean gravels, develop new side-channel habitats, and to maintain favourable water temperatures. Changing flow patterns have also resulted in the alteration of water velocity, degradation of habitat, passage effects at dams, and modification of predator species and predation rates (NRC 2004).

Dams also result in direct mortality to migrating juvenile Chinook as they pass over them on their way to the ocean. The mechanisms of injury and mortality is through rapid pressure changes, deceleration, shear forces, gas bubble disease (GBD), turbulence and the force of striking water in free-fall (Ferguson et al 2005; Backman et al 2002).

Hydromodification

Most of the river between Okanagan and Osoyoos Lakes has been straightened and dyked (Symonds 2000). The river between Okanagan and Skaha lakes has been reduced from 10 km to 3 km (Anonymous 1909; Summit 2003). Channelization reduces habitat complexity and thus reduces the quantity and quality of fish habitat. As a result, it is unlikely that summer habitat remains in the dyked sections of channel due to the absence of side channels and protected backwaters, lack of riparian vegetation, lack of channel structure and other areas where groundwater inflow may have a significant temperature-moderating effect. The amount of summer rearing habitat that has been lost due to reductions in groundwater flow is unknown.

Alien Species

The fish community within the Canadian portion of the Okanagan River has thirty species but only 19 are indigenous (NPCC 2004). Largemouth bass, smallmouth bass, pumpkinseed, bluegill sunfish, crappie, carp, bullhead, brown trout, brook trout, and lake trout have spread throughout the Columbia River and reside in Osoyoos Lake. These species have the capacity to impact on the fish community through predation and competition. Several introduced species prey on salmon eggs, fry, and eat salmon juveniles (Zimmerman 1999). Okanagan Chinook smolts and fry must pass through a gauntlet of piscivorous fish and birds on their migration downstream and if they rear in the Columbia River they must compete with other introduced species.

2.6 Sources of Uncertainties

Our lack of knowledge of the life history pattern specific to Okanagan Chinook has created considerable uncertainties in regard to habitat capacity. We lack understanding of juvenile rearing, juvenile migratory timing, and amount of intermingling with American stocks in the Columbia River. Another challenge associated with the Canadian population of Okanagan Chinook is related to the international characteristic of the stock. Increased enhancement or production in Canadian waters must be supported by the Americans or any efforts implemented will not be effective.

Rearing habitats and residency timing for juvenile stages needs to be established for both riverine and lacustrine habitats and for both summer and winter seasons. More extensive trapping and seining along the Okanagan River and Osoyoos Lake should be undertaken. The outlet of Osoyoos Lake, as well as further fry/smolt work at Vertical Drop Structures #13 will need to be completed to determine Chinook emigration timing. Emergence studies to establish the timing and behaviour of fry after emergence should be conducted. This will determine whether or not fry rear in the river downstream of red locations or in the lake, their period of residency, and their migration timing. Laser ablation work needs to be continued. This will determine if there are Chinook that spend their entire life within the Okanagan system. Further understanding of Canadian Okanagan Chinook life history will enable us to evaluate the benefits of current water management in the Okanagan River or if any modifications are required to the FWMT model.

Additional work on understanding the difference in Zosel Dam video counts and observed spawning ground counts needs to be conducted. In addition, further understanding on how Canadian storage dams can contribute to the increased survival through Columbia River hydroelectric dams should be investigated.

Our estimate of productive capacity was based on watershed area. The Okanagan River has some habitat conditions that differ from the rivers used to develop the habitat model. The model may therefore not be truly representative of the current productive capacity of the Okanagan stock and is likely an over-estimation. Although the methodology used to determine spawning habitat capacity is subjective, the variables we used were based on observed Chinook behaviour within the Okanagan River.

The locations where groundwater is entering the river needs to be confirmed and if possible upland sources of groundwater should be identified. This will permit the identification of optimal spawning areas and hopefully enable us to protect this resource. Additional thermal imaging will determine seasonal changes and possibly establish the habitat capacity of the system. Studies should be initiated to determine interactions with non-native fish species. The distribution, behaviour, abundance, and diet preferences of non-natives should be established. Stomach contents of the non-native species (specifically yellow perch, bass, and carp) should be analyzed to determine predation rates on juvenile salmonids.

3.0 Determination of Recovery Targets

3.1 Characteristics of Recovery

The targets of recovery should be defined by the Convention of Biological Diversity (1992) of which Canada is a signatory (EC 2006). The recovered population should be of a size that the ecosystem in which it occurs is able to maintain its normal structure and function and the population would sustain human use, rather than just be marginally greater than the risk of extinction. This definition is consistent with the concept of a healthy population. The recovered populations should be of a size that the ecosystem can support as well as sustain human use. Given the depressed nature of the Okanagan Stock this process will take years to accomplish.

Recovery goals and targets are difficult to develop for the Canadian Okanagan population without a clear understanding of its life history patterns. Three biological scenarios are examined below in the "source of uncertainties" section. Each possibility has different implications for recovery targets and recovery goals. The Okanagan Chinook population, if it is considered unique falls within the critical zone in the framework for considering recovery. The population has a high risk of extinction. The recovery target should be well above the numbers which would ensure that COSEWIC would consider the population as neither Threatened nor Endangered. If the population is considered to be genetically and ecologically exchangeable with US fish than considerable augmentation from US populations through a hatchery program would be acceptable and recovery time would be accelerated. The target if achieved should secure the long-term viability of Chinook within the Canadian portion of the Okanagan Basin. The long term objective would be to maintain a run of naturally spawning Chinook in the Canadian portion of the Okanagan River. The short term objectives will include the increase in run numbers through hatchery supplementation. The current PVA analysis concluded that to meet the necessary escapement maximum based on spawning ground estimates, 1.75 million hatchery reared smolts will need to be released annually.

3.2 Advised Targets

One possibility is that the population has a minimum abundance greater than the PVA estimated minimum. The minimum population size projected by a scenario in the PVA analysis was 295 individuals. This will require the supplementation of stocks from neighbouring populations. Any supplementation program should be planned to prevent detrimental genetic impacts through introduction of maladaptive traits and reducing the effective population size (Hedrick et al. 2000).

3.3 Source of Uncertainties

Starting with such a small populations in the Okanagan River, it is uncertain if the target population can be reached. The number of spawning adult Chinook required for supplementation of the population with 1.75 million smolts is far in excess of what could be supported by the collection and use of the less than 50 adults currently spawning in the Canadian portion of the Okanagan River. A supplementation program of this nature would require centuries of effort under baseline conditions and would be associated with substantial risks of extinction of the natural population (Appendix C). Recovery might be compromised by the potential presence of inbreeding or loss of genetic diversity that may have occurred as a result of bottlenecks within the natural populations.

Supplementation with Chinook from the Similkameen would reduce the amount of effort needed, but may alter the genetic composition of the Canadian stock. Either type of program is accompanied by substantial uncertainty regarding the long-term impacts of hatchery production on the productivity of natural populations (e.g., as summarised in ISRP 2005). Nonetheless, it has been demonstrated that hatchery production can yield a significant survival advantage in the early life-cycle relative to natural production, and that this survival advantage can translate into a significant increase in adult abundance (Rinne et al. 1986; Johnson and Jensen 1991).

Recovery goals and targets are difficult to develop without a clear understanding of the characteristics of the Canadian Okanagan population. Three biological scenarios exist based on possible differences in degree of isolation and degree of uniqueness of the population and each scenario has different implications for recovery time and recovery goals.

1) If a population containing a high proportion of non-anadromous (potadromous) adaptations has developed in Canada, then this population would be unique and should be regarded as non-replaceable. The finding of 1+ lake rearing chinook was considered to support this scenario (COSEWIC 2006). Large 1+ resident chinook have been captured in Osoyoos Lake, but apparently all were males. This form of male non-anadromous development is well known from other Columbia River Chinook populations (Zimmerman et al. 2003; Bechman and Larsen 2005). There is some preliminary evidence that freshwater maturation of females has occurred based on scale and otolith laser ablation studies. The low Sr:Ca ratios from the centre of fry otoliths and scales imply that the fry were the progeny of nonanadromous females. However, this new methodology is not definitive and is largely experimental. Also there is genetic evidence (presented earlier) that a few adults have contributed substantially to the Okanagan population. If non-anadromous fish exist they may have higher survival rates (reduced dam mortality) and are more likely to contribute genetic material. Thus, any recovery goals should consider the maintenance of this population's uniqueness. Attempts to rebuild this population would be initially curtailed by the low number of potential spawners as large scale hatchery augmentation using fish from the upper Columbia meta- population would likely cause the extinction of any unique features developed in the Canadian Okanagan River.

2) If the Canadian population is genetically related and ecologically exchangeable with other upper Columbia fish and is demographically isolated, then the population could be considered endangered but with a high potential for recovery. This possibility is viable only if very low rates of straying from the US can be demonstrated and if the population has not developed unique behaviours. Recovery goals might include activities that increase productivity and reduce mortalities associated with spawning and rearing in Canada.

3) If the Canadian Chinook population originated from the US and it is not isolated from other US Upper Columbia fish, it may be both genetically and ecologically exchangeable with US fish and its productivity may in part be dependent upon US strays. This scenario is more consistent with the COSEWIC (2007) designation, based on the rescue potential from US sources. Genetic analysis presented in the Recovery Potential Analysis (Davis et al. 2007) also supports this argument. The observation of marked hatchery fish on the spawning grounds is evidence of straying, although straying rates are difficult to measure. All hatchery fish have been marked but a portion of the strays may also come from river spawned American fish that are unmarked. Approximately 5% of the Chinook observed since 2003 in the Okanagan River were marked. If this

scenario is accepted then recovery goals might include considerable augmentation from US populations through a hatchery program and recovery time would be accelerated.

4.0 Survival Potential

A population viability model that used stochastic and deterministic elements was employed for parameter estimation and sensitivity analysis. This model was used to evaluate population trajectories under baseline conditions and to explore the potential impacts of multiple management alternatives. This technique is similar to population viability analysis used elsewhere (e.g. Ellner and Fieberg 2003; Fieberg 2004; Emlen 1995). The model used was based on the lognormal form of the Ricker spawner recruit function since Chinook display over-compensatory mechanisms of recruitment (see Appendix C). Parameters were included to account for interdam mortality in juvenile and adult stages. Ten thousand iterations of the model was run under varying scenarios, including altering fishing mortality, changing juvenile survival, and supplementing with hatchery produced smolts.

Two measures of population stability were assessed. The first was the running average over four broods of the minimum population size (MPS) in any given set of years for the number of spawners. This is a measure of population persistence and overall extinction risk (Connell and Sousa 1983, Grimm and Wissel 1997). The second measure was used to assess population recovery or stability at a point in the future. For our purposes we estimated spawners in calendar year 2050 (POP2050), assuming present day conditions or habitat restoration work with the same variability over the next 45 years.

The model strongly indicated that juvenile survival through the hydro-power system (D_j) limits population persistence. The same is true for adult survival (D_A), which is likewise constrained by passage through the hydro-power system (Table 1 and 2). Ocean survival (O_e) is another influential parameter, but values used in our simulations were derived from a period when ocean survival were among the highest recorded (i.e., the late 1990's). Thus, it is likely that observed rates of decline would exceed those observed in our simulations. While fishing mortality (F) also contributes to the decline, even complete cessation of harvest was found to be insufficient to recover the stock. Given the uncertainty that managers can dramatically improve juvenile and adult survival through the hydro-power system, it appears that hatchery production may be the only alternative that can feasibly forestall extirpation in the near-term. However, the magnitude of artificial production required to meet escapement goals of greater than 250 adults would require a large program (approximately 1.75 million smolts annually, based on scenario modelling), which would be accompanied by its own array of risks.

Table 1. Results of the simulations on MPS with standard errors.

Scenario Description	Mean Values	SE
Base MPS	0	0
Half F MPS	0	0
No F MPS	1	1
No F Double DJ MPS	76	12
No F Double DJ max DA MPS	109	17
Base + Supp 50 K MPS	25	5
Base + Supp 100 K MPS	42	9
Base + Supp 150 K MPS	57	13
Base + Supp 200 K MPS	75	18
Base + Supp 1.75M MPS	583	152
Base + Supp 1.75M MPS (half Fit)	295	75

Table 2. Results of the simulations on POP2050 with standard errors.

Scenario Description	Mean Values	SE
Pop2050 MPS	0	0
Half F Pop2050	0	0
No F Pop 2050	1	1
No F Double DJ Pop2050	662	176
No F Double DJ Max DA Pop2050	1501	285
Base + Supp 50 K Pop2050	104	22
Base + Supp 100 K Pop2050	210	45
Base + Supp 150 K Pop2050	305	65
Base + Supp 200 K Pop2050	412	88
Base + Supp 1.75M Pop2050	3107	657
Base + Supp 1.75M Pop2050 (half Fit)	1547	323

5.0 Identification of Mortality Sources

Many sources of both natural and human induced mortality have been identified and measured for the upper Columbia Chinook population as a whole and it is assumed the same mortalities would occur to the Canadian Okanagan Chinook population. Mortality is associated with dam passage, competition and predation by non-native species, fisheries, and habitat destruction. Natural sources such as ocean conditions and other environmental variability have a profound effect on the production of stocks. Determining the relationships between these factors and the viability of salmon populations is difficult due to life history complexity and mortality is often additive and not always quantifiable. Many of these issues have already been dealt within the section on Threats to Habitat.

Fisheries have a profound effect on Chinook numbers, though it was not demonstrated to be the primary threat by the PVA model for Okanagan Chinook. Nevertheless, a discussion on the source of mortality within the fishery is warranted. The Pacific Salmon Treaty substantially changed the objectives and structure of the Chinook salmon fisheries and assessment of Chinook salmon stocks. Salmon are managed through aggregate abundance based management (AABM) for ocean mixed stock fisheries and individual stock based management (ISBM) for all other Chinook fisheries (DFO 1999). Chinook harvest rates are set at levels that conserve depressed stocks and improve escapements of naturally spawning Chinook, based on the abundance of Chinook populations. Chinook from the Columbia River are divided into eight stock groups based on run timing and area of origin (PSC 2007). The Okanagan Chinook destined to spawn in Canadian waters most likely migrate with the Upper Columbia summer/fall Chinook that are part of the Columbia River summer stock group originating above Bonneville Dam. These fish are targeted in the ocean as well as the river by both tribal and non-tribal fisheries.

Under the Pacific Salmon Treaty, Columbia River summers are one of the 39 exploitation rate indicator stocks monitored by the Joint Chinook Technical Committee (CTC), (PSC 2007). CWT recoveries in all fisheries (including associated incidental mortality) and escapement are used to reconstruct cohort size by brood year for each indicator stock.

The total mortality by fishing year for the summer Chinook stock was calculated from 1979 to 2004 (PSC 2007), (Table 3). Average mortality was 63.9% and mortality ranged from 48.6% to 74.2%. From 1979-1980 the average total mortality was 71%. Total fishing mortality from 1987 to 1998 dropped to 44%. Average mortality has increased since 1999. The main source of mortality in Canada is the West Coast of Vancouver Island troll fishery while in the U.S. exploitation is mainly focused on the Alaskan troll and Southern US troll and sport fisheries. The estimated mortality by the fisheries is for all Upper Columbia River Summer stocks. The exact impact the fishery has on the Okanagan Chinook population is unknown, but we speculate that it is similar to the estimates made above for the American stocks.

The aforementioned mortality is not separated by brood year, so each year class is composed of fish ranging in age from three to six years old (PSC 2007). Brood year exploitation rates measures each year's harvests impact on each year class (Figure 6). The analysis of this data has been completed until 1999. The harvest impact on each brood year has varied. Between 1975 and 1977, the exploitation rate ranged from 30 to 70%. An exploitation rate of 68% was observed for 1983 and an exploitation rate of 18% was noted in 1991. Since 1991 the exploitation has increased steadily to 75% in 1999.

In recent years the in river fisheries have contributed to increased brood year exploitation.

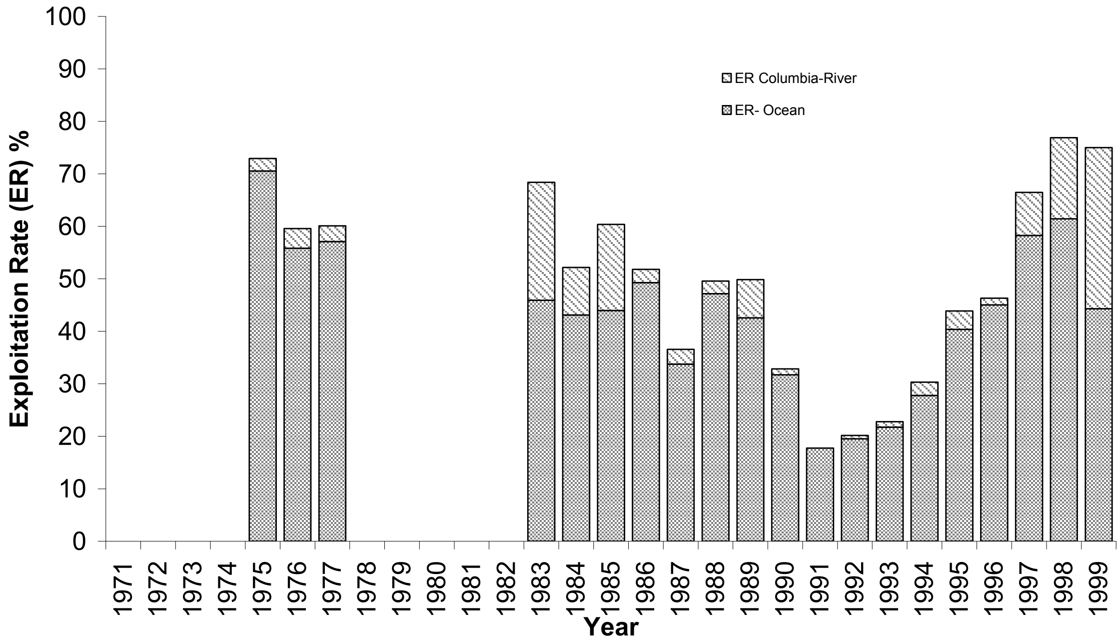

Figure 6. Brood year total exploitation rate for Columbia River Summer run (personnel communication R. Sharma)

Table 3. Sources of Columbia River Summer Chinook Total Fishing Mortality in Canada (shaded) and the United States by catch year (from PSC, 2007).

	Alaska			Canada								Southern U.S.			Alaska	Can	S U.S.		
Catch year	troll	net	sport	North Troll	Central Troll	N/CBC net	N/CBC sport	WCVI troll	GeoSt Tr&Sp	Can net	Can sport	troll	net	sport	**total**	**total**	**total**	**Total mortality**	**Escape-ment**
1979	14.4	0	1	9	4	8.5	0	18.9	7	1.5	0	0.5	4	4.5	**15.4**	**48.9**	**9**	**73.3**	**26.9**
1980	32.8	0	0.9	9.2	4.3	1.1	0	18.1	0	0	0	1.7	0.6	0	**33.7**	**32.7**	**2.3**	**68.7**	**31.3**
1987	16	0	0	8	3.7	4.3	2.5	7.4	0	0	0	19.8	11.7	0.6	**16**	**25.9**	**32.1**	**74**	**25.9**
1988	1.9	2.2	0	10	0	7.5	1.9	20.9	0	1.2	4	3.4	13.1	2.8	**4.1**	**45.5**	**19.3**	**68.9**	**31.2**
1989	7.1	2.1	0.7	5.6	0.7	0.3	0.6	16.4	1.4	1.9	2.4	14.9	7.5	2.5	**9.9**	**29.3**	**24.9**	**64.1**	**35.9**
1990	10.6	0	0	7.6	1.1	1.7	0	20.3	0.6	0.3	0	5.7	10.3	2.6	**10.6**	**31.6**	**18.6**	**60.8**	**39.5**
1991	4.1	0	0	2.3	0.5	0.9	0	6.3	0	1.1	0.7	3.6	4	2.3	**4.1**	**11.8**	**9.9**	**25.8**	**73.5**
1992	18.5	0	0	3.4	1.9	2.8	0	15.4	0.6	0	0	6.6	1.3	1.6	**18.5**	**24.1**	**9.5**	**52.1**	**49.8**
1993	7.8	0	0	1.4	0	0	0	15.6	0	0	1.8	5.5	3.2	1.4	**7.8**	**18.8**	**10.1**	**36.7**	**60.6**
1994	17.5	0	0	0	0	0	15	0	0	0	0	0	10	0	**17.5**	**15**	**10**	**42.5**	**57.5**
1995	4.1	0	0	0	0	3	0	7.4	0	1.4	0	2	2.7	0	**4.1**	**11.8**	**4.7**	**20.6**	**82.4**
1996	21.3	0.7	0	1.8	0	0.4	0	2.5	2.5	0.2	0	2.5	3.2	3.9	**22**	**7.4**	**9.6**	**39**	**58.3**
1997	9	0.1	3.7	0.2	0	0.1	1.2	1.8	0	0	0	3.3	1.1	0.9	**12.8**	**3.3**	**5.3**	**21.4**	**78.3**
1998	10.2	0.5	1.2	0.5	0	0.6	0.7	0	0	0	0.6	2.1	4.9	1	**11.9**	**2.4**	**8**	**22.3**	**78.2**
1999	13.6	5	3	0.3	0	3.8	3.8	0.5	0	0	5.2	9.1	1	3.3	**21.6**	**13.6**	**13.4**	**48.6**	**54.4**
2000	25.7	2.3	3.5	0.4	0	0	1.9	4.2	0.7	0.1	5.3	3.3	1	3.9	**31.5**	**12.6**	**8.2**	**52.3**	**47.8**
2001	16.4	5.9	1.5	0.5	0	0	1.6	11.2	0.2	0	4.4	17.6	0.7	6.5	**23.8**	**17.9**	**24.8**	**66.5**	**33.6**
2002	23.5	0.1	1.5	10.7	0	0	2.6	15.2	0.1	0	0.9	9	1	6	**25.1**	**29.5**	**16**	**70.6**	**29.2**
2003	26.2	1.8	1.1	11.1	0	0	5.9	11.3	0	0	0.9	6.5	2.7	6.7	**29.1**	**29.2**	**15.9**	**74.2**	**25.9**
2004	14.6	0.7	1.1	4.9	0	0	1.9	11.3	0.2	0	1.6	10.6	7.7	16.3	**16.4**	**19.9**	**34.6**	**70.9**	**29.1**
79-80	23.6	0.0	1.0	9.1	4.2	4.8	0.0	18.5	3.5	0.8	0.0	1.1	2.3	2.3	**24.6**	**40.8**	**5.7**	**71.0**	**29.1**
87-98	10.7	0.5	0.5	3.4	0.7	1.8	1.8	9.5	0.4	0.5	0.8	5.8	6.1	1.6	**11.6**	**18.9**	**13.5**	**44.0**	**55.9**
99-04	20.0	2.6	2.0	4.7	0.0	0.6	3.0	9.0	0.2	0.0	3.1	9.4	2.4	7.1	**24.6**	**20.5**	**18.8**	**63.9**	**36.7**

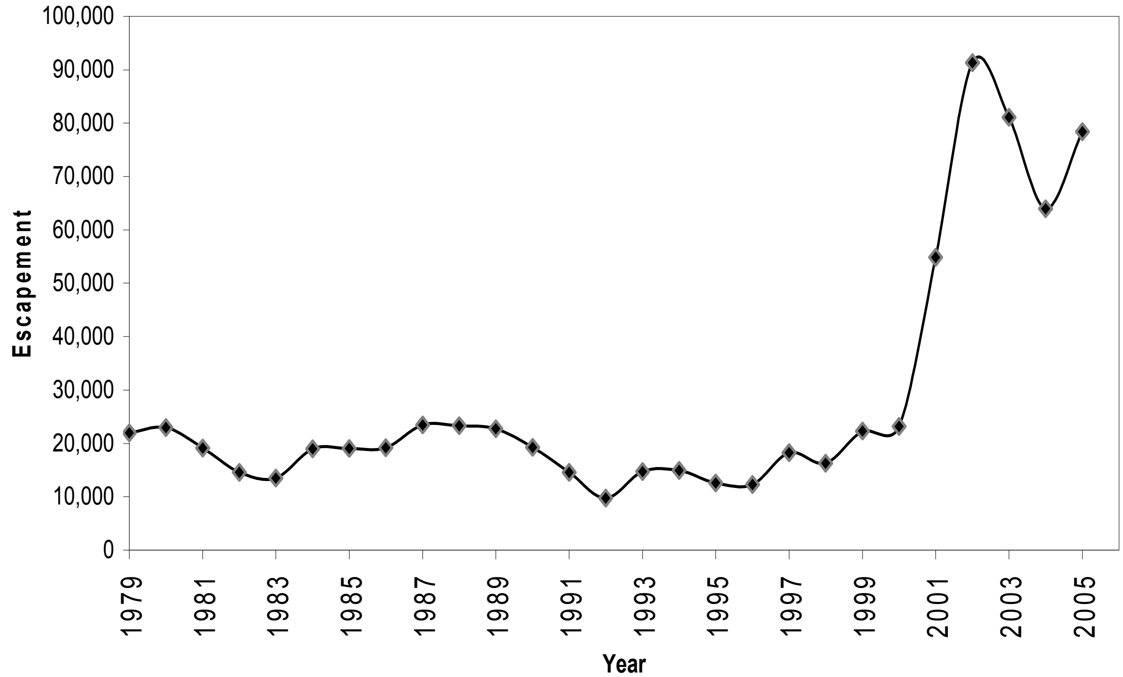

Figure 7. Summary of Upper Columbia Chinook escapement past Bonneville Dam and before the additional upstream fishery in the Columbia River (1979-2005).

Table 4. Summary of Columbia River escapement and harvest rates of Upper Columbia Summers management group for 2006.

Time in 2006	Number past Bonneville Dam	Total Harvest Rate
Before run	49,000 (predicted)	47.6% (allowable)
After run	76,200 (actual)	22.44% (actual)

The projected run size for 2006 was 49,000 fish (Table 4) (http://wdfw.wa.gov/fish/salmon_columbia07.htm). The actual return was 76,200. The 2007 forecast is 45,600, which is less than 2006 and the recent five year average but greater then the average of the 1990 runs. Under the current management plan, the maximum allowable total harvest rate was set at 17.8% for both the treaty and non-fishery.

In conjunction to fishing, rapid development in the basin has led to wide spread degradation of habitat contributing to a further decline (NRC 1996). Habitat degradation has been attributed to irrigation, logging, mining, damming and other human activities, which have reduced the size and capacity of spawning and rearing areas. These threats continue to alter aquatic habitat in the Columbia River to the present day. The number of naturally produced salmon in the Columbia basin is one eighth of their predevelopment abundance (NRC 1996). A considerable length of river was channelized in the Canadian portion of the Okanagan River and the expected declines due to habitat degradation should be greater for the Canadian population.

It has been estimated that 80-85% of the adult Chinook survive the upstream migration through dams and impoundments, but only 43% of juveniles survive the out bound migration (COSEWIC 2006). With the extensive hydropower works on the river and land use activities, US Columbia River habitat impacts can be severe. Smolts incur mortality as they pass through the turbines, bypasses and spillways. Mortality also occurs in the reservoirs. Smolt survival rates are affected by factors beyond stream flow and discharge, including migration distance, water temperature, spill-rate over the dams, water chemistry, and changes in both land use and the estuarine environment (NRC 2004, Ferguson *et al.* 2005). Juvenile mortality is associated with predators, temperature changes, entrainment in dams and direct habitat loss from activities such as channelization (details in Appendix A).

The spillway is considered to be the safest route through Columbia River dams while the greatest mortality is linked to turbine passage (Whitney *et al.* 1997; Ferguson *et al.* 2005). Reservoirs above the dams distribute flows over the year and reduce the peak magnitude of spring runoff and maximum volume when juvenile are migrating downstream. The reduced spill volumes available during migration forces juveniles to pass through the turbines. Mortality for juvenile salmon in turbines has ranged from 2.3 to 19% depending on the dam with an average of 11% (Whitney *et al.* 1997). The survival rate associated with spillways was 97% (Ferguson *et al.* 2005). With this level of mortality, it was estimated that less then half the number of fish migrating from the upper most reaches in the Columbia River would survive to below Bonneville Dam.

Table 5. Survival rates for yearlings from tailrace to tailrace of the listed dams (from http://www.fpc.org/survival/Survival_by_ReachQuery.html). Includes all mortality though dams.

River Reach	**Year**	**Survival**
Rock Island to McNary	**1998**	**0.758**
	1999	**0.760**
	2000	**0.786**
	2001	**0.597**
	2002	**0.639**
McNary to Bonneville	**1999**	**0.696**
	2000	**0.665**
	2001	**0.606**
	2002	**0.770**

Predatory fish and birds are responsible for a substantial amount of the smolt mortality incurred within the Columbia River (NRC 2004). In the fore-bay of the John Day dam on the mainstem of the Columbia River, pikeminnow diet was 66% salmonid (Ferguson *et al.* 2005). Another study estimated 78 % of the smolts were lost to predatory fish in John Day reservoir from 1983 to 1986 (Fresh *et al.* 2005). The delay of out-migrants associated with lower flows and delays at dams can increase mortality. Smallmouth bass, channel catfish, and walleye also prey heavily on smolts. Within the Columbia River estuary, Caspian terns' populations on manmade islands have drastically increased and are consuming large numbers of juvenile fish (Fresh *et al.* 2005). Juvenile salmonids constitute close to half of the diet mass of Caspian terns.

Salmonids that display stream type behaviour patterns are more likely to be consumed, since they migrate through the estuary as Caspian terns begin nesting.

6.0 Alternatives to Activities Causing Harm

Within the Canadian portion of the Okanagan River, stream channel habitat has likely remained unchanged over the past 50 years. In fact following improvements to sewage treatment, water quality in the river has probably improved over the last 20 years. Other habitat improvements include the addition of fish screens to many water intakes on the river and the experimental addition of rock riffles (to increase habitat diversity and improve fish passage) in the channelled section of river. A water management initiative directed at improving decision-making for the benefit of fish in the mainstem river and lakes (COBTWG 2004) might be considered beneficial but further evaluation is required. This initiative is expected to significantly improve salmon smolt production.

To further improve habitat, enhancement programs in the Okanagan need to be implemented. There are plans to re-naturalize the Okanagan River to its fullest extent, with proposed measures such as: re-establishing oxbows above the lake, set-back dyking, riparian restoration, and construction of instream riffles (Gaboury *et al.* 2000). Connecting the oxbows with main channel will drastically lengthen the available habitat. The oxbows currently show significant groundwater input and connecting these oxbows to the main river will create areas of thermal refugia and new spawning locations. Measures will have to be taken to prevent invasive species currently residing in the oxbows from impacting the ecosystem within the mainstem. Riparian vegetation can be planted to lower summer water temperatures, serve as cover, and create habitat diversity within the channel. Creation of winter habitat may be necessary if nonanadromus Chinook are found to overwinter as juveniles within the Okanagan River in Canada. Implementation of some of the proposed measures has begun with a section of the Okanagan River identified for set-back dyke restoration.

Measures can be implemented to modify the temperature regimes imposed by the McIntyre Dam. A siphon could be constructed that would draw cooler water from lower depths of the lake and discharge it at the base of the dam. A hypolimnetic siphon has been proposed for Skaha and Vaseux Lakes (Bull 1999). They are expected to cost 1 million and 2 million dollars respectively. Water from lower levels of Skaha Lake would reduce temperatures in the Okanagan River upstream of Vaseux Lake by two degrees. The benefits would cease as the water sank to the depths of Vaseux Lake. However, a similar siphon constructed in Vaseux Lake would yield similar downstream results. A reduction in temperature can be anticipated following the planting of riparian vegetation along river banks through the entire length of the river. An increase in flows beyond the dam may also decrease temperature costs and will ensure adequate flows through all life stages. Research needs to be completed on the impacts of various flow regimes on habitat and in-river survival rates of chinook and other salmonids.

McIntyre Dam can currently be managed to allow fish passage and minor modifications of the dams at the outlet of Skaha and Okanagan lakes are required to allow fish passage. This will open up large unused areas upriver of Okanagan Lake to Chinook spawning. Studies will have to be completed to determine the impacts of this on anadromous and resident stocks.

Within the U.S., the control of water within the FCRPS has evolved into an extensive and complex water management strategy that is intended to increase water velocities, reduce travel times, and increase survival rates of migrating smolts and thus improving migratory conditions for smolts (NRC 2004, Anderson 2003). Flow augmentation is the release of additional water from the large storage reservoirs, including the Grand Coulee reservoir and a complex of storage reservoirs in Canada and Montana. It is designed to increase water velocities through reservoirs speeding the passage of juvenile salmon and reducing predation. The increase in flow especially during the summer will also lower water temperature, improving migratory and rearing conditions for both juvenile and adult salmonids.

Further increases in water volume may occur through releases from Canadian dams for the benefit of Canadian salmon. The Mica, Revelstoke and Keenleyside Dams could increase the water volume released during spring and summer thus increasing the volume of water through the lower Columbia River.

Although work continues on methods for improving juvenile survival through the dams on the Columbia River, it is unlikely that this will result in recovery of the population of Okanagan Chinook Doubling through dam survival will result in a minimum population size of 109 and an average population of 609 individuals (based on MPA modelling; Appendix C). The doubling of the survival within the system is unlikely, therefore hatchery supplementation must be considered. A supplementation of 1.75 million smolts annually will be required to reach the spawner abundance associated with the maximum sustainable yield at current mortality rates.

If you accept that the Canadian Okanagan population is a genetically distinct unit, than you must recognize that only the existing spawners (< 50 returning fish) can be utilized (Appendix C). A supplementation program implemented with this low number of spawners would likely require centuries of effort. Evidence from the genetic analysis (Appendix B) supports the concept that the Canadian Okanagan population is genetically similar to the large pool of spawners south of the border. As a result, adults from US portions of the Similkameen River could be used as brood stock to increase production and reduce the time of recovery. A program of this type would be accompanied with substantial risks related to the reduction or loss of any distinct genetic characteristics that have developed in the Canadian population.

Hatchery production is accompanied by substantial uncertainty in respect to the long-term viability of natural populations (e.g., as summarized in ISRP 2005). Nonetheless, it has been demonstrated that hatchery production can yield significant survival advantages in the early life stages relative to wild production. This survival advantage can translate into a significant increase in adult abundance (Rinne et al. 1986 and Johnson and Jensen 1991). Likewise, for imperilled populations, hatcheries can serve as a vehicle to maintain or increase genetic variation (Hedrick et al. 1994) and potentially contribute to life-history diversity (Franklin 1980) that might be lost in the absence of intervention.

The number of humans residing within the Okanagan is increasing and in the future there will be greater demands for water. Improved monitoring of the amount of water taken from both groundwater and surface water systems is needed. Programs that promote conservation of water resources are required.

To reduce the impacts of non-native fish, these species can be targeted for commercial and recreational fishery. Potentially targets for a Canadian recreational freshwater fishery include bass and yellow perch. There is considerable potential for Carp to be harvested in the Okanagan and sold to ethnic fish markets in Vancouver.

7.0 Conclusions and Advice

Okanagan Chinook are the only Columbia River stock currently residing within Canada. Their abundance has declined to its current low levels as a result of over-harvesting, mortality associated with dams, and habitat alterations. The very early declines in Chinook abundance were the result of over-harvesting. Now even with a complete cessation of harvesting, numbers will continue to decline because of severe mortalities associated with dam passage.

Our analysis of survival potential indicates that the juvenile survival through the hydropower system is the most serious threat to the population and renders persistence unlikely without intervention. Ocean survival is also an influential threat parameter. However, even complete cessation of fishing will be insufficient to recover the stock but investigating the feasibility of reductions in ocean fisheries should be conducted. Currently it is uncertain if survival through the downstream hydropower system can be improved. This is an international issue.

Hatchery supplementation is the only option that will prevent the extirpation of the stock. A production target of 1.75 million smolts annually will be needed to achieve a minimum population of 295. Hatchery augmentation is accompanied by its own array of risks. A naturally spawning and rearing population is required to maintain the population's characteristics. Thus, future activities must maintain, enhance, and possible expand Chinook habitat within the Canadian portion of the Okanagan watershed.

Much of the specific information regarding habitat, life history patterns, and genetic diversity for the Canadian Okanagan population is unknown. Thus, research programs to resolve these uncertainties are required to clarify recovery goals and strategies. Continuation of otolith ablation studies to assess whether or not adult female chinook are offspring of non-anadromous females. Genetic data should continue to be collected and analysed. The extent of immigration (straying) from US natural and hatchery populations should be established. The apparent discrepancy between Zosel dam counts and the number of spawning adults counted during spawning ground surveys should be clarified. Studies that examine the location and importance of groundwater should be done to improve our understanding of factors associated with spawning habitat. An understanding of juvenile rearing habitat, early life history of chinook, and the impact of invasive species is important in establishing what critical rearing habitat is.

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Appendix A. Habitat Assessment and Analysis

for

Chinook Salmon
Okanagan Population

Oncorhynchus tshawytscha

Report prepared for

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1.0 Introduction

Habitat is the physical, biological and chemical characteristics of a specific environment that is occupied by an organism (Cunjak 1996). Riparian habitat, channel morphology, streamflow, deposited sediment and winter snow and ice accumulation is the principal environmental characteristics that influence salmon habitat selection in the interior of British Columbia (Brown 2002; Cunjak 1996). Specific habitats used within the system are dependent upon on life stage.

While, Chinook currently cannot pass McIntyre Dam at the outlet to Vaseux Lake their historic range in the Okanagan Basin likely included some of the major tributaries of the river and mainstem lakes as far upstream as Okanagan Lake (Ernst 1999; Ernst and Vedan 2000). Chinook in the Canadian portion of the Okanagan Basin can access 16 km^2 of lake and river habitat that is suitable for rearing and/or spawning.

2.0 Species Biology

Chinook salmon (*Oncorhyncus tshawytscha* Walbaum) is one of six species of Pacific salmon native to North America. Okanagan Chinook appear to exist in Canada only in the Okanagan River (a tributary to the Columbia River) (Ernst 1999; Ernst and Vedan 2000). The current northern extent of the population is the McIntyre Dam at the outlet of Vaseux Lake and its southern Canadian limit is the northern basin of Osoyoos Lake, immediately north of the BC border with Washington. Okanagan Chinook was recognised as a designated unit based on 1) genetic differentiation from other Canadian Chinook salmon populations; 2) geographic and reproductive isolation; and 3) unusual life history characteristics, including evidence of extended freshwater rearing and possible freshwater maturation (COSEWIC 2006).

The life history of Chinook salmon, especially its anadromy and homing to natal streams for reproduction, results in geographic and reproductive isolation, genetic differentiation, and the development of local adaptations. Chinook display the most diverse range of life history patterns of all other oncorhynchids. This includes variation in the age at seaward migration, length of freshwater, estuarine, and oceanic residence, ocean distribution, ocean migratory patterns, and age and season of spawning migration (Healey 1991). The diversity of life history traits can be seen as the result of adaptive strategies that maximise the opportunities under population pressures in nutrient limited systems (Brannon *et al.* 2004).

The Canadian population spawns entirely within Canada although anadromous individuals migrate through the Columbia River from the Pacific Ocean. Within the Columbia system, adult Chinook must migrate upstream past nine mainstem U.S. dams before entering Osoyoos Lake and the Okanagan River. They enter the Okanagan River in June/July and hold until they spawn in October (Wright and Long 2006). This is typical of ocean-type populations in the Upper Columbia River basin (Waknitz et al 1995). Peak spawning typically occurs in the third week of October when water temperatures are about 10-14^{0}C. Chinook spawning habitat includes a broad range of water depths, water velocities, and substrates (e.g. Scott and Crossman 1973; Healey 1991). Spawning is often erratically distributed within apparently uniform reaches, suggesting that other factors, such as intra-gravel flow, may be critical (COSEWIC 2006).

Fry may rear in the Okanagan River and/or Osoyoos Lake for a period ranging from weeks to possibly a year or more (Phillips *et al.* 2005). Anadromous migrants probably exit Osoyoos Lake during May/June or in early July. Although no direct evidence has been collected, we suspect Okanagan juvenile also rear in the American portion of the Okanogan River and the Columbia River within Washington State.

The marine phase of their life history ranges from 1–4 years with adults returning primarily as four or five year olds. Okanagan Chinook may spawn earlier at three years. In the ocean, Chinook may remain in coastal area or complete extensive offshore migrations (Healey 1991). One of the peculiarities of Okanagan Chinook is that it appears a portion of the stock does not migrate but instead has an extended period of freshwater rearing by juveniles and comes to maturity in Osoyoos Lake. The evidence for this comes from seven young (2003 -6 Chinook aged 1+, 2004 -1 Chinook) Chinook captured in Osoyoos Lake in September 2003 and August 2004. The fish were absorbing scales, consistent with scale resorption prior to reproduction, as observed in older anadromous salmon (COSEWIC 2006). The stomach samples of six of these seven Chinook contained sockeye fry, indicating piscivory (an adult characteristic). These seven Chinook also displayed additional internal features of sexual maturation. In the 2005 Okanagan River samples, 4 of 17 female Chinook were fully reproductively mature at three years of age, earlier then known for anadromous females. Their reproductive success is unknown. Lastly, genetics from the 2005 broodyear suggests significant family relatedness between samples originating from very few progeny. A plausible explanation for this increased survival is that several sources of mortality (downstream and upstream migration, fishing, and predation) did not occur due to their history wholly in freshwater.

3.0 Habitat Use

3.1 Spawning Habitat

Chinook spawn in water that is shallow or deep, slow or fast, where the gravel is coarse or fine, in rivers, and on gravel shoals in lakes (Scott and Crossman 1973; Healey 1991). While Chinook spawning habitat includes a broad range of water depths, water velocities, and substrates, in some cases such simple metrics have been useful predictors of preferred Chinook spawning habitat (Gallagher and Gard 1999). However, in some locations Chinook spawning is patchily distributed within apparently uniform habitats, suggesting that other factors, such as intra-gravel flow, may also be important.

Table A1 presents the water depth and velocity, and substrate and redd size measured at Chinook redds in Okanagan River.

Table A1. Chinook spawning habitat characteristics in the Okanagan River.

	Depth (m)	Mean Velocity (m/s)	D_{90} (m)	D_{50} (m)	Redd Size (m^2)
Mean	0.49	0.65	0.10	0.05	6.0
Std Dev.	0.16	0.19	0.03	0.02	2.0
Range	0.55	0.8	0.09	0.08	7.9
Minimum	0.20	0.34	0.05	0.03	3.1
Maximum	0.75	1.14	0.14	0.10	11.0
Count	18	18	18	18	20

As presented above, Chinook redds in Okanagan River have been observed in water depths as between 0.20 m and 0.75 m and in water velocities as low as 0.34 m/s ranging to 1.14 m/s (Wright and Long 2006). Substrates in and around redds are dominated by gravel and small cobbles, although coarse sand is a major component of the substrate in several spawning areas with median substrate particle sizes ranging between 0.03 m and 0.10 m. The mean redd size for Chinook in Okanagan River is 6.0 m^2, with the largest and smallest being 11.0 m^2 and 3.1 m^2, respectively. Burner (1951) calculated mean Chinook redd sizes in tributaries of the Columbia River to be between 2.5 m^2 and 6.5 m^2. If the redd sizes in Okanagan River were scaled to account for a difference in measurement method, the mean Okanagan Chinook redd size would be about 4.5 m^2, which translates to a spawning territory of 18 m^2.

Chinook redds are typically placed adjacent to instream bars or bar complexes in the natural section of river and where the original (1954) river crosses the existing channel. Nearly all redds are also placed near areas of identified groundwater influence.

While simple metrics like water depth, velocity, and substrate may be useful in predicting Chinook habitat usage in some situations, often additional factors may be as or more important. Burner (1951) determined that Chinook were attracted to areas with relatively high levels of intragravel water percolation and a predominance of medium to fine gravel, with little fine silt or clay. Vironskiy (1972) reported that approximately 95% of the Chinook redds examined in the Kamchatka River basin on the Asiatic coast of the Pacific were located at the crest of a riffle (i.e. at the downstream margin of a pool or run). Chapman (1943), working in the Columbia Basin, also noted a preference for spawning near riffle crests. Other important spawning areas that are likely selected due to high intra-gravel water flow rates include pools just below log jams and on the upstream face of lateral dunes such as are found in the Nechako River (Russel et al. 1983). This preference for spawning sites with high rates of intragravel flow appears to have a physiological basis, since the large size of Chinook eggs and thus reduced surface-to-volume ratio makes them sensitive to reductions in oxygen concentrations and water percolation rates (Healey 1991).

Nearly all of the redds in the natural section of river were located near riffle crests or bars, or where the channel is substantially narrowing (Wright and Long 2006; Wright and Long 2005; Phillips et al 2005; Davis et al 2007). Three redds were observed along the channel margin in the natural section. Within the channelized section, all of the redds were observed in relatively deep, calm water. The spawning sites in the channelized section of river are highly correlated with intersections of the original river and the constructed channel (Figures A 1 to 3), suggesting that these may be areas of increased intra-gravel flow.

There are many points in the river where thermal imaging indicates groundwater influence and all but four of the 31 identified redds were adjacent to these groundwater inflow areas (ONA unpublished data). Of the four redds that were not adjacent to identified areas of groundwater inflow, two were located on crossovers of the original and current river channels and the other two were immediately adjacent to a hydraulic control structure in the river. Figures 1 to 3 present areas where spawning has been observed and areas with identified groundwater influence on water temperature.

3.2 Current Okanagan Chinook Spawning Habitat Availability

Construction of dams has reduced accessible Chinook habitat to a fraction of its former size, eliminating access to the mainstem river, lakes and tributaries upstream of McIntyre dam (i.e. outlet of Vaseux Lake). In addition, approximately 91% of the mainstem Okanagan River in Canada has been modified, resulting in a major loss of spawning and rearing habitat (Bull 1999). However, little information is available to quantify the numbers of Chinook that spawned upstream of Vaseux Lake or where they spawned and reared. The focus of this section is on current spawning habitat availability in the Canadian Okanagan Basin, which is limited to the mainstem river between Osoyoos Lake and McIntyre Dam (i.e. outlet of Vaseux Lake).

Three estimates of Chinook spawning habitat availability in Okanagan River were made, between the Town of Oliver and McIntyre Dam (Table A2). There may also be a small amount of additional spawning habitat between Oliver and Osoyoos Lake; however, this downstream section of channel typically has finer substrates than those upstream of Oliver and is used much less than upstream areas by spawning salmon (Summit 2001, 2002; ONAFD 2003, 2004).

Chinook spawning habitat availability has been examined in several ways (Phillips et al 2005).

1. All portions of channel with the same water depth and velocity, and substrate characteristics as those known to be used by Chinook in the Okanagan are mapped to provide a usable estimate of spawning habitat.
2. Areas in the channelized section of river that are underlain by the pre-channelized river have been observed to be correlated with usage by spawning Chinook, so all such areas are predicted to provide usable spawning habitat.
3. Since Chinook redds in the naturalized section of the river are usually associated with bars, each bar/bar complex is predicted to be associated with about 1000 m^2 of spawning habitat.

In addition, the habitat-based model developed by Parken et al. (2006) was used to predict the maximum sustainable yield and replacement point for Okanagan Chinook between McIntyre Dam and Osoyoos Lake.

The first method of spawning habitat availability estimation mentioned above is referred to as the “cells method” (Phillips et al 2005). In 2002 and 2003, Water depth and velocity, and substrate composition were measured at 2 m intervals along transects spaced every 200 m throughout the river between vertical drop structure (VDS) #13 and McIntyre Dam. Each measurement point is assumed to represent a rectangle or “cell” of channel that extends half way to each neighbouring measurement point/transect (i.e. generally 2 m wide and 200 m long). If the values for all three parameters fall within the observed range for these metrics for Chinook spawning in the Okanagan River then the cell (i.e. 400 m^2) is considered available spawning habitat. At a few transects conditions were too hazardous to take measurements so the cells centered on these transects were the width of the full wetted channel. There were 345 cells in 2002 and a 397 in 2003. Due to the relatively low water levels in 2003 there were less transects that could not be measured and thus more cells. No redds were observed in any areas that were too hazardous to sample.

The second spawning habitat availability estimation method applies only to the channelized (dyked) section of channel (Phillips et al 2005). In the channelized section there is a clear association between redd locations and points where the channelized river is crossed by the original (i.e. 1954) channel. Figures A1 to A3 present an overlay of the original channel on the current channel. For the purposes of the habitat availability analysis we have assumed that only these channel intersections provide suitable habitat for Chinook in the channelized section. We have estimated that there are 300 m^2 of suitable habitat at each intersection (i.e. the mean usable width of the existing modified channel multiplied by the mean width of the original channel).

The third habitat availability estimation method applies only to the natural section of channel, which includes the undyked channel and a portion of the channel with dykes that are set back far enough to permit some channel movement and bar formation (Phillips et al 2005). Within the natural section of channel there is an association between instream bars/bar complexes and Chinook redds. For the purposes of the habitat availability analysis we have estimated that each major bar or bar complex creates about 1,000 m^2 of suitable Chinook spawning habitat, much less than the area that we have observed sockeye using in these same locations.

The second and third estimation methods are considerably more subjective, but are based on observed Chinook behaviour in the river (Phillips et al 2005). Nearly all Chinook redds that have been identified in the Okanagan River have been associated with either instream bars or, in the channelized section, with locations where the original (1954) channel crosses the new one.

The cells method quantifies habitat availability solely on the basis of three easily measured metrics, namely water depth, average water column velocity, and median bed particle size (i.e. D50) (Phillips et al 2005). No consideration is given to other factors that may limit habitat values for Chinook; such as, intragravel water percolation rates, which may be an important spawning habitat constraint for Chinook. This method likely significantly overestimates the amount of suitable spawning habitat available to Chinook in the Okanagan River.

Burner (1951) estimated that the area defended by a pair of Chinook is about four times the average redd size so the mean size of measured Chinook redds in the Okanagan River is used to estimate the number of spawning pairs that could spawn in the Okanagan River for each of the above habitat availability estimates. Chinook in Okanagan River would be expected to defend territories of about 18 m^2. The estimates of available habitat shown in Table A 2 are also presented as the number of Chinook pairs that could spawn in the available habitat (i.e. area/18 m^2).

Table A2. Chinook spawning habitat availability estimates under typical (2002) and low (2003) flow conditions.

	Spawning Habitat Estimates for each Channel Section by area (m^2) and number of spawning pairs that could be accommodated[1]			
Estimation Method	**Oliver Bridge to VDS 13[2]**	**Dyked Channel Upstream of VDS 13**	**Natural and Set-back Dyked Channel**	**Total**
1) Cells – 2002 (11.0 m3/s)	0[2] [0]	23,600 [1,310]	55,230 [3,070]	78,030 [4,340]
– 2003 (6.5 m3/s)	0[2] [0]	30,020 [1,670]	37,660 [2,090]	67,680 [3,760]
2) Channel Crossings	1,500 [83]	2,700 [150]		26,200 [1,460]
3) Bars and Bar Complexes[3]			22,0003 [1,220]	

[1]The number of spawning pairs that could be accommodated is shown in square brackets [ ].
[2]No habitat is shown between Oliver Bridge and VDS 13 because most of this area is too deep and slow for Chinook spawning. Spawning has been observed immediately upstream of VDS 12/Oliver Bridge.
[3]There are 22 major bars or bar complexes. Each one is assumed to create 1,000 m^2 of spawning habitat (i.e. habitat for 56 spawning pairs).

The combined estimate provided by the channel crossings and bar/bar complex methods is probably the most defensible estimate of Chinook spawning habitat availability provided in this report and may be a reasonable basis for initial Chinook management planning in the Canadian Okanagan River basin.

In contrast, the habitat-based Chinook productivity model of *Parken et al. (2006)* (Appendix C) estimates that the maximum sustainable yield of Chinook adults for the section of river between McIntyre Dam and Osoyoos Lake is 3,400, with a population replacement point (i.e. productive capacity) of 10,000 spawners (Table A 3).

Table A 3. Watershed area habitat model predictions for the Okanagan River downstream of McIntyre Dam of the number of spawners required to replace the population (Srep) and maintain the maximum sustainable yield (Smsy).

	Estimate	**CV_1**	**Bootstrap Percentiles**						
			5th	10th	25th	50th	75th	90th	95th
$\hat{S}_{MSY}$	3,400	0.14	2,700	2,800	3,000	3,300	3,700	4,000	4,200
$\hat{S}_{REP}$	10,000	0.13	8,000	8,300	9,100	9,800	10,700	11,600	12,100

[1]Coefficient of Variation.

The above predictions are based on the area that drains directly into the Okanagan River downstream of McIntyre Dam (604 km^2 or 8% of the watershed upstream of Osoyoos Lake). However, the estimate may be too high considering that the Okanagan River is in a drier climate and has been more heavily modified that the rivers used to create the model. If the estimates are reduced by 50%, the productive capacity estimate (5,000 spawners, or 2,500 spawning pairs) falls within the range of habitat availability estimates presented in Table A 2.

Regardless of which of the habitat or productive capacity estimates are used, it is clear that neither spawning habitat availability nor productive capacity is the limiting factor for the Canadian Okanagan Chinook population, which currently numbers in the tens, not thousands.

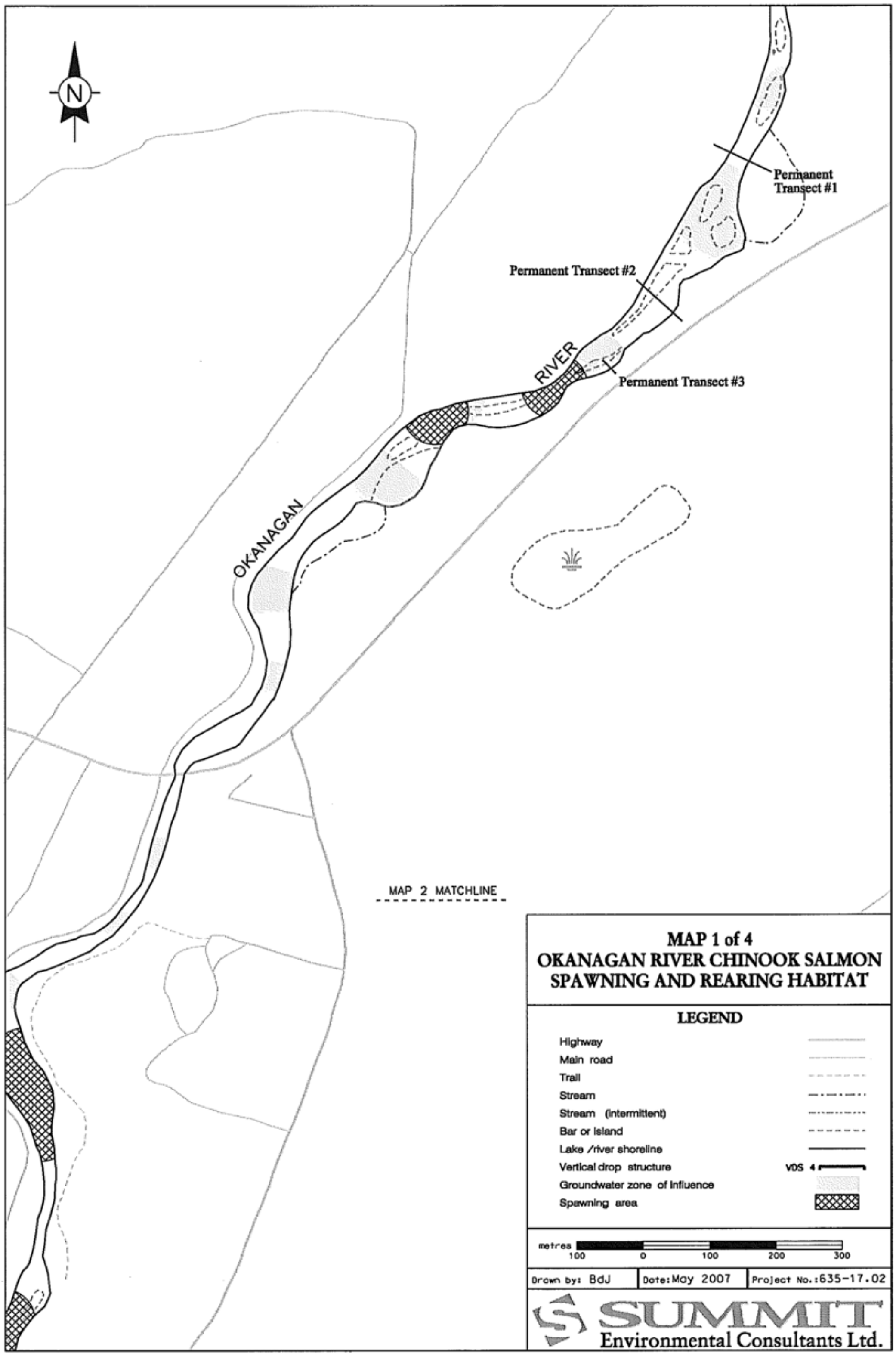

Figure A1. Map showing areas of groundwater input and spawning areas for the Okanagan River.

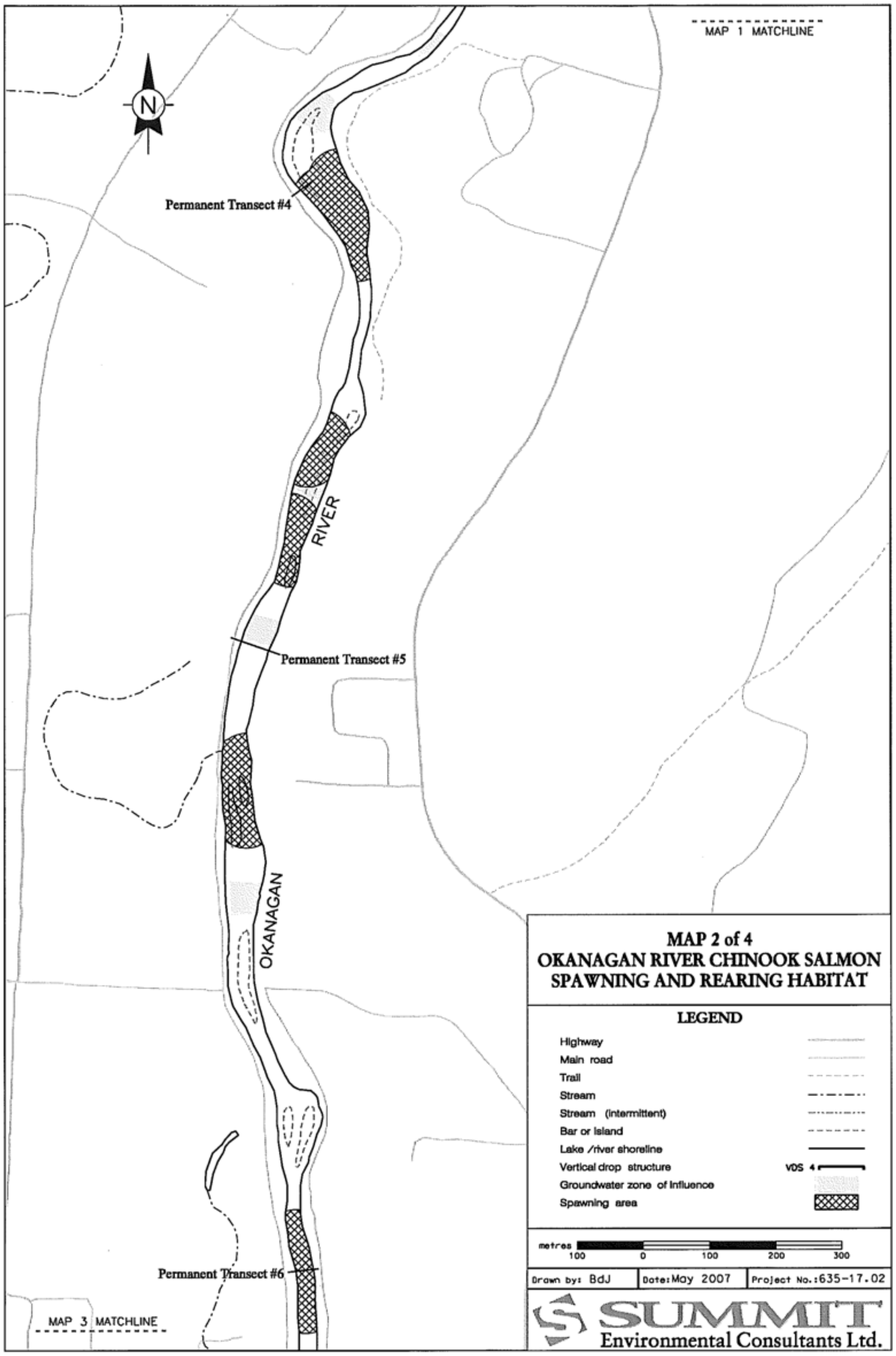

Figure A2. Map showing areas of groundwater input and spawning areas for the Okanagan River (2nd section).

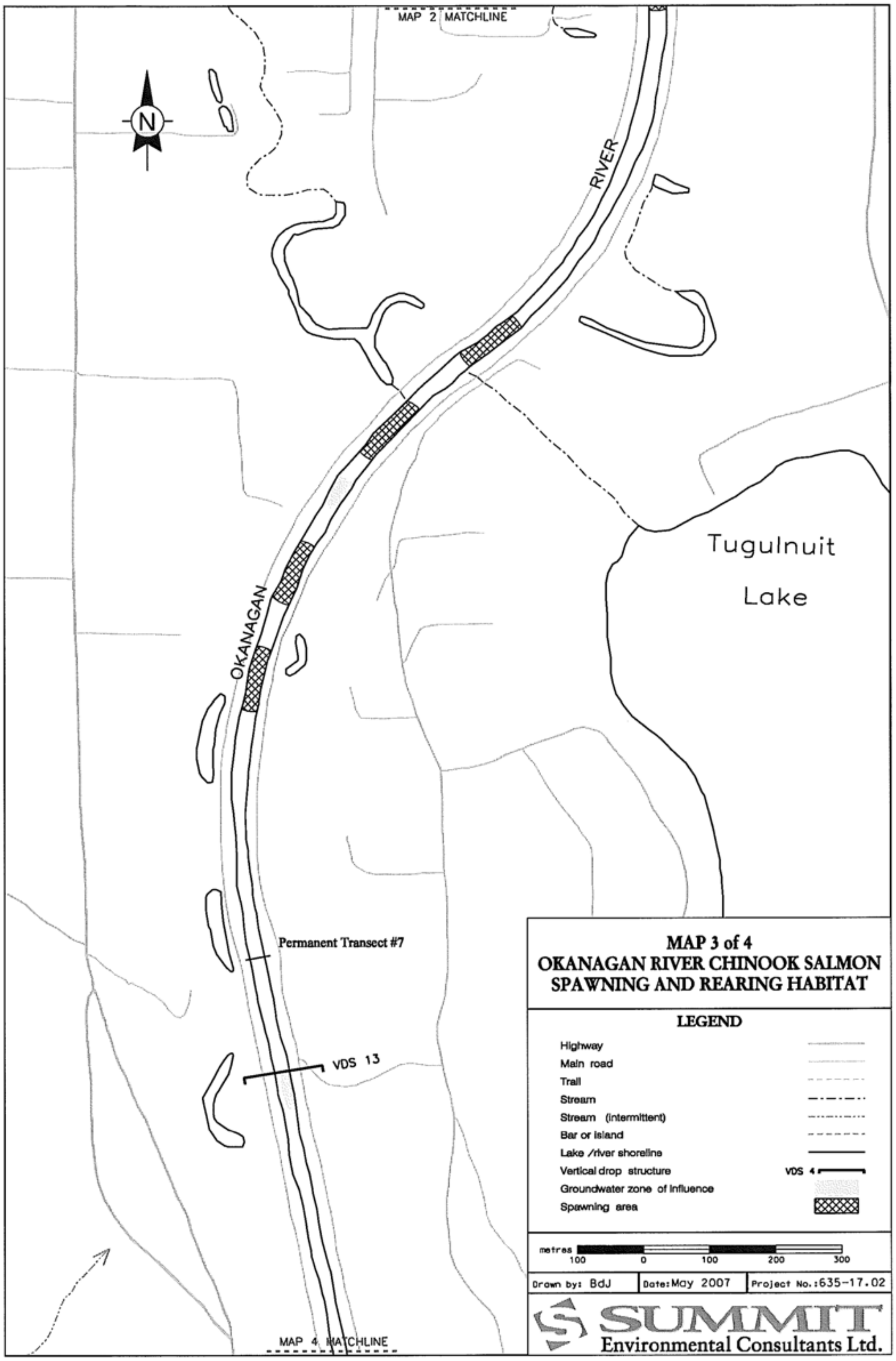

Figure A3. Map showing areas of groundwater input and spawning areas for the Okanagan River (3rd section).

3.3 Rearing Habitat:

Juvenile Chinook salmon rear in rivers, streams, lakes, estuaries, and/or the ocean (Healey 1991). Bjorn and Reiser (1991) identified suitable rearing habitat as dependent on streamflow, channel morphology, gradient and riparian/instream cover. The best habitats are those that allow optimal foraging with minimal energy expenditure.

Upper Columbia summer stocks emerge primarily in April and May (Evenson and Talbot 2003). Although no emergence studies have been done on Okanagan Chinook we believe that the Okanagan Chinook emerge at the same time as the other upper Columbia stocks because of the size of juvenile fish caught in fyke nets downstream of spawning areas in May (ONA unpublished data). Fry likely immediately move immediately downstream into Osoyoos Lake or further downstream.

Most of the river between McIntyre Dam and Osoyoos Lake has been straightened and channelized. The amount of summer rearing habitat in the river (i.e. groundwater fed side channels) that has been lost is unknown. However, it is likely that little usable summer habitat remains in the channelized sections of river due to the absence of side channels and other areas where groundwater inflow may have a significant temperature moderating effect. This prediction is supported by the infrared imagery, which identified only a few points where water temperature was significantly altered by groundwater (ONA unpublished data).

Rearing juvenile Chinook have been captured in Okanagan River in May and August (Wright and Long 2005); while, rainbow trout have been observed rearing in side channels when other parts of the river are too hot. In July 2002, water temperatures in a few side channels were found to be up to 9°C cooler than the main river channel, which was 23°C (Alexis *et al.* 2002). Areas in the river that had water temperatures more than 3°C warmer than the surrounding river water are presented in Figures A 1 to 3. Each of these areas has the potential to provide summer rearing habitat for Chinook, but whether the effect is significant during higher summer flow conditions (i.e. about 20 m^3/s, compared to about 6 m^3s when the thermal imaging was taken) and whether salmonids actually use these areas have yet to be determined. In 2006, the water temperature in Okanagan River (Water Survey of Canada station; *Okanagan River near Oliver*) was above 25°C for most of July, peaking at about 28°C in late July. A temperature reduction of 5°C would keep temperatures below the lethal level for salmonids throughout the year.

A field program will need to be conducted to identify significant thermal refuges in the river and to determine whether salmonids rear in these areas. Most of the identified areas of groundwater influence are concentrated along the channel margins and in side channels. Presumably, groundwater flowing into the thalweg of the river would be rapidly diluted so would be much less likely to be observed on the surface of the river; thus, there may be temperature refuges near the bed of the river that were not identifiable using thermal imaging.

Osoyoos Lake may provide suitable rearing area for juvenile Okanagan Chinook. Time spent in the lake for juveniles is unknown but might range from days as a migration corridor to the Columbia River or rearing from one to several years. In Shuswap Lake, Chinook were found rearing along the lake foreshore (Russell et al. 1981). They reared and migrated within the littoral zone and seemed to prefer lake delta type habitats with there associated areas with sandy bottoms.

Juvenile Chinook use of Osoyoos Lake may be limited by competition with other non native fish species (Brown, personal communication). Yellow perch, bass, pumpkinseed, carp, and crappie are considered to be alien invasive fish species and these may act as predators and/or competitors to Chinook (Scott and Crossman 1998). They present a threat to Chinook juveniles and may reduce the habitat options available for Chinook rearing.

Migration patterns and habitat usage specific to Okanagan Chinook fry is unknown. Generalizations can be made based on the case histories of other stocks in the Columbia River. Chinook fry migrate seaward at any time of year in their first eighteen months of life (Healey 1991). Most subyearlings migrate between April and June of their first year. Fingerlings prefer shoreline areas and move at night in the Columbia River. The shoreline area may potentially serve as cover, source of food, thermal refugia or may reflect energy saving strategies associated with low-velocity near shore habitats (Kemp et al. 2005). This behaviour may increase the rate of migration, but it may also increase predation rate by foreshore predators. An extended residence has been reported that was related to slow growth (Healey 1991). Juvenile migrants actively feed before emigrating and throughout the period of migration continue to feed in low velocity habitats created by eddies in constrained segments as they migrate (Healey 1998; Stanford et al. 2006).

3.4 Winter Rearing:

To date Chinook juveniles have not been found over-wintering within the Canadian portion of the Okanagan drainage. Sampling for juvenile Chinook has occurred within the Okanagan River during winter months. In December 2006, no fry were found. Habitats that were primarily targeted by the surveys included areas along banks with overhang and deep pools. Chinook that overwinter in larger rivers often move out of tributary streams and into the river main stem, where they occupy deep pools and interstitial spaces between boulders and rubble during the winter and are strongly nocturnal (Hillman et al 1987; Healey 1991; Cunjak 1996). Chinook in the Okanagan River may not exhibit a residual over-wintering behaviour or it is possible that the surveys were conducted in the wrong locations at the wrong time. It is likely the fish emigrated downstream into Osoyoos Lake or the mainstem of the Columbia River prior to the onset of winter although it is possible a few fish may utilize groundwater sources to rear through the winter.

Point groundwater sources may provide warmer microhabitat for stream salmonids and serve as refugia from instream problems such as ice and variable stream flow (Cunjak 1996). Upwelling has been associated with increased survival of Chinook salmon in British Columbia over winter (Bustard 1986). Positions closest to the groundwater source may not always be the preferred habitat (Cunjak 1986). Fish may prefer areas slightly downstream where waters are cooler but still above freezing. Salmonids may not be physically adapted to higher water temperatures in winter. The increased temperatures associated with the groundwater source will result in the need for increased feeding and assimilation efficiency. These areas will also serve as thermal refugia during periods of high temperature stress in summer.

3.5 Oceanic and Estuary Usage:

The estuary serves a transition zone from the freshwater river environment to the salinity of the open ocean (Bottom *et al.* 2006; Bottom *et al.* 2005; Healey 1998; Fresh *et al.* 2005; Romanuk and Levings 2005). Okanagan Chinook populations are assumed to mix with other Columbia stocks as they pass through the estuary. Juvenile Chinook salmon are distributed based on water depth within the Columbia River estuary and may remain there for periods ranging from days to many months (Fresh *et al.* 2005; McCabe *et al.* 1986). The smallest size classes tend to be most closely associated with the most shallow, peripheral tidal marshes and forest marsh habitat. Larger juveniles will be found in deeper pelagic areas and located more centrally to the mainstem channel. Shifts in habitat preference may have a specific size threshold.

Chinook are present within the Columbia estuary twelve months a year (Bottom *et al.* 2006). Ocean type fish enter the estuary within the first three months of life and remain close to shore in sheltered water for several months (Healey and Groot 1987; Brannon et al 2004). Sub-yearlings were most abundant between May through December (Fresh *et al.* 2005). Stream-type fish spend little time in the estuary and move to the open ocean after a short period (Brannon *et al.* 2004).

Ocean migratory patterns may have evolved as a balance between the relative benefits of accessing specific feeding grounds and the energy expenditures necessary to reach them. Ocean type Columbia Chinook remain largely or entirely within coastal waters, while stream-type fish make more extensive migrations. Chinook are generally found north of their river of origin, but some populations remain relatively close to their natal river (Quinn 2005). Stream-type Chinook migrate to the eastern North Pacific concentrating over the continental shelf water (Healey 1991).

Chinook remain at sea from 1 to 6 years although usually the time at sea is 2 to 4 (Myers *et al.* 1998). Mid Columbia Chinook stock has a far north ocean migration pattern similar to the stream type. They are harvested in ocean fisheries in southeast Alaska, northern BC and off the west coast of Vancouver Island (Evenson and Talbot 2003).

Oceanic conditions can have a major impact on the survival of Columbia basin Chinook. El Niño, Pacific Decadal Oscillation (PDO) shifts and areas of coastal upwelling alter physical conditions in the ocean (Bottom et al. 2006; Bottom et al. 2005). Variations in the intensity and frequency of these events influence biological production and the recruitment of pelagic fish. During weak periods of upwelling bands of chlorophyll were located closer to shore, serving as a highly productive base for the food web. MacFarlane et al. (2005) noted greater growth for juveniles during strong El Niño in 1998 and 1999. The oceanographic data indicated elevated temperatures, lower salinity, greater freshwater outflow, northerly flowing coastal currents, and positive upwelling index anomalies which combined to result in greater zooplankton productivity. Greater zooplankton productivity and higher temperatures allowed for enhanced growth.

There are large-scale and sometimes very rapid changes in atmospheric pressure which are reflected in ocean properties and circulation (Francis et al. 1998). The Pacific Decadal Oscillation (PDO) shifts between alternative climatic regimes every twenty to thirty years (Bottom et al. 2006). The PDO causes changes in the California current which regulates the thermal structure and advective processes that determine shore distribution of nutrient and location of the sub arctic boundary (Bottom et al. 2006). Survival of salmonids has been linked to the degree of density stratification, but they are likely linked to changes in river and estuary conditions. The PDO alternates between cold and warm cycles (Fresh et al. 2005). Cold phases (1945-1976) result in higher levels of salmonids production in the Pacific Northwest, while higher production occurs in northern British Columbia and Alaska during the warm phase between 1977 and 1998.

3.6 Open Ocean and Adult Migration Routes:

Chinook Adult migration in river is a precise homing process of over 1500 km (Keefer *et al.* 2006; Quinn 2005). This migration is largely driven by chemically based olfactory clues. The odours of natal streams and possibly the entire outward journey are imprinted on juveniles as they move toward the ocean. They are played back in reverse order on the way back to spawning streams. These events are largely genetically controlled (Quinn 2005). As tributaries meet with the mainstem Columbia River, downstream vertical and lateral gradients of sediment, dissolved gases and temperatures gradients can remain over hundreds of kilometres (Keefer *et al.* 2006). The distance downstream these cues are detected is dependent on discharge volume, duration and quality of imprinting, prevailing winds and currents, and stratification. Mixing will occur at dams and may cause disorientation of fish. These factors create both aversion and attraction behaviour where fish will either move toward or away from specific stimuli.

Salmon have been observed orienting themselves on the shoreline to the strongest environmental gradients (Keefer *et al.* 2006). Adults tend to swim along the shore that is associated with their natal tributary. Spawners from shore tributaries show a bias towards migrating along the south shore.

Other factors that affect the speed of upstream migration may include temperature, flow, and turbidity. General requirements for temperature varied between 3-20 ^{0}C (Bjornn and Reiser 1991; Keefer *et al.* 2006). Temperatures between 13.9 and 20.0 ^{0}C were required for summer Chinook migrators. The minimum depth for all Chinook was established to be 0.24 meters and water flow to be at 2.44 meters per second (Bjornn and Reiser 1991). Flow determines the pattern of upstream adult migration (Keefer *et al.* 2006). Chinook increased use of the north shore spillway at the Dalles Dam as flow increased. Fish may have favoured the higher volume or velocity. Migration of adult salmons is delayed by high sediment loads unless previously acclimatised to it (Bjornn and Reiser 1991). Migration in the lower Columbia River was found to be delayed at Secchi disk levels less than 0.6m. The turbidity levels were dependent on glacial melt runoff levels.

Adult salmon vagrants are known to return to spawning locations outside their natal streams. These strays are more likely to return to locations near their natal system (Quinn 2005). This feature is a fundamental attribute of salmon and may be genetically controlled. At some level straying is evolutionarily advantageous by allowing salmon to colonize new areas, and increase genetic heterozygosity. Strays frequently fail to reproduce due to differences in life histories (Tallman and Healey 1994).

4.0 Threats to Habitat

Chinook in Canada have been adversely impacted by human induced changes to the ecosystem. The impact of human change to Chinook habitat is difficult to assess however trends can be inferred by changes in salmon population numbers and changes in distribution. The main threats to Okanagan Chinook habitat include; water withdrawals, construction and operation of dams (for power generation or water diversion), channel modification, water pollution, and introduction of non-native fish species (Raymond 1988; Myers *et al*. 1998).

4.1 Water withdrawal

Water is withdrawn from both groundwater and surface water sources. Within the Columbia Basin, the primary use of use of the withdrawn water is for irrigation. Three-quarters of all water used in the Okanagan Basin goes to agriculture activities (Rae 2005). The general demand for water is from June to September, while most of the water flow occurs in April and May. A significant problem is the timing of peak water needs compared to the timing of peak water availability. In some cases irrigation practices have resulted in dewatering of streams for at least portions of the year.

There are two aquifers within the Canadian portion of the Okanagan River. The first aquifer is in the north section from south of Vaseux Lake to Tugulnuit Lake and the second from Tugulnuit Lake south. Both are classified as 1A (BC Water Resources Atlas 2007). They have undergone considerable development and are highly vulnerability to contamination, which gives them a high priority for management. The level of development is determined by comparing the amount of groundwater withdrawn with the aquifer's ability to replace this groundwater (Berardnucci and Ronneseth 2002). Over 500 groundwater wells occur near the Okanagan River used by Chinook for spawning. These wells have yields between 10 gallons (35 L/min) and 1250 gallons per minute (4700 L/min) (BC Water Resources Atlas, Jan. 12, 2007). A decrease in aquifer water level will result in a decrease in the rate of water discharging into the river.

About 90% of all streams in the Okanagan are already at, or beyond, their capacity to have water withdrawn for human use (Rae 2005). In areas where water is being withdrawn past their capacity, fish and wildlife lose out when water shortages occur. By 2020 human demand will exceed the available water supply. Even without water withdrawals on Okanagan streams, the low flows naturally occur in summer and autumn that limit fish production and survival. Water withdrawals simply exacerbate this limitation.

A third of the water used for irrigation is returned to the system (NRC 1996). Water returned has been altered and degraded. The return flow has higher water temperatures; increased salinity; pathogens; decreased dissolved oxygen concentrations; and increased concentrations of pesticides, herbicides, nutrients and sediment. Many of these factors are important in the habitat requirements of salmonids.

The withdrawal of water can result in loss of fish habitat. Reduced flows and water levels, increased water temperatures and lowered oxygen concentrations usually result in a reduction in habitat. Migrating juveniles can be diverted into irrigation channels or impinged on intake screens (Bottom *et al*. 2005). The level of mortality associated with intake screens is unknown.

4.2 Dams

The Columbia River system has been dramatically altered as a result of the hydropower system. Development of the hydropower system on the Columbia River started in the late 19th century on the tributaries (NRC 1996; Coutant *et al.* 2006). The first dam on the mainstem of the river was Rock Island Dam completed in 1933. Grand Coulee Dam blocked the mainstem in 1941 and Chief Joseph Dam was constructed downstream of Grand Coulee dam in 1955. The series of dams provide power generation, flood control and permitted the withdrawal of water for irrigation. The hydropower system has fundamentally restructured the Columbia's hydrological character and its related ecological resources and creates significant fish passage and water quality problems (NRC 1996; Coutant *et al.* 2006). Chinook populations are highly susceptible to effects of dams on rivers because they carry out most of their freshwater life history within mainstream habitat (Hanrahan et al. 2004). These factors have lead to a decreased Chinook survival.

Modifications to the Okanagan River within Canada began in the early 1900's and changes continued to the current system of water control between Okanagan Lake and Osoyoos Lake (Symonds 2000). Zosel Dam at the outlet of Osoyoos Lake is passable by migrating fish, while McIntyre Dam at the outlet of Vaseux Lake blocks passage to the rest of the basin, including 35,000 hectares of Okanagan Lake and its tributaries. While Chinook currently cannot pass McIntyre Dam their historic range in the Okanagan Basin likely included some of the major tributaries of the river and mainstem lakes as far upstream as Okanagan Lake (Ernst 1999; Ernst and Vedan 2000). No estimates of habitat lost due to loss of access have been made. Chinook in the Canadian portion of the Okanagan Basin can access 16 km^2 of lake and river habitat that is suitable for rearing and/or spawning.

The series of dams and storage reservoirs have altered both the volume and seasonal patterns of the Columbia's flows (Coutant *et al.* 2006; NRC 2004). The system is designed to store the spring freshet and to release it for power production in winter. High spring flows are important to the ecology of rivers by increasing turbidity, flushing substrates, transporting fish downstream and maintaining favourable water temperatures during spring and summer. Changing flow patterns have resulted in the alteration of water velocity, degradation of habitat, high mortalities associated with dam passage, and modification of predator species and predation rates (NRC 2004). These impacts affect Chinook's ability to use the Columbia River as a migration corridor and as a rearing area.

The dams on the Columbia River create a series of reservoirs which act as lakes with reduced water velocities. The NRC (2004) reviewed early literature on travel time for yearling Chinook and found it had increased at least twofold over pre-impoundment conditions and had ultimately decreasing smolt survival. Conversely Giorgi *et al. (*1997) observed no response to changes in flow for summer migrating subyearling Chinook. Peak summer Chinook smolt migration is primarily in July and August when current water levels are lower than the historical averages (Ferguson *et al.* 2005). The slowed passage through the river increases exposure to predators and thus increasing predation rates on juvenile Chinook (Ferguson et al 2005; Fresh et al 2005).

Fish life history patterns have been influenced by reduced water volumes, loss of riparian vegetation, and resultant increases in water (Stanford et al. 2006). Water temperature controls the timing of life history events such as spawning and migration (Brannon et al. 2002). At 12 to 13°C, smoltification is inhibited and outward bound smolts may revert to parr (NRC 2004). For adult Chinook, high temperatures slow passage upstream. Most dams have installed fish passage ways that allow passage of adults. These facilities increase stress and pre-spawning mortality, result in delays in upstream migration and reduce the success of late spawners (NRC 1996).

Warmer water released from the surface of the reservoir behind McIntyre Dam may further increase water temperatures in the Canadian Okanagan River. Maximum temperatures are a limiting factor within the Okanagan River (NPCC 2004). Okanagan River typically has mean daily temperatures of over 20°C from early July to mid September. Adults are not seen in the river until temperatures drop below 17°C.

Chinook smolts migrating downstream have to navigate the hydropower facilities, such as the spillways, bypass facilities or turbines. Although there is much debate about the amount of mortality associated with these structures, there is consensus that smolt survival has declined as a result of passage through hydropower facilities (Ferguson et al 2005; NRC 2004). The lowest levels of mortality are associated with the spillway followed by bypass systems and turbines (Muir et al 2001). The mortality at each spillway is likely 0-2%, although, it will vary among dams and within the dam spillway under various conditions. The exact mechanism of injury and mortality is through rapid pressure changes, deceleration, shear forces, gas bubble disease (GBD), turbulence and the force of striking water in free fall (Ferguson et al 2005; Backman et al 2002). Flow deflectors have been installed in the spillways to reduce super saturation of gases as it flows over the dams to reduce the occurrence of BGD (Bickford and Skalski 2000).

In periods of reduced flow, spill volumes decline forcing juveniles to pass through the turbines. Mortality in turbines is likely the result of strike, pressure, cavitation and shear (Ferguson et al. 2005; Mathur et al 1996). Indirect mortality has been associated with possible delayed affects of turbine passage including disorientation and increased susceptibility to predation that may affect the longer term survival of fish (Absolon et al. 2003). In studies completed up to 1992, turbine survival averages approximately 90% per dam.

Efforts are being made to further increase the survival of Chinook as the pass through the hydroelectrical system. A program to increase spill was implemented in 1988 to reduce the mortality connected to migrational delay, exposure to predators, high temperatures and disease (Whitney et al 2005). According to the population viability analysis, Sharma (2006) has determined that further increases in survival will not result in greater populations of Chinook in the Okanagan.

Within the estuary and ocean environments, hypropower development has also had a major impact on the physical characteristics. Hydrological flows have changed the surface area of the plume, the volume of the plume water, the extent and intensity of frontal features and the extent and distances offshore of plume waters (Fresh et al. 2005). These features change the patterns of biological production, temperature, water density and biomass and thus altering the ability of Chinook to feed and rear within the estuary.

Dams act as an agent for habitat degradation, creating habitat fragmentation which can disrupt regional links among populations through elimination of core populations and isolation of remaining populations (Williams et al. 2006). This increases risk of extinction by reducing the probability of repopulation by neighbouring stocks.

4.3 Channel modification

Major losses of spawning and rearing habitat in the Canadian Okanagan River have resulted from channelization which occurred 50 years ago. Most of the river between Okanagan and Osoyoos Lakes has been straightened and dyked (Symonds 2000). Where there once was over 10 km of channel (about 80,000 m^2) between Okanagan and Skaha Lakes that was suitable for use by spawning sockeye and Chinook, there is now only about 3 km of suitable channel remaining (Anonymous 1909; Summit 2003). The Canadian portion of the Okanagan River has been reduced by 24km (50%) and has lost 88% of its riparian area (Bull et al. 2000).

Channelization reduces habitat complexity and thus reduces the quantity and quality of fish habitat. This results in a reduced capacity to produce fish. An estimate of rearing habitat loss for the accessible Canadian portion of the river channel is 91% (Bull 1999). However, this loss of rearing habitat does not necessarily correspond to an equivalent reduction in spawning habitat.

The amount of summer rearing habitat that has been lost due to reductions in groundwater flow is unknown. However, it is likely that little usable summer habitat remains in the dyked sections of channel due to the absence of side channels, protected backwaters, lack of riparian vegetation, lack of channel structure and other areas where groundwater inflow may have a significant temperature-moderating effect. Very little groundwater is reaching the channelized sections of the river (ONA unpublished data). Thermal refugia in both the summer and winter have been lost. Rivers influenced by groundwater provide a more consistent food supply (Stanford *et al.* 2006). By removing groundwater sources, and depositing rip rap on the river banks we suspect salmonid productivity has been reduced.

The amount of large woody debris (LWD) is associated with habitat complexity within the Columbia River, especially in flood plain environment where no boulder or other structures exist (Stanford *et al.* 2006). Within the Okanagan Basin large woods debris has actively been removed from the river (NPCC 2004) and no sources of new large woody debris exist as there is very little over hanging vegetation. This has resulted in a decline in habitat diversity throughout the system.

The most significant anthromorphogenic effects have been on the estuary and its ability to support juvenile salmon. The pre-development river mouth was characterised by shifting shoals, sandbars and channels forming tidal deltas. Attempts to stabilise the natural shifting process within the estuary has resulted in the infilling of estuarine shoreline. Approximately 62% of tidal marshes that existed prior to 1870 have been lost (Bottom *et al.* 2006). There has also been a 12% loss of deep-water habitat (Fresh *et al.* 2005) and estuarine surface area has decreased by 20% as a result of dyking or filling of tidal marshes (Bottom *et al.* 2006). The total area of tidal swamps has decreased by 77% and tidal flats in the lower estuary have declined 7%. Direct loss of salmon habitat is caused by dredging and jetty construction that limits the ocean fed supply of sediment, as well as by flood control measures used to convert land to pasture. The majority of habitat loss has resulted from the filling in of tidal marshes.

Loss of estuarine habitats has resulted in altering the magnitude and character of habitat capacity (Fresh *et al.* 2005). The loss of these production areas has reduced estuarine emergent plant production by 82%. The organisms that feed on this macro-detritus would be expected to be reduced to 1/12 of pre-development abundance (Fresh et al 2005; Romanuk and Levings 2005). The shallow aquatic detrital food organisms have been replaced with deep water, benthic and pelagic consumers, such as longfin smelt, surf smelt, Pacific Herring and American shad.

4.4 Introduction of non-native species

Currently 81 organisms have been introduced into the lower Columbia River since the mid 1800s of which 28 % are fish (Sytsma et al 2004). Many of these fish such as largemouth bass, smallmouth bass, walleye, and yellow perch were introduced at the turn of the century to create a recreational fishery. Hydromodification in the Columbia River has created a suitable environment for these invasive species. The Columbia River reservoirs have become dominated by non native species, most of which are known to be predators and competitors with salmonids. Pikeminnow, a native fish is considered to be the number one predator on juvenile salmonids mainly because of its abundance and consumes >80% by weight of juvenile salmonids (Petersen 2001). Okanagan Chinook smolts and fry must pass through this gauntlet of piscivorous fish on their migration downstream and if they rear in the Columbia River they must compete with other introduced species.

The fish community within the Canadian portion of the Okanagan River has 38 species but only 24 are indigenous (Rae 2005). Fourteen species have been introduced along with Eurasian water milfoil, and the freshwater shrimp *Mysis relicta*. Largemouth bass, smallmouth bass, sunfish, crappie, carp, bullhead, brown trout, brook trout, and lake trout have spread throughout the Columbia River. All of these species were intentionally introduced. Many of these species prey on salmon eggs and fry, and some eat salmon juveniles (Zimmerman 1999). Large and small mouth bass are well known piscivores and they have been implicated in reduction of salmon productivity (NMFS 1998; Wright et al 2002). They are abundant within the Canadian Lakes above and below current Chinook distribution. Yellow perch are capable competitors and they dominant the littoral zone of Osoyoos Lake. Carp also prey on salmon and salmon eggs, and these predators are abundant in the Okanagan River. Other invasive fish species such as black crappie, black bullheads, bluegill, pumpkinseed, black bullheads, and tench alter the fish community, but their impact on salmon productivity is unknown (Wright et al 2002).

5.0 Conclusion

The human population residing within the Canadian Okanagan Basin is estimated at 300,000 people, and this is expected to grow to 450,000 by 2031 (Rae 2005). Population growth has implications for Chinook survival, not only from urbanization's direct effects on land use and hydrology (e.g., hydroelectric demands, decreasing of surface waters percolating to groundwater) but also because additional people will create a greater demand for Okanagan River water and related resources. Before it was altered by human activities, the Okanagan River flowed through a wide flood plain. Annual flooding was natural, and the many wetlands along the length of the valley from Penticton to Osoyoos absorbed and stored the flood waters.The region has changed dramatically over the past 150 years and given human population growth projections, even more rapid future changes are likely with direct consequences on the habitat of Chinook.

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Appendix B. Genetic Analysis

for

Chinook Salmon Okanagan Population

Oncorhynchus tshawytscha

Report prepared for

Okanagan Nation Alliance

Prepared by:

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October 2007

The genetic analyses have been conducted on a total of 82 Chinook salmon tissues sampled between 2000 and 2006 by the ONA that produced high quality DNA amplification in the Molecular Genetics Laboratory at the Pacific Biological Station. Sixty-six samples were from adult Chinook salmon sampled in the Okanagan River and 16 were from immature Chinook salmon sampled in Osoyoos Lake (Table B 1). The larger number of adults sampled in 2005 and 2006 allowed analysis of fish from each year separately, as well as analysis of fish from both years combined. The fish were screened at the twelve microsatellite loci used in the DFO coastwide Chinook salmon baseline (Beacham et al. 2006).

The genetic data were used to address three questions about the Chinook salmon returning between 2000 and 2006 to the Okanagan River (Canada). These questions were:

1) What is the genetic affiliation of the Canadian Okanagan Chinook population?

2) Do any of the Chinook salmon that spawn in the Canadian Okanagan River produce returning adults?

3) If so, do the successful spawners represent a small, isolated population or are they part of a larger metapopulation (connected by straying)?

Genetic affiliation of the Canadian Okanagan River samples

Both the 2005 and 2006 samples of Okanagan River Chinook salmon were most closely related to Chinook salmon from the other two Upper Columbia fall/summer run fish in the DFO coastwide database; those from the Similkameen and Wenatchee rivers (Figure B 1). The genetic differentiation (F_{ST} value) between the 2005 Okanagan River and a multi-year (1993, 2005, 2006) Similkameen River sample was low (0.011) but significantly different from zero, whereas the value between the 2006 Okanagan and Similkameen River sample (0.002) was not significantly different from zero.

The upper Columbia watershed is unique in containing two genetically distinct and almost completely isolated sympatric lineages of Chinook salmon. One lineage is characterized by spring adult migration and stream-type juvenile life-history and the other lineage is characterized by summer/fall adult migration and ocean-type juvenile life-history (Waples et al. 2004). As a result, the summer/fall run Chinook salmon of the upper Columbia, including the Similkameen and Canadian Okanagan River fish, are more closely genetically related to spring, fall and summer run Chinook salmon elsewhere throughout the Columbia drainage, and to Chinook salmon in the Central Valley of California, than they are to spring-spawning Chinook salmon populations in the Upper Columbia drainage (Waples 2004, Beacham et al. 2006). The upper Columbia summer/fall run populations are more distantly related to Canadian Chinook salmon populations, with the closest genetic ties to Chinook salmon populations on the east coast of Vancouver Island (Beacham et al. 2006, Waples et al. 2004).

Table B 1. Okanagan River and Osoyoos Lake Chinook salmon tissue samples that provided genetic data.

Year of sampling	Location	Sample size	Sample numbers
Adults			
2000	Okanagan River	1	2000_9
2002	Okanagan River	1	2002_10
2003*	Okanagan River	1	2003_21
2004	Okanagan River	4	2004_36, 37, 40, 41
2005**	Okanagan River	28	2005_2699, 2701-2708, 2710-2713, 2715-2729
2006***	Okanagan River	31	2006_4003-4007, 4009-4017, 4019-4035
Yearlings+			
2003†	Osoyoos Lake	3	2003_4, 6, 13
2003††	Osoyoos Lake	6	2003_103, 105, 107-109, 113
Juveniles (fry)			
2004	Osoyoos Lake	7	2004_44-50

* DNA analysis was successful on 3 additional samples from 2003 (16, 18 and 19) but these fish were adipose-clipped and therefore did not originate in the Okanagan River

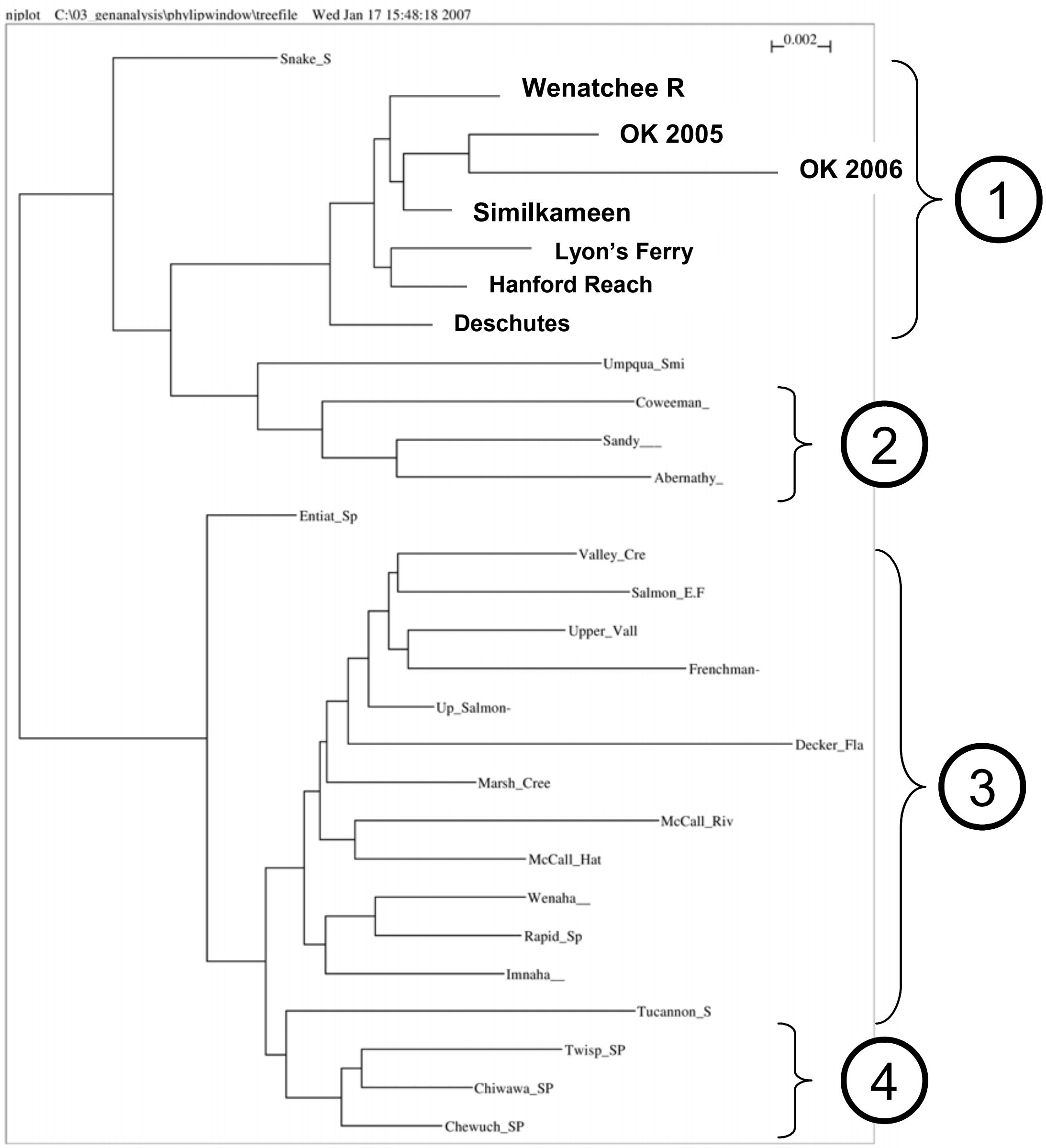
** 31 samples received but one sample (2700) was not from a chinook salmon, one sample was from an adipose-clipped fish (2709) and one sample (2714) was excluded because it was from the same fish as sample 2704.

*** No sample 4018 was received and sample 4008 provided no results.

† Three additional samples (15, 42, 43) were duplicate samples from the same three fish.

†† These samples were obtained from the scale lab (scales) and ecology lab (stomachs) after it was determined that they were chinook salmon. They were originally numbered 3, 5, 7-9, and 13. An additional sample (12) provided no results.

Figure B 1. Genetic relationships among Chinook salmon populations of the Columbia River drainage. The lineages are the 1) Upper Columbia summer/fall run , 2) Lower Columbia fall run, 3) the Snake River spring run and 4) Upper Columbia Spring run. The Chinook salmon sampled from the Okanagan River in 2005 and 2006 belong to the Upper Columbia summer/fall run.



Evidence for successful reproduction in the Canadian Okanagan River

The capture of immature Chinook salmon in Osoyoos Lake in two years (juveniles one or more years of age in 2003 and underyearling fry in 2004) indicated that successful spawning took place at least twice in the Canadian portion of the Okanagan River and produced juvenile fish that migrated to Osoyoos Lake. The presence of fish greater than one year old in the Lake also indicated that some of the juveniles produced from one of the spawning events may have 'residualized' in the Lake, because Upper Columbia summer/fall fish are typically 'ocean-type', meaning that they migrate out of freshwater as underyearlings. Residuals are fish that remain in a freshwater environment, such as Osoyoos Lake, until maturity.

Genetic relationships among the juvenile fish sampled in Osoyoos Lake in 2003 and 2004, and returning adults sampled from the Okanagan River in 2004, 2005 and 2006, were examined using the program COLONY (Wang 2004) to identify probable full- and half-siblings. This analysis confirmed that the two groups of juveniles were the result of two different spawning events as sibling relationships were not apparent between the two age classes of juveniles. However, there were three large half-sibling families that contributed to the residualized yearlings in Osoyoos Lake in 2003, and to the adult returning fish sampled from the Okanagan River in 2004, 2005 and 2006. The multilocus genotypes of these fish and the parents that likely produced them are shown in Tables 2-4. Note that Parent 2 participated in spawning in both Families 1 and 2.

In total, the 33 fish belonging to the three families accounted for 40% of the Chinook salmon sampled between 2000 and 2006 in the Okanagan River and Osoyoos Lake. They included all nine of the residualized yearlings sampled in 2003, two out of three adults sampled in 2004, 18 out of 28 adults sampled in 2005 and four out of 31 adults sampled in 2006. The most reasonable explanation for the large numbers of fish from these families returning to the Okanagan River between 2004 and 2006 is that they arose from a spawning event that took place in the Okanagan River, perhaps in 2001. Some of the juveniles produced residualized and stayed in Osoyoos Lake rather than migrating to the ocean in the spring of 2002. They constituted the fish caught in the Lake as yearlings in 2003 and contributed to those that returned to the River for spawning in 2004, 2005 and 2006. Thus, the parental genotypes shown in Tables 2-4, reconstructed by Mendelian inheritance rules from the progeny genotypes, represent the genotypes of six fish that spawned successfully in the Canadian portion of the Okanagan River. Other parents clearly participated in the spawning, but it was not possible to reconstruct their genotypes with certainty from the available progeny data.

Over half the adults sampled in 2005 belonged to the three half-sibling families and the presence of so many related fish in the sample influenced the allele frequencies of this sample. This likely accounts for the fact that the 2005 sample from the Okanagan River was more distinct from the Similkameen River Chinook salmon than was the 2006 sample, in which only four of the adults were from those three families and the remaining fish tended to be unrelated.

None of seven Chinook salmon fry sampled from Osoyoos Lake in 2004 were from the three large families, but the fry group did contain two sets of siblings. Fish 2004_46 and 47 were likely half- or full-siblings with fish 44. Fish 2004_45 and 48 were a second pair of probable full-siblings. However, removal of samples 46, 47 and 48 provided an unbiased (by family relationships) sample of four more fish that were representative of a probable successful spawning event in the Okanagan River. This spawning event produced fry that were sampled in Osoyoos Lake; it is not certain whether any adults returned to the River from this spawning event. However, in the family analysis, four adults sampled in 2006 (2006_4020, 4023, 4027 and 4035) were identified as probable half-siblings to either fry 50 or the pair of sibling fry, 45 and 48.

Tables B2-B4. Chinook salmon ‘residuals’ sampled from Osoyoos Lake in 2003 and adults sampled from Okanagan River in 2004, 2005 and 2006 belonging to three large half-sibling families and reconstructed genotypes of six of the parental fish.

Table B2. Half-sibling Family 1 consisting of two full-sibling groups sharing Parent 1.

Fish	Multilocus Genotype											
	Ssa197	Ots107	Ots101	Ots104	Ogo2	Ogo4	Ots100	Oke4	Oki100	Omy325	Ots2	Ots9
Family 1a												
Parent 1	**02/09**	**21/29**	**06/19**	**14/15**	**03/15**	**26/29**	**12/12**	**29/35**	**04/05**	**08/25**	**11/11**	**16/31**
Parent 2	**13/13**	**14/23**	**06/14**	**13/14**	**01/03**	**26/28**	**10/10**	**17/47**	**04/05**	**12/20**	**08/09**	**20/25**
Progeny												
2003_4	09/13	14/21	06/06	14/14	01/03	26/29	10/12	17/29	04/04	20/25	09/11	16/25
2003_6	02/13	21/23	06/14	14/15	01/15	26/26	10/12	?/?	04/04	12/25	09/11	16/25
2003_108	09/13	14/21	06/06	14/15	03/15	26/26	10/12	17/35	04/05	08/12	09/11	16/20
2003_109	02/13	23/29	06/19	13/15	03/15	26/26	10/12	17/35	04/05	20/25	09/11	16/20
2003_113	09/13	21/23	14/19	13/14	03/03	26/29	10/12	17/35	04/05	08/20	09/11	16/20
2005_2713	09/13	14/29	06/19	13/14	03/15	26/29	10/12	17/29	04/05	20/25	09/11	25/31
2005_2718	09/13	14/21	06/19	13/14	03/15	28/29	10/12	35/47	04/04	12/25	08/11	16/25
2005_2723	02/13	14/21	06/19	14/15	03/03	26/26	10/12	17/35	05/05	20/25	09/11	20/31
2005_2728	02/13	23/29	06/06	13/14	03/03	26/29	10/12	17/35	04/05	08/20	08/11	16/20
Family 1b												
Parent 1	**02/09**	**21/29**	**06/19**	**14/15**	**03/15**	**26/29**	**12/12**	**29/35**	**04/05**	**08/25**	**11/11**	**16/31**
Progeny												
2003_103	09/12	23/29	06/19	11/15	03/15	12/26	12/12	25/35	04/04	10/25	09/11	16/30
2005_2701	09/12	18/29	06/19	12/15	?/?	08/26	12/12	?/?	?/?	?/?	?/?	16/29
2005_2707	09/12	18/21	06/31	11/15	03/03	08/26	12/12	?/?	04/05	08/13	09/11	30/31

Table B3. Half-sibling Family 2 consisting of five full-sibling groups sharing Parent 3.

Fish	Multilocus Genotype											
	Ssa197	Ots107	Ots101	Ots104	Ogo2	Ogo4	Ots100	Oke4	Oki100	Omy325	Ots2	Ots9
Family 2a												
Parent 2	**13/13**	**14/23**	**06/14**	**13/14**	**01/03**	**26/28**	**10/10**	**17/47**	**04/05**	**12/20**	**08/09**	**20/25**
Parent 3	**06/07**	**23/24**	**27/27**	**04/10**	**03/05**	**26/29**	**09/10**	**25/26**	**05/05**	**13/17**	**08/08**	**27/30**
Progeny												
2003_13	06/13	23/23	06/27	04/14	01/03	26/28	09/10	25/47	04/05	12/17	08/09	25/30
2003_105	07/13	23/23	14/27	10/14	03/03	28/29	10/10	26/47	05/05	12/17	08/09	20/30
2004_36	06/13	23/23	06/27	04/14	01/03	26/28	09/10	25/47	05/05	12/17	08/09	20/30
2005_2712	07/13	14/24	14/27	10/13	03/05	26/29	09/10	17/26	04/05	17/20	08/09	25/30
2005_2717	06/13	14/23	14/27	10/14	03/05	26/29	10/10	17/25	05/05	12/13	08/08	20/27
2006_4006	07/13	14/23	06/27	04/13	03/05	26/29	09/10	17/26	05/05	12/17	08/09	20/30
Family 2b												
Parent 3	**06/07**	**23/24**	**27/27**	**04/10**	**03/05**	**26/29**	**09/10**	**25/26**	**05/05**	**13/17**	**08/08**	**27/30**
Parent 4	**06/41**	**21/25**	**21/22**	**12/12**	**01/05**	**18/36**	**11/11**	**20/23**	**04/05**	**12/19**	**10/11**	**13/15**
Progeny												
2004_37	06/41	23/25	22/27	10/12	01/03	18/26	10/11	20/25	05/05	12/17	08/11	15/27
2005_2699	07/41	21/24	21/27	04/12	03/05	26/36	10/11	?/?	05/05	12/13	08/10	13/27
2005_2708	07/41	24/25	22/27	10/12	03/05	26/36	09/11	23/26	04/05	17/19	08/10	15/27
2005_2721	06/07	21/24	21/27	04/12	05/05	29/36	09/11	23/25	05/05	12/13	08/10	13/27
2006_4010	06/07	21/23	22/27	04/12	03/05	18/26	09/11	20/26	04/05	12/17	08/10	15/30

Family 2c												
Parent 3	**06/07**	**23/24**	**27/27**	**04/10**	**03/05**	**26/29**	**09/10**	**25/26**	**05/05**	**13/17**	**08/08**	**27/30**
Progeny												
2005_2705	07/19	16/24	19/27	04/12	05/08	26/29	09/12	26/35	05/06	12/13	08/09	27/34
2006_4026	06/19	16/23	19/27	10/12	05/14	26/26	10/12	25/35	05/06	13/23	08/08	30/34
Family 2d												
Parent 3	**06/07**	**23/24**	**27/27**	**04/10**	**03/05**	**26/29**	**09/10**	**25/26**	**05/05**	**13/17**	**08/08**	**27/30**
Progeny												
2005_2706	07/12	23/24	06/27	10/11	03/05	08/26	10/11	24/26	05/10	1 0/13	08/09	27/30
Family 2e												
Parent 3	**06/07**	**23/24**	**27/27**	**04/10**	**03/05**	**26/29**	**09/10**	**25/26**	**05/05**	**13/17**	**08/08**	**27/30**
Progeny												
2006_4025	06/34	?/?	15/27	04/12	03/05	27/29	09/09	25/31	05/05	12/17	08/09	16/30

Table B4. Half-sibling Family 3 consisting of three full-sibling groups sharing Parent 5.

Fish	Multilocus Genotype											
	Ots107	Ots101	Ots104	Ogo2	Ogo4	Ots100	Oke4	Oki100	Omy325	Ots2	Ots9	Ssa197
Family 3a												
Parent 5	**10/20**	**14/31**	**18/25**	**12/15**	**03/05**	**22/28**	**10/10**	**19/33**	**04/42**	**10/11**	**11/11**	**15/37**
Parent 6	**03/28**	**15/18**	**15/16**	**09/17**	**03/03**	**12/32**	**10/10**	**29/30**	**04/05**	**10/20**	**09/11**	**30/37**
Progeny												
2003_107	10/28	14/15	16/18	?/?	03/05	12/22	?/?	19/30	04/42	10/11	09/11	?/?
2005_2703	10/28	15/31	15/18	09/15	03/03	28/32	10/10	29/33	04/05	11/20	11/11	37/37
2005_2704	10/28	14/18	15/25	12/17	03/05	12/22	10/10	30/33	04/04	10/20	09/11	30/37
2005_2726	03/20	15/31	15/25	15/17	03/05	12/28	10/10	30/33	04/05	10/20	09/11	37/37
Family 3b												
Parent 5	**10/20**	**14/31**	**18/25**	**12/15**	**03/05**	**22/28**	**10/10**	**19/33**	**04/42**	**10/11**	**11/11**	**15/37**
Progeny												
2005_2720	07/10	20/31	15/25	14/15	03/05	28/30	10/12	23/33	04/40	10/11	10/11	32/37
Family 3b												
Parent 5	**10/20**	**14/31**	**18/25**	**12/15**	**03/05**	**22/28**	**10/10**	**19/33**	**04/42**	**10/11**	**11/11**	**15/37**
Progeny												
2005_2722	06/10	14/18	22/25	15/15	03/05	22/33	10/12	32/33	04/08	10/20	09/11	15/26

Are successful spawners a small, isolated population or are they part of a metapopulation?

Chinook salmon with clipped adipose fins were present among the salmon sampled in the Okanagan River, indicating that at least some of the fish present in the Okanagan River were strays from hatchery production in the USA. These fish were not included in the genetic analysis. However, it is possible that some fish included in the analysis were unmarked or unrecognized strays from nearby US populations. The presence of these fish in the sample might account for the lack of differentiation in allele frequencies observed between the 2005, and in particular the 2006, Okanagan River samples and the Chinook salmon in the Similkameen River (which enters the Okanagan River downstream of Osoyoos Lake in the US). If strays are present in the population at a frequency high enough to obscure real allele frequency differences between the samples, and if the strays reproduce successfully in the Okanagan River, then the spawning population in the Okanagan River is clearly part of a larger metapopulation, currently connected to nearby populations through gene flow.

However, it is possible that strays are present but not contributing successfully to spawning because they are poorly adapted to spawning conditions in the Okanagan River. Under these circumstances, the possibility exists that the Chinook salmon successfully spawning in the River represent a small isolated population that is not connected to other populations by gene flow. This small population, producing fish from only a few families each year, might represent a genetically distinct remnant population.

The family analysis described in the last section provided a set of ten genotypes that represent successful spawners in the Okanagan River (the six reconstructed parental genotypes and the four unrelated fry genotypes). We can test several predictions based on the hypothesis that successful spawners and their progeny are part of an isolated remnant population with a small effective population size:

1) The remnant population will have different allele frequencies from nearby large Chinook salmon populations due to genetic drift and inbreeding.
2) The remnant population will have lost alleles due to small size and will therefore have a lower level of standardized allelic richness than nearby large Chinook salmon populations.
3) The loss of alleles in the remnant population will have reached a sufficient level to reduce the level of heterozygosity of individual Chinook salmon in the remnant population relative to fish from large populations.

An example of a geographically and temporally isolated Chinook salmon population, although it is not as small as the putative remnant population of the Okanagan River, is the population spawning in the Birkenhead River of the Fraser River drainage. This population has the most distinctive allele frequencies of over 50 populations sampled in the drainage, possesses only one-half the level of allelic richness of the most proximate populations and has a lower level of heterozygosity than all other Fraser Chinook salmon populations (Beacham et al. 2003).

The allele frequencies of the ten successful Okanagan River spawners/progeny were not significantly different from allele frequencies in the nearby Similkameen and Wenatchee rivers (both $P > 0.05$). The allelic richness (standardized to a sample size of 10 fish) and expected heterozygosity values of the ten successful Okanagan genotypes, and the entire 2006 sample of adults, as well as for nearby spawning populations are shown in Table B 5. Neither the successful spawners nor the 2006 Okanagan sample of all adult fish show a reduced level of allelic diversity or expected heterozygosity compared with Chinook salmon of the large Similkameen and Wenatchee River populations.

Table B 5. Levels of allelic richness and heterozygosity in Chinook salmon. The Okanagan River population is represented both by fish known to have successfully spawned/hatched in the River and by the entire 2006 sample of adult fish.

Population	Allelic richness	Heterozygosity (%)
Similkameen River	9.4	84
Wenatchee River	9.3	84
Okanagan spawners/progeny	10.2	85
Okanagan River 2006	9.1	85

The results of this analysis indicate that few if any of the Chinook salmon sampled between 2000 and 2006 in the Canadian portion of the Okanagan River, including successful spawners and their progeny, were members of an isolated remnant population of Chinook salmon. Instead, the fish present in the Canadian portion of the River are part of a much larger metapopulation and are currently receiving, or have recently received, gene flow from nearby larger populations, likely including the Similkameen River population.

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Appendix C. Population Viability Analysis

Canadian Okanagan Chinook Salmon
(*Oncorhynchus tshawytscha*)

Report prepared for

Okanagan Nation Alliance Fisheries Department

Westbank, BC

Prepared by:
R. Sharma

1.0 Introduction

Although escapement data are limited, existing data suggested that Okanagan summer Chinook salmon are a highly depressed component of the extant Upper Columbia River Chinook salmon populations; with fewer than 40 spawners counted since 1965 (COSEWIC 2006). Chinook salmon residing in the Canadian section of the Okanagan River were originally believed to be a members of a continuous population extending downstream to the confluence of the Okanagan with the Columbia River. However, genetic data taken from Chinook salmon in the Canadian Okanagan suggested that this group may be reproductively isolated from lower Okanogan River spawners (Anonymous 2006). Given the recent evidence for their reproductive isolation and imperilled status, a population viability analysis (PVA) is warranted. Since limited data are available specifically for the Canadian portion of the Okanagan population, the PVA constructed must utilize data from the United States component of the upriver summer Chinook salmon populations that spawned above Rock Island Dam in the US as a surrogate (Figure C 1).

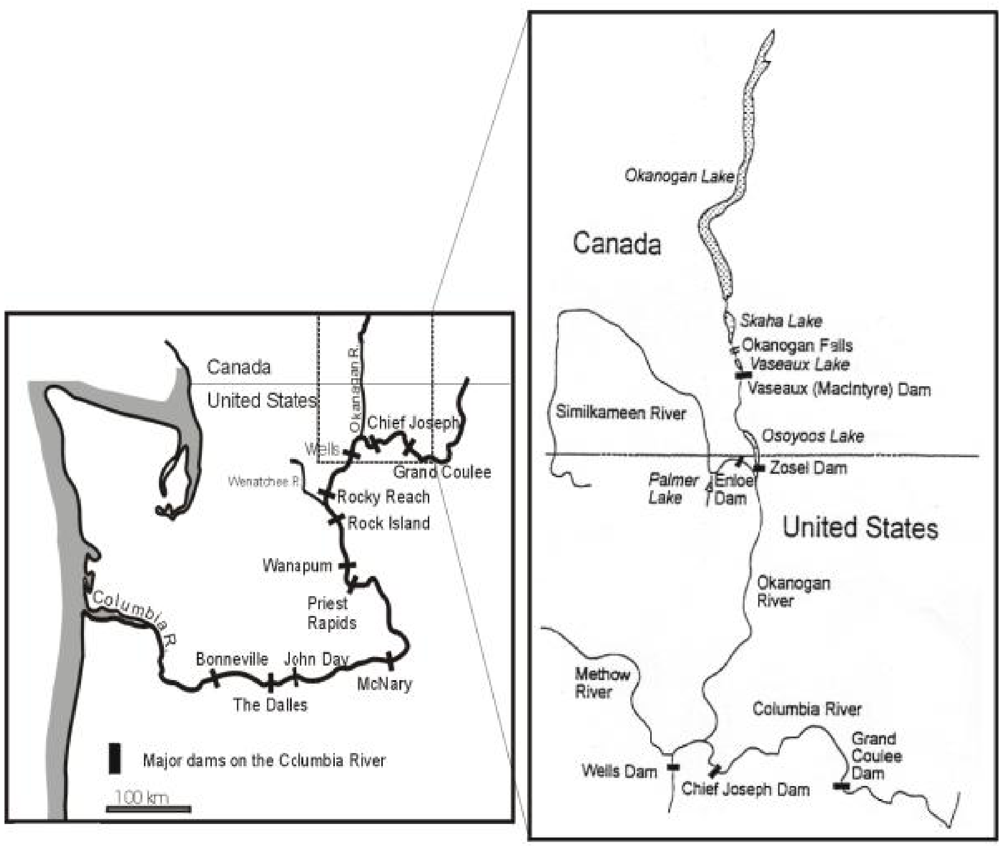

Figure C1. Location of the Okanagan Summer Chinook Population (COSEWIC 2006).

2.0 Materials and Methods used in the PVA

2.1 Population Dynamics Model

The technique used here is similar to PVAs used elsewhere in conservation biology for evaluating extinction risk (e.g., Ellner and Fieberg 2003, Fieberg 2004, Emlen 1995). The Ricker spawner recruit function (Ricker 1974) was utilized as the basis for the model, owing to the observation that Chinook salmon often exhibit over-compensatory mechanisms of recruitment. We modeled these recruitment processes using the log-normal form of the Ricker curve (Hilborn and Walters 1992):

$$\hat{R}_{yr_i} = \alpha O \hat{S}_{yr_{i-1}} e^{-\frac{S_{yr_{i-1}}}{\beta}} e^{N(0,\sigma^2)} \quad (1)$$

$$\hat{R}_{yr_{+1i}} = \hat{R}_{yr_i} \times (SU)_i (1-\hat{\mu}_o)(1-M_i). \quad (2)$$

In these equations α is the density independent parameter that relates spawners to the number of juveniles produced, β is the density dependent parameter, and O is the ocean survival. The parameter R is the ocean recruitment in year i and is a function of S (escapement or spawners) in year i-1, and σ is the process error used in the simulation. Recruits in any subsequent year are a function of Chinook salmon abundance at the previous age and time accounting for natural mortality at that age (SU), fishing mortality in the ocean ($\hat{\mu}_o$), and maturation (M) as shown in equation 2. The last age class is assumed to be age 5 where maturation is 100%.

Spawners in any given year are estimated by equation 2.

$$\hat{S}_{yr_i} = \sum_{i=2}^{5} (\hat{R}_{yr-i})(1-\hat{\mu}_o) M_i (1-\hat{\mu}_t) \quad (3)$$

where S in year i is a function of R from the previous 5 year classes (excluding jacks [year i-1]), and $\hat{\mu}$ is the proportion harvested in ocean (o) and in-river (t) fisheries.

However due to passage mortalities observed in the Columbia River (Petrosky et. al. 2001, Schaller et. al. 1999), two additional parameters are introduced. These parameters account for inter-dam mortality in the juvenile and adults life stages. They change equation 1 and 3 as follows:

$$\hat{R}_{yr_i} = \alpha D_j O_e \hat{S}_{yr_{i-1}} e^{-\frac{S_{yr_{i-1}}}{\beta}} e^{N(0,\sigma^2)} \quad (4)$$

$$\hat{S}_{yr_i} = \sum_{i=2}^{5} (\hat{R}_{yr-i})(1-\hat{\mu}_o) M_i (1-\hat{\mu}_t) D_A \quad (5)$$

In these equations D accounts for hydropower (Dam) based mortality for juveniles (j) and adults (A), and O the mortality after the dams to early ocean survival, and i indicates the age of the Chinook.

2.2 Simulation structure

The structure used in the simulation is shown in Figure 2 below, where equations 3 and 4 were projected from 2007 to 2050. The starting value for the total number of spawners was 50 (*based on maximum estimates by ONA; Howie Wright and DFO; Rick McNicol, Chuck Parkin, and Richard Bailey)*. Two measures of population stability were assessed; i) the running average over four broods of the minimum population size (MPS) in any given set of years for the number of spawners (a measure of population persistence and overall extinction risk, Connell and Sousa 1983, Grimm and Wissel 1997), and ii) to assess population recovery or stability at a point in the future. For our purposes we estimated spawners in calendar year 2050 (POP2050), assuming present day conditions or habitat restoration work with the same variability over the next 45 years. Both stochastic and deterministic parameters were utilized in the model (Table C 1).

Since many of the parameters are confounded, only a few were chosen to be stochastic to illustrate the effect of uncertainty on the population growth rate. The first parameter made stochastic was the stock recruit relationship, which is influenced by process error (σ_e) that affects both the (α) and (β) values. To avoid overemphasizing stochasticity, the (α) and (β) values remained deterministic (Hilborn and Walters 1992, TC-Chinook 2002). Other parameters such as D_j and O_e were confounded, so it was elected to utilize the parameter which was accompanied by better data. We wished to assess differing ocean survival regimes (O_e), and therefore kept that parameter fixed. Finally, it has been demonstrated the population growth rate is most sensitive to changes in early life-cycle mortality (Kereiva et. al. 2000), so survival was kept in later ages as well as maturation rates deterministic, as most of the variability in salmon survival occurs in the year of ocean entry (Peterson and Schwing 2003, Lawson et.al. 2004, Logerwell et. al. 2004, Mueter et. al. 2002).

Table C 1. Stochastic or deterministic Parameters used in simulation; L corresponds to low sensitivity and H to high sensitivity.

Parameters	Structure	Magnitude of Impact on results	Values
alpha(α)	Deterministic	L	136
beta (β)	Deterministic	L	2400
Process Error (Stock recruit, σ_e)	Stochastic	H	0.53
μ_o	Deterministic	L	60%
μ_t	Deterministic	L	18%
D_j	Stochastic	H	44%
σ_{Dj}			0.09
O_e	Deterministic	H	2.5%
D_A	Stochastic	H	68%
σ_{DA}			0.15
M_2	Deterministic	L	4%
M_3	Deterministic	L	26%
M_4	Deterministic	L	72%
M_5	Deterministic	L	100%
Su_2	Deterministic	L	60%
Su_3	Deterministic	L	70%
Su_4	Deterministic	L	80%
Su_5	Deterministic	L	90%

Ten thousand iterations of the simulation model were performed to estimate variance in MPS and population size in 2050 (POP2050) under the following scenarios:

1. baseline conditions, as described by the parameter values in Table C1;
2. decreasing fishing mortality by 50%;
3. halting all fishing mortality;
4. halting fishing mortality and doubling juvenile survival;
5. halting fishing mortality plus doubling juvenile survival and increasing adult survival to 90%; and
6. utilizing hatchery production under baseline conditions with out of basin smolt production varying from a low of 50,000 smolts to a high of 1.75 million smolts (which we term “hatchery augmentation”).

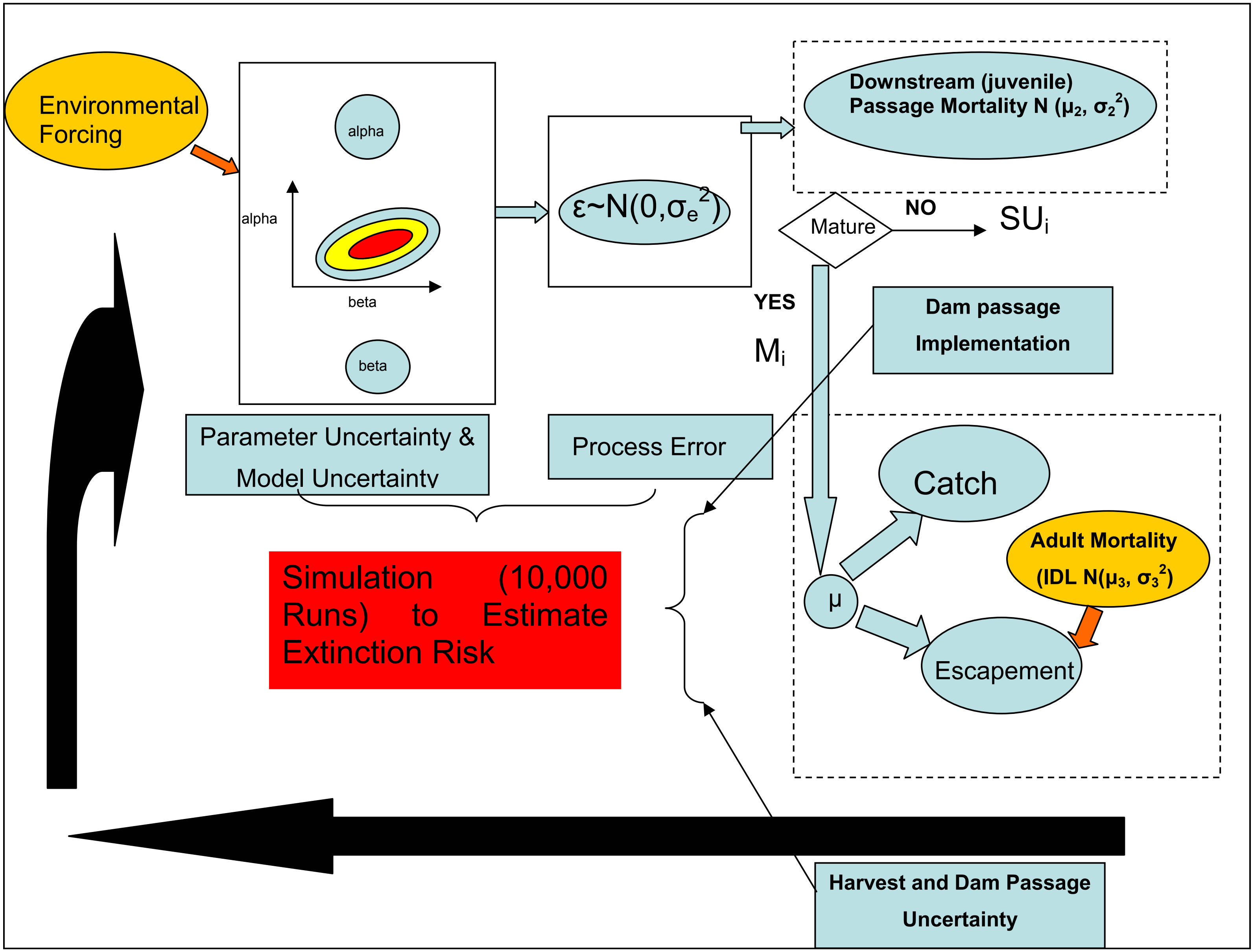

Figure C2. Simulation to assess extinction risk of Okanagan summer Chinook salmon spawning in Canada.

3.0 Parameter Estimation

3.1 Stock Recruit Parameters

Stochasticity was modeled as a function of process error in the stock recruitment relationship that was estimated from juvenile and adult data in US waters (Yuen 2006, Figure C 2) upstream of Rock Island (Figure C 1). Data used to estimate the process error and fit are shown based on Yuen (2006) data (Figure C 3).

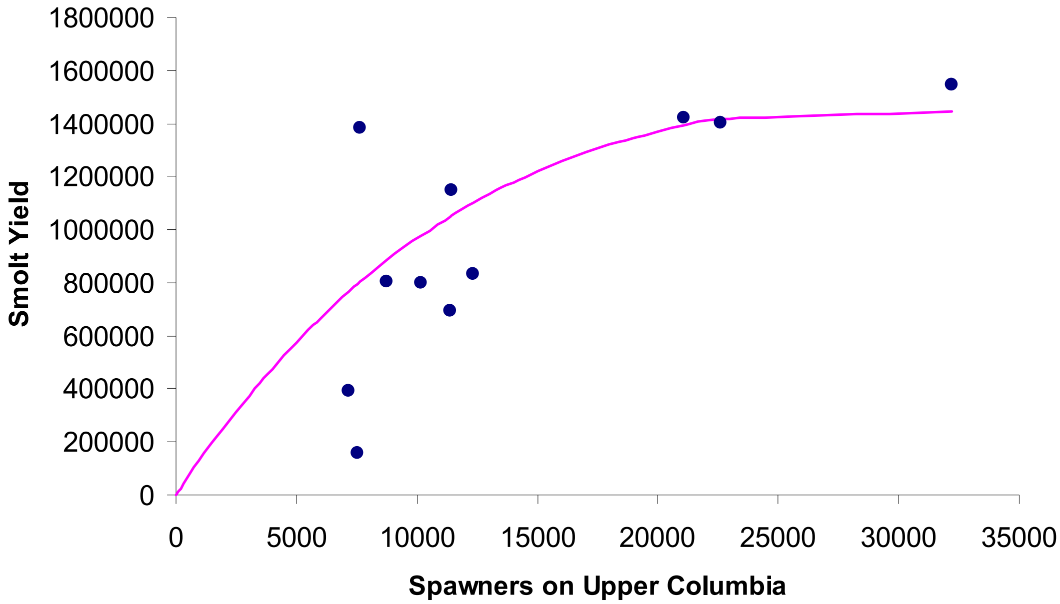

Figure C3. Smolt yield and spawner count estimated for upper Columbia summer Chinook salmon from Yuen (2006).

Based on the fit and using the closed form solution of the lognormal error structure (Hilborn and Mangel 1997) we estimated process error (σ_e=0.53, Table C 1) that was used in our simulations (Figure C 2). Density independent, juvenile recruitment (α) was also based on these data, and yielded an estimate of 136 smolts per spawner (Figure C 4). Ricker (β) values were obtained from the Parken *et al*. (2004) approach to estimate overall equilibrium population size and was set to 2,400.

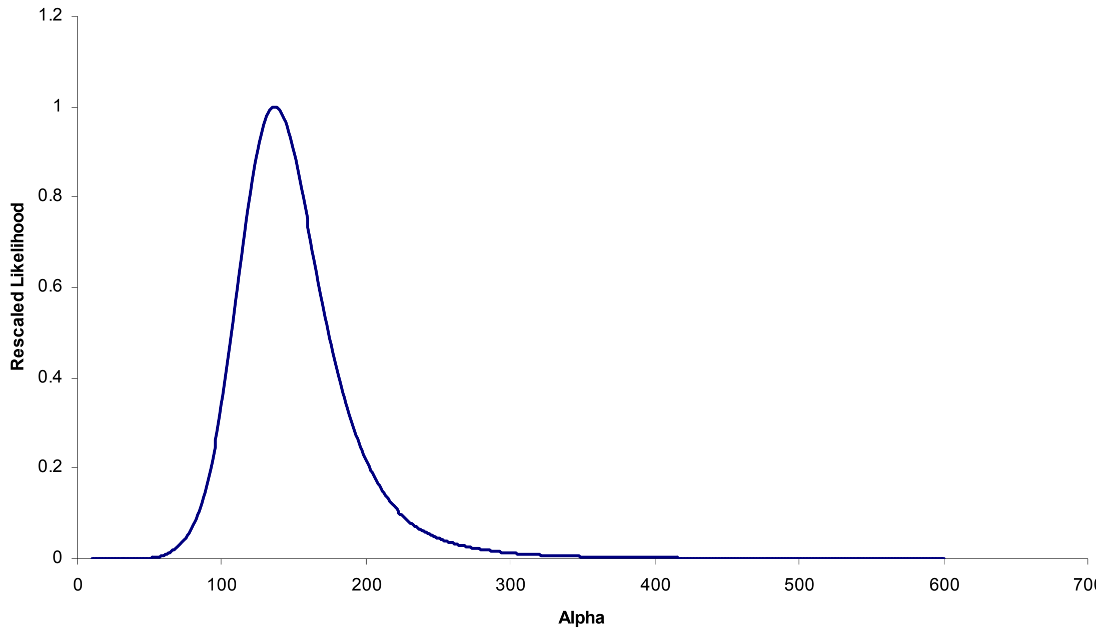

Figure C4. Uncertainty in α. based on a model fit from the data shown in Figure C3.

3.2 Dam Mortality Parameters

Two additional parameters were used to introduce stochasticity; juvenile (D_j) and adult dam (D_A) mortality. Parameters for juvenile mortality were obtained from Passive Integrated Transponder (PIT) Tag data obtained from the Fish Passage Center (http://www.fpc.org/survival/Survival_by_ReachQuery.html). Methods to estimate survival between the first detection site and the series of dams are a function of the Cormack-Jolly-Seber (CJS) release-recapture method outlined in Burnham et. al. 1987 [1]Multiple survival events with their associated variance were estimated to Bonneville dam (the lowermost Columbia River dam; Figure C 1) by assuming independent survival across dams and sites, which is plausible given that the migration times don't overlap (Table C 2, Figure C 5). [1]

[1] This methodology is used to estimate survivals both to and between the dams in the hydro system possessing PIT tag detection capabilities, along with an estimate of collection efficiency at these dams. The CJS method is based on mark release-recapture theory in which the subsequent detection histories on a known number of marked fish re-released at a particular dam is used to estimate the number of fish that past that particular dam alive but undetected. The software program MARK (White and Burnham 1999) was used to perform the survival estimates with the "identity "design matrix and "identity" link function set. The program MARK provides estimates of survival between the tailraces of each detection site. Generating extended multi-dam reach survival estimates requires taking the product of a set of these shorter reach estimates. The associated variance for the extended reach estimate is computed using formulas for propagation of error in products of non-independent estimates (Meyer 1975). Extended reach survival estimates with associated 95% confidence intervals are obtained for each species, and release location and period of interest.

Table C 2. Juvenile downstream survival (Dj) based on PIT tag data from Rock Island Dam to Bonneville Dam

Year	Dj	σ_{Dj}
1999	0.49	0.09
2000	0.52	0.11
2001	0.31	0.03
2002	0.44	0.07

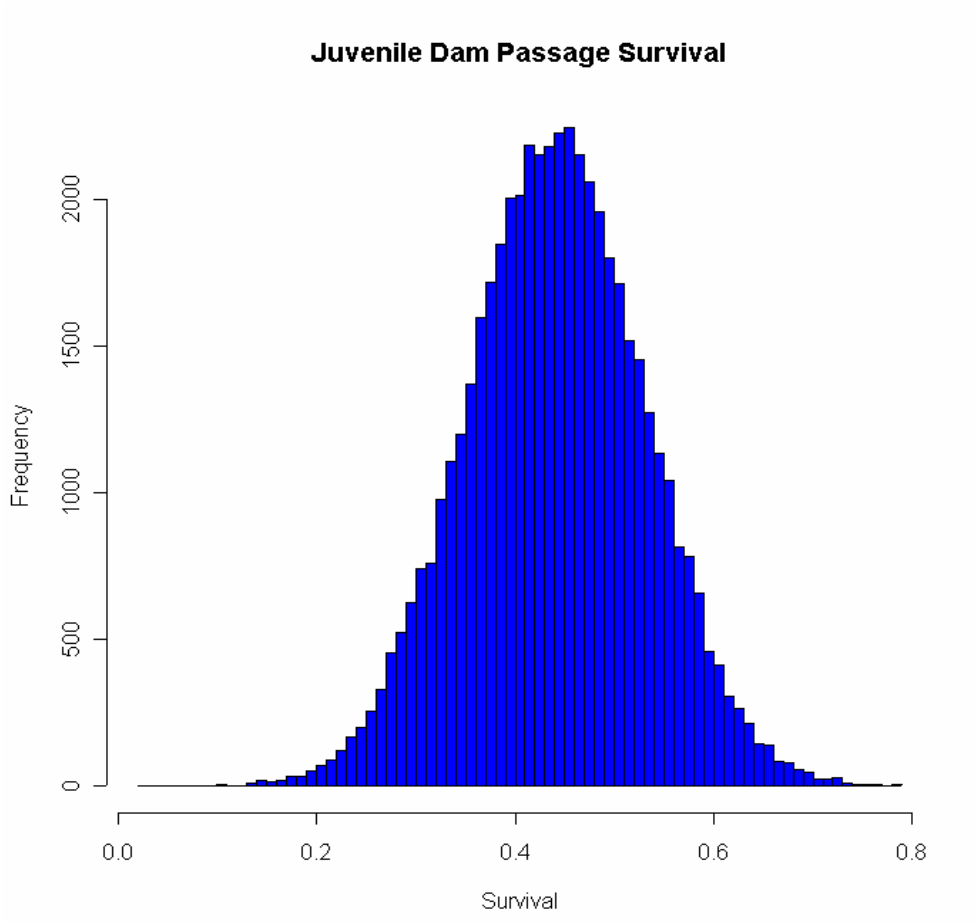

Figure C5. Downstream survival (Dj) from Rock Island Dam to McNary Dam used in simulations.

Adult survival data were obtained from the TC-Chinook Model (TC-Chinook 2005, Figure C 6) that uses inter dam loss values obtained from the Technical Advisory Committee. This technical team conducts stock assessment activities in the Columbia River under the jurisdiction of the *United States Vs Oregon* court case (Lee 1993). Note that the distribution used in Figure C 6 is truncated at 1, as that is the maximum number of fish that would survive, i.e. 100%.

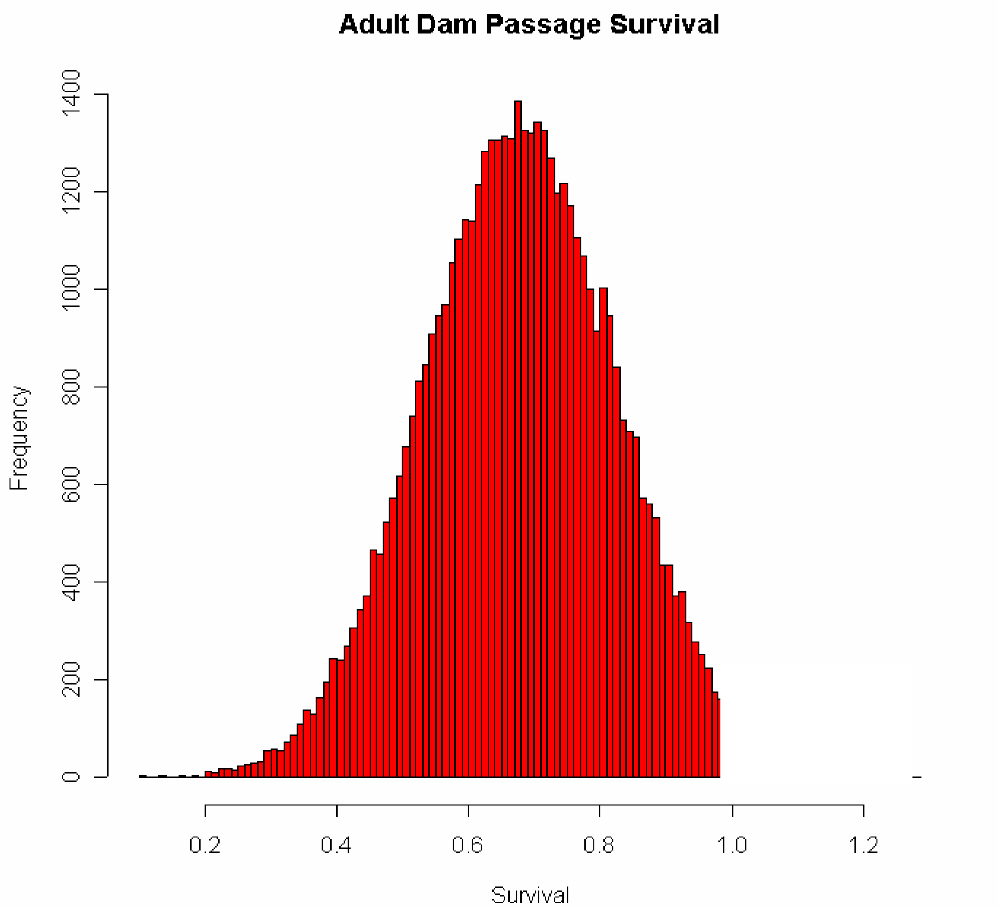

Figure C6. Adult survival (D_A) from Rock Island Dam to McNary Dam used in simulations.

4.0 Deterministic Parameters

4.1 Ocean Survival

CWT data used by the Chinook technical committee (CTC) in the exploitation rate analysis was used to estimate the survival to the ocean for fish tagged from the Wells and Similkameen Hatchery (TC-Chinook 2005). However, we can also estimate survival to Bonneville dam based on PIT tag data, (Table C 2). Unfortunately, we have only one complete brood year with overlapping data (1999) to use in estimating ocean survival, as:

$$O_e = \frac{CWTOC_{1999}}{D_j} = \frac{0.012}{0.49} = 2.5\% \qquad (6)$$

4.2 Harvest rates

Harvest rates were determined from CWT data as well (TC-Chinook 2005) and were averaged for the last 5 years (2000-2004) for ocean and freshwater fisheries; yielding μ_o = 62% and μ_t =18% respectively (Table C 3).

Table C 3. Ocean and Terminal harvest rates based on CWT recoveries for Summer Chinook (from CTC-AWG)

Year	μ_t	μ_o
2000	6%	57%
2001	7%	64%
2002	10%	67%
2003	24%	64%
2004	43%	49%
Mean	**18%**	**60%**

5.0 Maturation and Survival

Maturation and survival rates were based on estimates obtained over all Chinook used in the exploitation rate analysis and model calibration by the CTC (TC-Chinook 2005), and are shown in Table C 1 respectively.

6.0 Results

Based on each of the scenarios mentioned in the simulation structure section we assessed uncertainty in minimum population size (MPS) and population size in 2050 (POP2050). The results are summarized in Figures C 7, c 8 and C 9 and Tables C 4 and C 5 respectively.

Figure C 7 illustrates the potential impacts of changing fishing mortality and harvest. The simulations predict that even if fishing mortality and harvest were zero, Okanagan summer Chinook salmon would be extinct by 2050. A combination of zero fishing mortality and harvest coupled with reductions associated in dam passage would be required to enable persistence.

Figure C 8 illustrates population status under the assumption that current harvest and dam operations remain unchanged, but that hatchery augmentation is exercised. Under this scenario, the population persists at low abundance. This result assumes that hatchery and natural origin adults exhibit equal fitness. Nonetheless, to achieve the optimal escapement goals calculated by Parken et. al (2004) would require the production of approximately 1.75 million smolts (Figure C 9).

Clearly, infinite combinations of harvest, dam, and hatchery management could be explored. We evaluated a scenario where harvest mortality (μ_o and μ_t) was zero, juvenile survival (D_j) was doubled, and adult dam survival and (D_A) values were 90% (Figure 10). These management actions decrease the reliance on supplementation required to ensure persistence (Figure C 11).

Table C 4. Results of the simulations on MPS with standard errors.

Scenario Description	Mean Values	SE
Base MPS	0	0
Half F MPS	0	0
No F MPS	1	1
No F Double DJ MPS	76	12
No F Double DJ max DA MPS	109	17
Base + Supp 50 K MPS	25	5
Base + Supp 100 K MPS	42	9
Base + Supp 150 K MPS	57	13
Base + Supp 200 K MPS	75	18
Base + Supp 1.75M MPS	583	152
Base + Supp 1.75M MPS (half Fit)	295	75

Table C 5. Results of the simulations on POP2050 with standard errors.

Scenario Description	Mean Values	SE
Pop2050 MPS	0	0
Half F Pop2050	0	0
No F Pop 2050	1	1
No F Double DJ Pop2050	662	176
No F Double DJ Max DA Pop2050	1501	285
Base + Supp 50 K Pop2050	104	22
Base + Supp 100 K Pop2050	210	45
Base + Supp 150 K Pop2050	305	65
Base + Supp 200 K Pop2050	412	88
Base + Supp 1.75M Pop2050	3107	657
Base + Supp 1.75M Pop2050 (half Fit)	1547	323

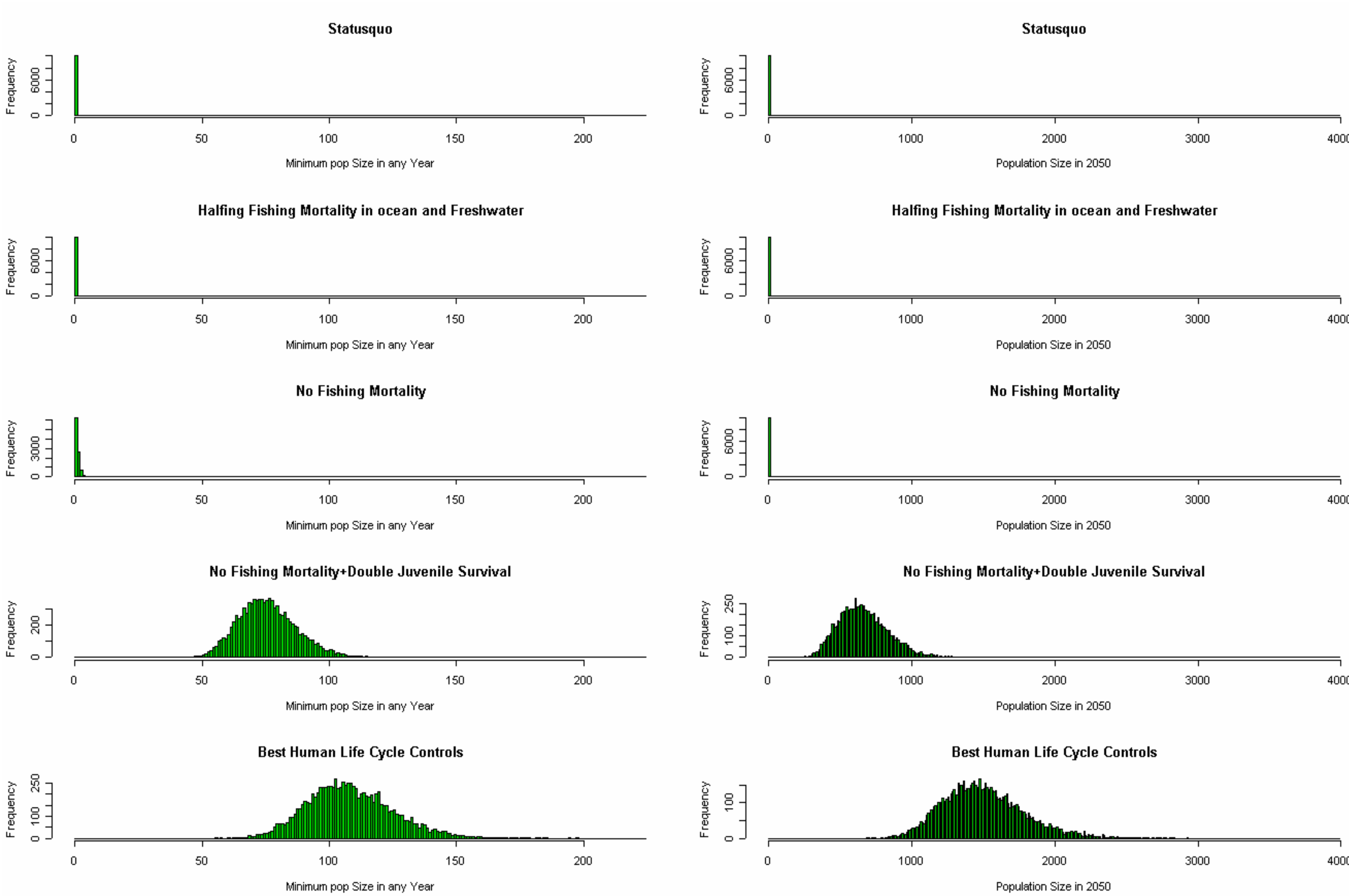

Figure C7. MPS and POP2050 obtained under various management alternatives on harvest and dam operations.

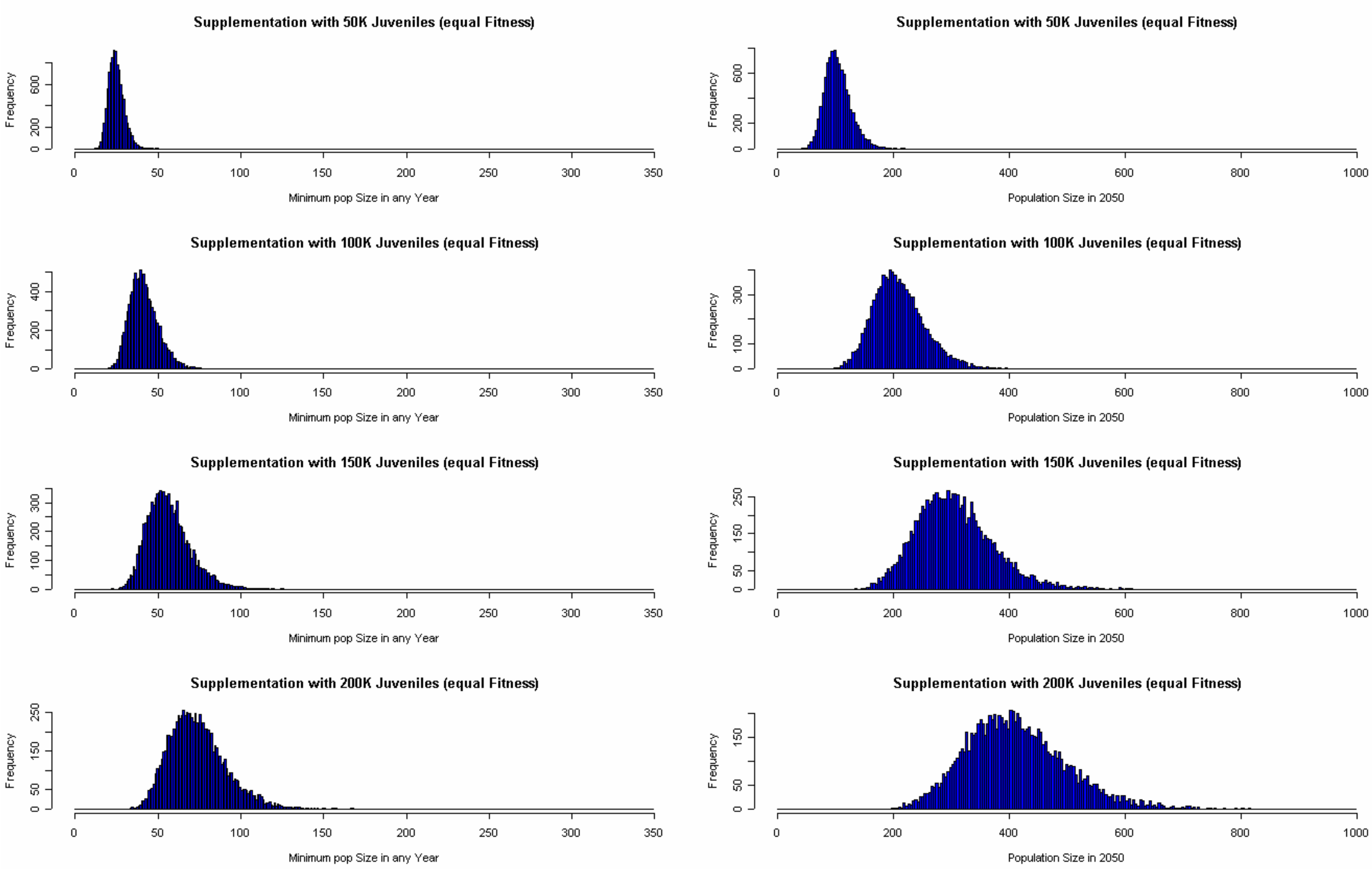

Figure C8. MPS and POP2050 obtained assuming implementation of hatchery augmentation assuming equal fitness of hatchery and natural origin adults.

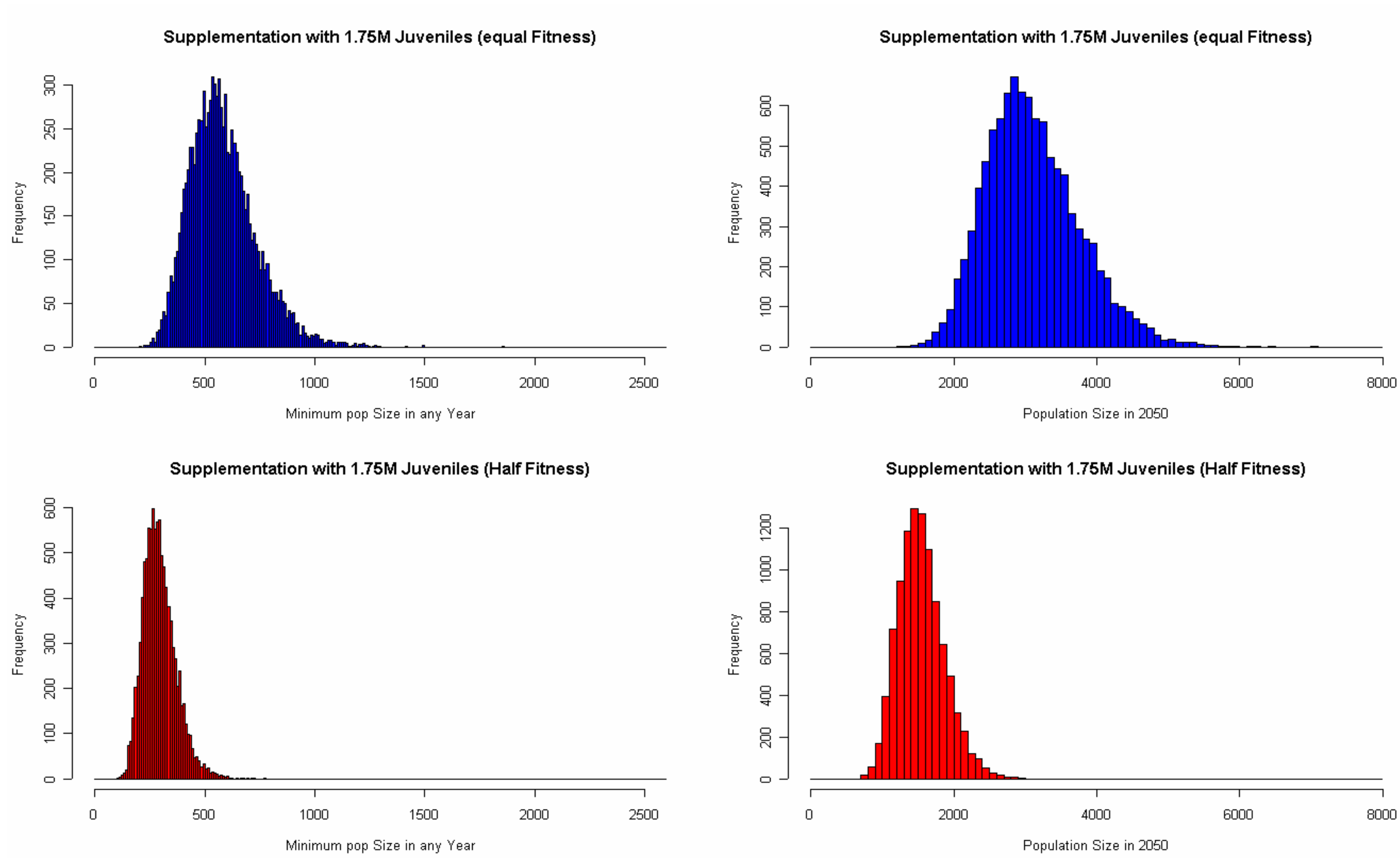

Figure C9. MPS and POP2050 obtained using hatchery augmentation of 1.75 million smolts assuming different levels of fitness.

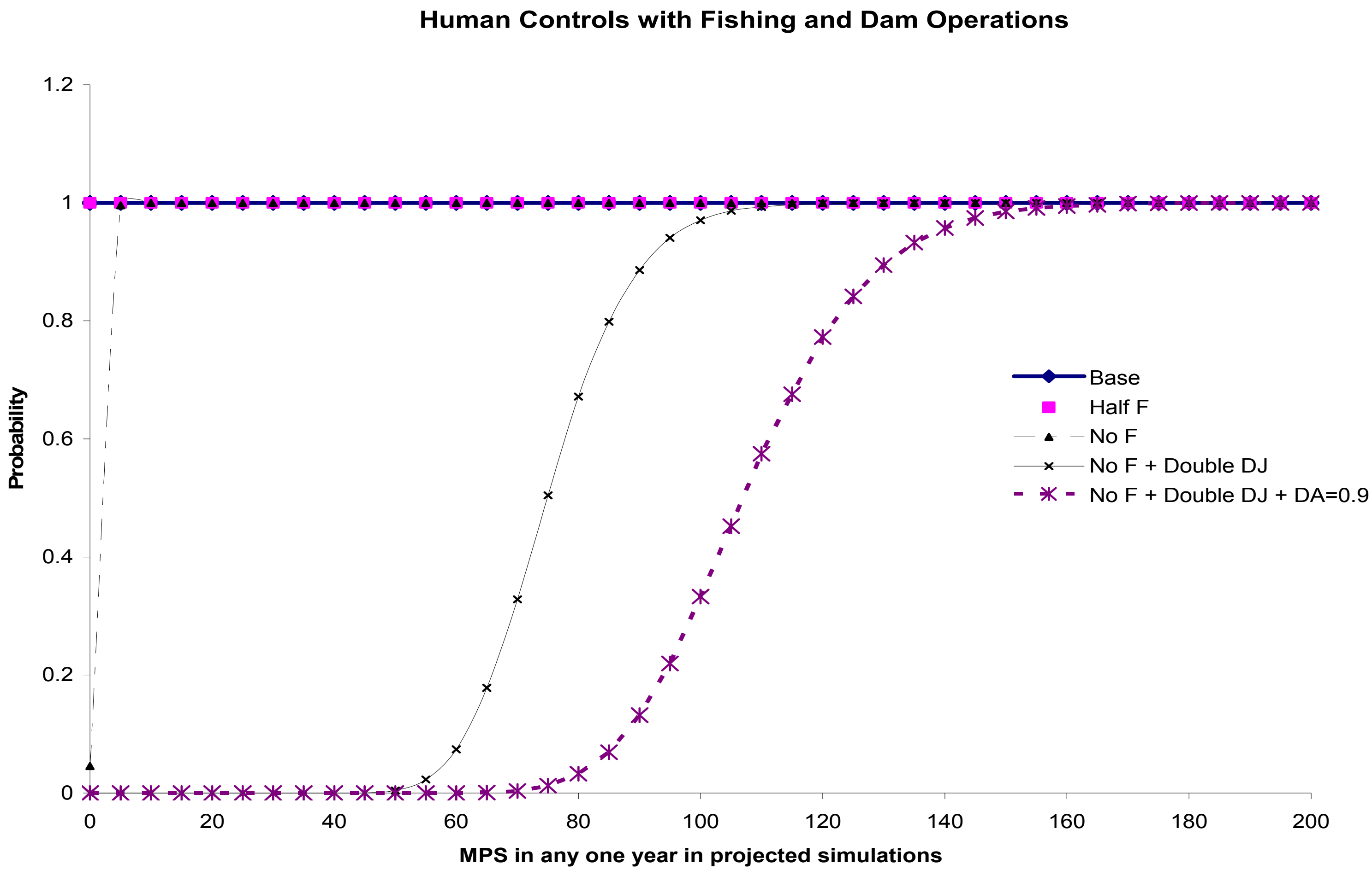

Figure C10. Cumulative distribution displaying the minimum population size (MPS) in any one year over the projected simulation for human controlled scenarios.

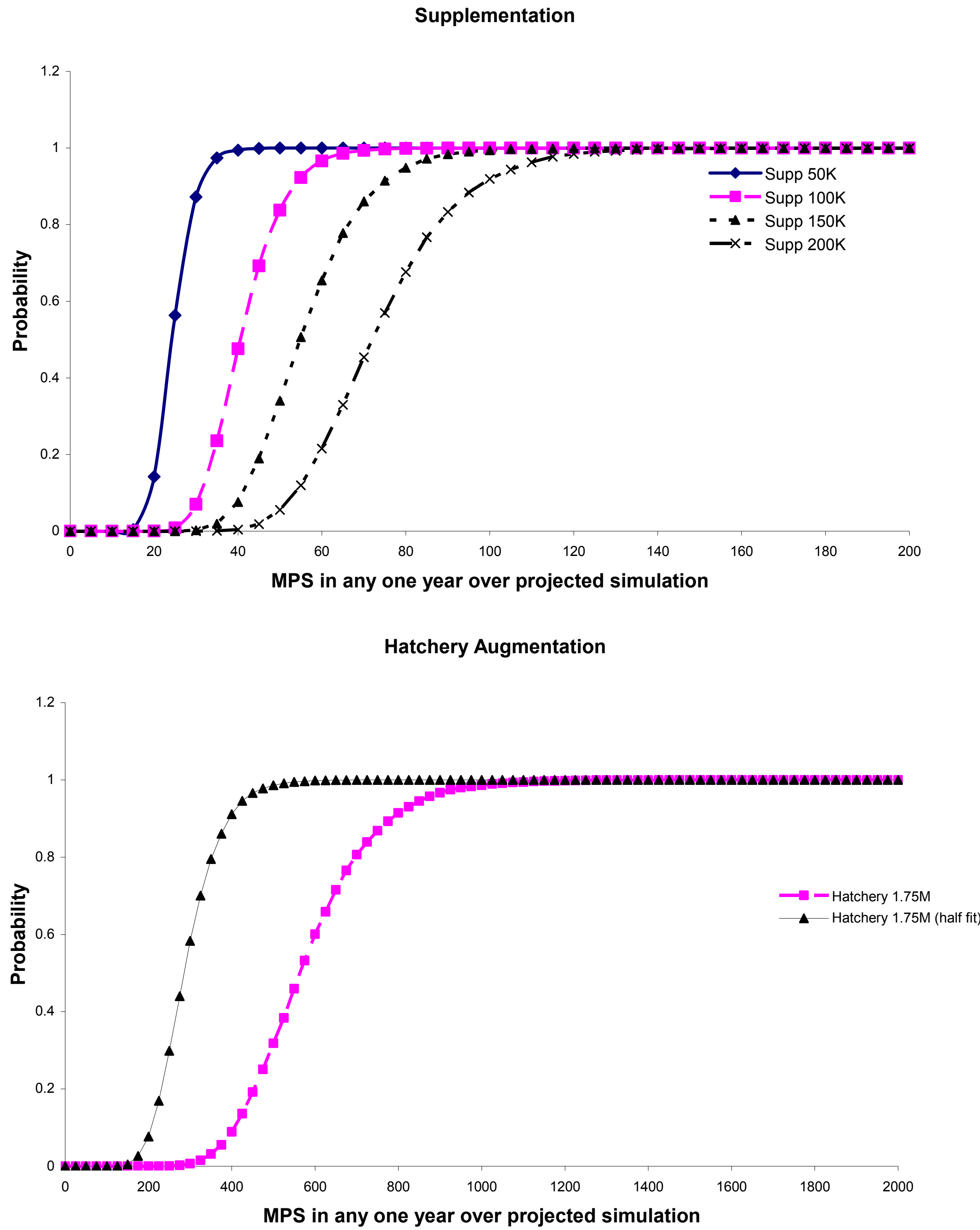

Figure C11. Cumulative distribution displaying the minimum population size (MPS) in any one year over the projected simulation for two hatchery augmentation scenarios.

7.0 Discussion

Our simulations demonstrated that impacts from current operations at hydro-power facilities in the Columbia River and current harvest rates will result in the extirpation of summer Chinook salmon in the Canadian range of the Okanagan. Notably, the current scenario (i.e. the base) simulated here included some of the best ocean survival values observed in the recent past (e.g., the 1998 brood exhibited a four fold increase over the last decade, but the 1999 brood was about half of the 1998 brood survival based on Coded Wire Tags). However, as demonstrated by the simulations, even the best ocean conditions in the recent past are incapable of offsetting mortality imposed on juvenile Chinook salmon resulting from passage through the Columbia River hydro-power system.

Even a cessation of fishing was incapable of preventing extinction. Scenarios with zero fishing mortality were marked by low adult returns. Only decreased fishing mortality in combination with a substantial increase in juvenile survival values (i.e., reductions in hydro-power related juvenile mortality) increased persistence probabilities. The conclusions obtained in this report are similar to those given for the Snake River Chinook salmon and Steelhead populations (Schaller *et al.* (1999), Petrosky *et al.* (2001) and Yuen and Sharma (2005)). This is not surprising given that the upper Okanagan is impacted by the same dam passage obstacles; requiring juveniles and adults to navigate nine dams to reach the Okanagan versus eight for Snake River populations. Even if juvenile survival through each of the hydro-power facilities was 90%, the overall survival to the Bonneville Dam (the lowermost Columbia River dam) from the cumulative impact of nine dams would equal only 38% overall. This is roughly what we obtained in our simulations, with survival rates of 44% from Rock Island Dam to Bonneville Dam, based on PIT tag data (Table C 2). The calculated 44% survival actually resulted in an individual survival rate of 91% for each of the nine dams.

It is unlikely that juvenile survival through the hydro-power system will improve, and that ocean fisheries catch will decline (prior to 2002, summer Chinook in-river fisheries were non-existent). Thus, it appears unlikely that the natural population will persist without aggressive management intervention (Figure C 7 and C 10). One alternative, modeled here, is the use of hatchery production. However, achieving escapement goals would require hatchery production on the order of 1.75 million smolts annually; far in excess of what could be supported by the collection and use of natural origin adults in broodstock. Thus, to implement a supplementation program (i.e., based on natural-origin local broodstock) would likely require centuries of effort under baseline conditions. A program of this type would be accompanied by substantial risks associated with the extinction of the natural population (e.g., the time required to achieve production goals might exceed the estimated time to extinction for the population) and might be compromised in the long-term by the potential presence of inbreeding or loss of genetic diversity that may have occurred as a result of bottlenecks within the natural population. An alternative approach, for example utilizing adults from the US portion of the Okanagan River, would reduce the period required to achieve production goals, but would compromise the potentially unique genetic composition observed for the summer Chinook salmon residing in the Canadian portion of the Okanagan River (COSEWIC 2006). Either type of program is also accompanied by substantial uncertainty regarding the long-term impacts of hatchery production on the productivity of natural populations (e.g., as summarized in ISRP 2005). Nonetheless, it has been demonstrated that hatchery production can yield a significant survival advantage in the early life-cycle relative to natural production, and that this survival advantage can translate into a significant increase in adult abundance (Rinne et al. 1986 and Johnson and Jensen

1991). Likewise, for imperilled populations, hatcheries can serve as a vehicle to maintain or increase genetic variation (Hedrick et al. 1994) and potentially contribute to life-history diversity (Franklin 1980) that might be lost in the absence of intervention.

In short, if the limitations of this analysis (see Limitations below) do not render its conclusions ineffectual, managers are faced with the decision to remedy the threats contributing to the decline of Okanagan summer Chinook salmon (i.e., passage mortality through the Columbia River hydro-power system and harvest mortality), pursue management alternatives to offset mortality (i.e., hatchery production), or allow the extinction of a potentially unique and irreplaceable population. Each alternative is accompanied by substantial political, socio-economic, and ecological challenges and consequences.

8.0 Limitations

Given the paucity of data relevant to the stock of interest, our analysis relied on parameters derived from a neighbouring US summer Chinook salmon population. Despite the fact that the US population offers the nearest approximation for which certain parameters can be derived, it still assumed that these values are representative of Canadian Okanagan summer Chinook salmon; which may be an erroneous assumption. In addition Yuen (2006) noted that some of the juvenile data used in his analyses required expansion factors that might positively bias his conclusions. Thus, the derived estimates of productivity used in this report may likewise be overestimated. Regardless, even if the productivity estimate used in this report (136 smolts per spawner) is positively biased, our analysis suggested that the population is likely to become extinct. So, even if realized productivity is lower, the overall conclusions derived from our analysis are unlikely to change. The same is true for ocean survival, as it is unlikely, based on the period of observation, that ocean survival will improve beyond conditions experienced in the 1990's and early 2000 (Peterson and Schwing 2003). The good conditions in those years were a function of good ocean conditions and northern euphausiid abundance in waters off the mouth of the Columbia...

In addition, in-river data on US Okanagan stocks indicated that the fish might mature at later ages (primarily age 5 and 6), and using average maturation rates across all indicator tag Chinook used by the Chinook Technical Committee (as done in out analysis) might provide a more optimistic result. If we did use the later maturation schedule, the overall spawners returning would probably be lower than currently modeled (as the fish would face another year of natural mortality in the ocean, versus returning at younger ages to spawn). This in turn, would increase the overall extinction risk in our simulations.

9.0 References

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