Risk, Benefits, and Uncertainties Associated with Using Hatchery Supplementation to Recover the Cheakamus River Steelhead Population, and Rules to Assess Recovery Status

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Prepared For:
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February 23, 2006

Hatchery supplementation of the Cheakamus River steelhead population is currently being considered to mitigate the effects of the CN spill. Hatchery supplementation should only be considered if: 1) future returns will be significantly reduced because of the spill, and the projected time for natural recovery to occur is long; 2) hatchery supplementation will increase the rate of recovery; and 3) supplementation does not pose undo genetic or demographic risks to the wild population. This document provides a summary of the impacts of the spill on Cheakamus steelhead, reviews the factors influencing the rate of recovery, and discuses the benefits, risks, and uncertainties associated with hatchery supplementation (Part I). It is in the interest of all parties to develop a set of 'rules' by which the recovery status of the population can be assessed. Part II of this document provides some suggestions for recovery rules for the Cheakamus steelhead population and discusses them in the context of hatchery supplementation. I recommend that hatchery supplementation be used to help recover the Cheakamus steelhead population. Part III provides a brief rationale for this recommendation.

Part I: Benefits and Risks of Using Hatchery Supplementation to Help Recover the Cheakamus River Steelhead Population

Summary of Spill Impact on Steelhead

The mortality rate for young-of-year (YoY) steelhead resulting from the CN spill was estimated to be 97-98% based on a comparison of backpack electrofishing catch rates before and after the spill, and 90% based on a comparison of post-spill densities in 2005 with densities measured in previous years (McCubbing et al. 2006). No parr were captured by electrofishing following the spill in 2005 but parr were captured by backpack electrofishing before the spill in 2005 and in previous years. The additional mortality of YoY due to the spill is considered to be very reliable, but the parr estimate is more uncertain because this life stage is not well represented in habitats that can be sampled by backpack electrofishing. Steelhead parr are known to utilize mainstem habitats and do not make extensive use of relatively isolated backwater habitats like coho, and therefore were likely fully vulnerable to the toxic conditions in the mainstem. It is reasonable to assume that mortality on parr was similar in scale to that of YoY as the data suggest. However, it has been hypothesized that juveniles produced in the Cheakamus could have dispersed into the Squamish and its lower tributaries prior to the spill as part of their normal life history strategy. This hypothesis is not consistent with changes in parr catches before and after the spill but cannot be definitively refuted.

Korman et al. (2005) estimated that the recovery time for the adult steelhead population in the Cheakamus River is between 10 and 50 yrs (Fig. 1, Table 1). The range in recovery time is very large because of the considerable uncertainty in freshwater productivity (smolts per spawner at low spawner abundance) and marine survival rates. The recovery model assumes equal (90%) mortality for all life stages (YoY, 1+ to 3+parr) and uses the relatively well-defined proportions of the number of fish departing at different freshwater and at-sea ages (Van Dischoeck 2002) to predict future adult returns. The projection produces an abundance pattern similar to what is seen for some Fraser River sockeye populations, with dominant, sub-dominant, and weak-cycle lines. This pattern is caused by the high mortality applied to 3 consecutive brood years (2003, 2004, 2005) whose juveniles were in the river at the time of the spill (Table 1). Predicted returns in 2008 (sub-dominant 'line' or 'cycle') are estimated to be about ¼ of the escapement estimated in 2005 of 380 fish. Escapement in 2009 and 2010 (weak-cycle) is projected to very low (<50 fish). The cyclical pattern persists at about a 5 yr recurrence interval (e.g. 2014/2015). The persistence of cycles over the next few decades depends on the extent of overlap in generations (which is relatively well known), and the overall stock productivity, which is the product of smolts/spawner and marine survival rate (not well known).

Recovery rates depend on stock productivity, the extent of overlap in generations, and the strength of broods not affected by the CN spill. It is worth noting that a large flood in the fall of 2003 may have had a severe impact on smolt production from brood years 2002-2003, and a moderate impact on the 2001 brood (C. Melville, Instream Fisheries Research, pers. comm.). The number of steelhead caught in Rotary Screw Traps in 2004 and 2005 (9 and 21 smolts, respectively) was much lower than catches between 2000-2003 (average of 281 smolts; Melville and McCubbing 2005, C. Melville, unpublished data). It is uncertain whether this change was due to high flood-induced mortality of steelhead juveniles, or the flood-induced reconfiguration of the trapping site. Steelhead smolts numbers from the upper paradise side channel, where the efficiency of trapping was not influenced by the flood, dropped by 87% after the flood (2001-2003 vs. and 2004-2005). We should see the effects of the 2003 flood on returning adults beginning in 2006 (due to loss of 3 and 4 yr smolts from the 2001 brood), with the majority of impact occurring in 2007. Note that both the CN spill and the 2003 flood will influence returns in 2008. If both the 2003 flood and CN spill are as severe as the juvenile data suggest, there will be little production from four consecutive brood years that spawned in 2002 through 2005.

Reduced future returns and the presence of weak lines create a series of potential risks to the sustainability of the Cheakamus population. Predation rates on the low numbers of outmigrating juveniles could be higher than normal rates because of depensatory mortality mechanisms. Birds, seals, and other juvenile and smolt salmon predators may increase foraging time to attain the same levels of consumption as in normal steelhead abundance years, thereby increasing the mortality rate on the remaining fish. The low numbers of fish on weak-cycles could lead to inbreeding depression and loss of rare alleles with potential reductions in fitness and evolutionary potential if the stock remains at low abundance over many generations. Lower returns will reduce angling catch per effort resulting in a decrease in angler satisfaction and angler effort, with subsequent economic impacts.

Objectives, Benefits, Risks, and Uncertainties in Steelhead Supplementation

A steelhead supplementation program is currently being evaluated to assist in recovering the Cheakamus River steelhead population (G. Wilson, BC MWLAP). As with any management action, it is very important to be clear about the objectives of the program, which presumably, should focus around the impacts caused by the CN spill. Below I list four possible objectives:

Objective 1: Increase the Overall Rate of Wild Steelhead Recovery

Objective 2: Enhance Abundance of Weak Lines Created by the Spill

Objective 3: Maintain Genetic Diversity and Evolutionary Potential

Objective 4: Maintain or Enhance Fishing Opportunities

These objectives are not completely independent. Increasing the rate of recovery will require an increase in the abundance of weak lines. Higher abundance during these periods will increase/maintain genetic diversity and also improve fishing opportunities. It is probably worthwhile for the steering and technical committees to define and prioritize the objectives of a supplementation program, as each objective may imply a different approach to supplementation.

Supplementation can increase the overall rate of recovery of the wild population if:

1. The product of the smolts produced per spawner in the hatchery, and the survival rate from release to return, exceeds the spawner-to-return rate in the wild; and

2. Hatchery-origin fish that spawn in the wild produce viable progeny that return to spawn.

Rates of production in the hatchery are well known. Release-to-return rates, while relatively easy to measure in some systems, have been poorly documented. The production derived from hatchery-origin fish that spawn in the wild has not been documented. This is understandable because the molecular genetic tools to evaluate this production have only recently been developed.

Given good hatchery practices and release strategies, and the production of a significant number of smolts, it is likely that low steelhead returns due to the spill can be offset in the short term by returns of hatchery-origin spawners. The large uncertainty lies in the ability of supplementation to increase the abundance of wild returns in future generations. The importance of this uncertainty depends on the priority of recovery objectives. Do we simply want to improve steelhead escapement after the spill (objective 4), or do we want to improve the escapement of wild spawners (objective 1)? Put another way, do we simply want more steelhead in the Cheakamus, or do we want more 'Cheakamus steelhead'?

There are at least two operational alternatives for increasing the rate of recovery via supplementation. Wild fish returning during the dominant cycles (e.g. 2006/2007) could be used to produce smolts to be released in 2007/2008 that would in turn produce returns in 2009-2011. After 2007 (or 2006, depending on impact of 2003 flood), it is unlikely that there will be enough fish for broodstock collection until 2009 at which time most of the returns will probably be of hatchery origin. One then has to decide whether to use ('recycle') some of these hatchery-origin fish for broodstock to help fill in the upcoming weak-cycle. This difficulty could potentially be overcome by taking wild parr or smolts for broodstock in early years of the supplementation program. Note that a wild-only broodstock policy will not provide as quick a recovery as a mixed-origin one, but the risks of outbreeding depression (by rearing in a hatchery environment) will be lower (Ford 2002, Korman and Ward, 2005).

If the steering/technical committees puts their priorities on increasing abundance of wild fish as quickly as possible and eliminating weak cycles, the likely best policy is to take broodstock in all years when there is 'sufficient' escapement (to be defined), even if some of those broodstock are hatchery-origin fish. If the priority is to minimize genetic effects of the hatchery, a wild-only broodstock policy, taking fish from only dominant lines, perhaps supplemented with juvenile broodstock, is likely the best approach. The objective of a wild-only broodstock program is to minimize outbreeding depression by not using hatchery-origin fish, as well as to minimize the risk of inbreeding depression that would occur in the wild due to very low numbers of spawners.

Whatever decision on supplementation is made, the outcome and efficacy of the effort is **highly uncertain**. There are many plausible hypotheses that do not support the use of supplementation to recover the Cheakamus steelhead population. We could have overestimated the extent of the spill impact if steelhead parr did not incur the same extent of mortality that was reliably estimated for young-of-year. In this case there would be no need for supplementation and releasing hatchery fish could have negative impacts on the wild stock (say due to residualization of released smolts). The wild stock productivity could be much higher than the values used in the model projections. In this case, even if there was a significant reduction in returns due to the spill from those broods that were in the river at the time of the spill, the initial low returns would be nearly sufficient to fully seed the available habitat, leading to a complete recovery by the following generation. The cradle-to-grave 'productivity' of the hatchery is also uncertain, as the release-to-return rate could be lower than expected. The productivity of hatchery-origin fish that spawn in the wild is completely unknown, but there are few (if any) cases that show an increase in wild-spawner abundance due to a hatchery operation. Hatchery supplementation could have negative genetic consequences for the wild stock (see Bradford and Wood 2004 for a review).

If steelhead supplementation is undertaken on the Cheakamus, it is imperative that it be viewed as a **highly experimental** option. With financial support from CN, coupled with the relatively intense monitoring network already supported by BC Hydro, we have an unprecedented opportunity to actually determine the efficacy of using hatcheries to restore weak stocks, a topic of much debate among and within fisheries scientists and anglers. Release-to-return rates could be accurately assessed with data provided by the adult steelhead monitoring program currently funded by BC Hydro (Korman et al. 2005). The ratio of hatchery (adipose-clipped) to wild fish (no clips) seen by divers would be multiplied by the total escapement estimate to determine wild and hatchery-origin returns. It will likely only be possible to reliably determine the origin of a fraction (25%) of all steelhead seen by divers. An independent, and probably more reliable ratio of wild and hatchery-origin fish could be determined from a census of catches from a volunteer angling program. Tracking the numbers of smaller adipose-clipped steelhead over time, which will be identified during swim counts, could be used to assess the extent of residualization. Release strategies could be modified to reduce the rate of residualization, or alternatively, residuals could be removed by directed angling, trapping, or boat electrofishing.

Uncertainties in the productivity of hatchery-origin fish that spawn in the wild would be addressed using molecular genetic markers. DNA samples would be taken from all hatchery-spawned fish and a large sub-sample of wild spawners. By sampling fish in subsequent generations, whether they come from anglers, fry sampling, or from outgoing smolts caught in the rotary screw traps, it will be possible to determine whether each fish had a parent, grandparent, etc., that was spawned in the hatchery. Over time this information will provide a reliable answer to the question of whether hatchery-origin fish that spawn in the wild produce viable progeny that return to spawn. Radio telemetry of wild and hatchery-origin returns conducted as part of the snorkel survey program could also be used to evaluate the potential for interbreeding.

Current estimates of steelhead smolt run size in the mainstem Cheakamus at the rotary screw traps are very uncertain because both the numbers of steelhead smolts (probably 3,000-10,000 smolts), and the efficiency of the traps for catching steelhead smolts, are low (Melville and McCubbing, 2005). Twenty spawners taken for broodstock would produce approximately 20,000 smolts. The proportion of the total smolt release that is caught in the trap would provide an estimate of the trap efficiency. In conjunction with counts of wild smolts and the assumption that hatchery- and wild-origin smolts are equally vulnerable, the total run size for the wild population could then be determined. A small fraction of hatchery smolts would be acoustically tagged to estimate the proportion of released fish migrating past the trap, which is required to estimate trap efficiency. By staggering the release of hatchery smolts over time intervals and under different river conditions during the release period, it will be possible to develop a predictive relationship to estimate trap efficiency, and hence wild run size, in years when hatchery smolts are not released. The acoustic tagging data will also be important to evaluate the extent of residualization and how it is influenced by release location and timing. In short, the release of hatchery-produced steelhead will provide a much more reliable estimate of wild steelhead smolt run size, which is a critical parameter to evaluate the effects of the hatchery, as well as overall recovery of the stock. Reliable outmigrant run size estimates can be used with the escapement data to estimate parameters of a spawner-to-smolt stock-recruitment curve. Such a relationship would be invaluable if we had it today, as it determines the rate of stock recovery. The likely strong contrast in spawners in upcoming years created by the spill, while unfortunate from a resource perspective, provides the ideal conditions to estimate stock-recruitment parameters.

Catch of returning steelhead by anglers is an integral component of the supplementation monitoring program proposed here. We need to catch returning spawners for radio tagging, and collection of DNA samples. Records of the ratio of hatchery and wild fish caught by anglers would supplement the ratio estimated by swim counts. Any potential bias (e.g. overreporting of hatchery origin fish by anglers that are proponents of a supplementation program) can be determined (and corrected) via DNA analysis of the samples they provide. If the river is closed to the general public because of concerns about catch and release mortality on stock recovery, a volunteer scientific angling program will be required to provide essential data to evaluate the efficacy of the hatchery program. Extensive radio telemetry work conducted on Vedder-Chilliwack steelhead shows that catch-and-release mortality rates are less than 1.6-5.8% (Nelson et al. 2005). Note that these estimates include normal pre-spawn mortality as well as the additional handling stress of applying both radio and Floy tags. A rate of less than 2% is probably likely when these factors, and tag regurgitation rates, are taken into account. This estimate is consistent with mortality estimates for over 100 steelhead radio tagged in the Cheakamus River (Korman et al. 2005). These studies strongly suggest that the additional mortality associated with sampling fish by angling is not significant enough to impact the rate of recovery.

A supplementation program to recover steelhead on the Cheakamus River, combined with the intensive monitoring described above, provides an unprecedented scientific opportunity to improve our understanding about the benefits and risks of hatchery supplementation. The monitoring program is critical to evaluate the effectiveness of supplementation for recovery of the Cheakamus steelhead population.

Table 1. Estimated escapement between 1996 and 2005 (1998 value is mean of 1997 and 1999 estimates) and predicted smolt production (total and by smolt age) based on assumed spawner-to-smolt stock-recruitment parameters of 47 smolts/spawner and a carrying capacity of 8,000 smolts. Smolt numbers highlighted in yellow show brood production potentially influenced by the 2003 flood (no flood mortality factor was applied). Smolt numbers highlighted in bold italics show brood production influenced by the CN spill and are computed by applying a 90% mortality rate to the production predicted by the stock-recruitment relationship.

Brood Yr	Escapement	Total Smolts	Smolts by Age		
			2	**3**	**4**
1996	291	8000	1040	6160	800
1997	117	5499	715	4234	550
1998	159	7473	971	5754	747
1999	201	8000	1040	6160	800
2000	107	5029	654	3872	503
2001	331	8000	1040	6160	800
2002	501	8000	1040	6160	***80***
2003	374	8000	1040	***616***	***80***
2004	375	8000	***104***	***616***	***80***
2005	380	8000	***104***	***616***	***80***

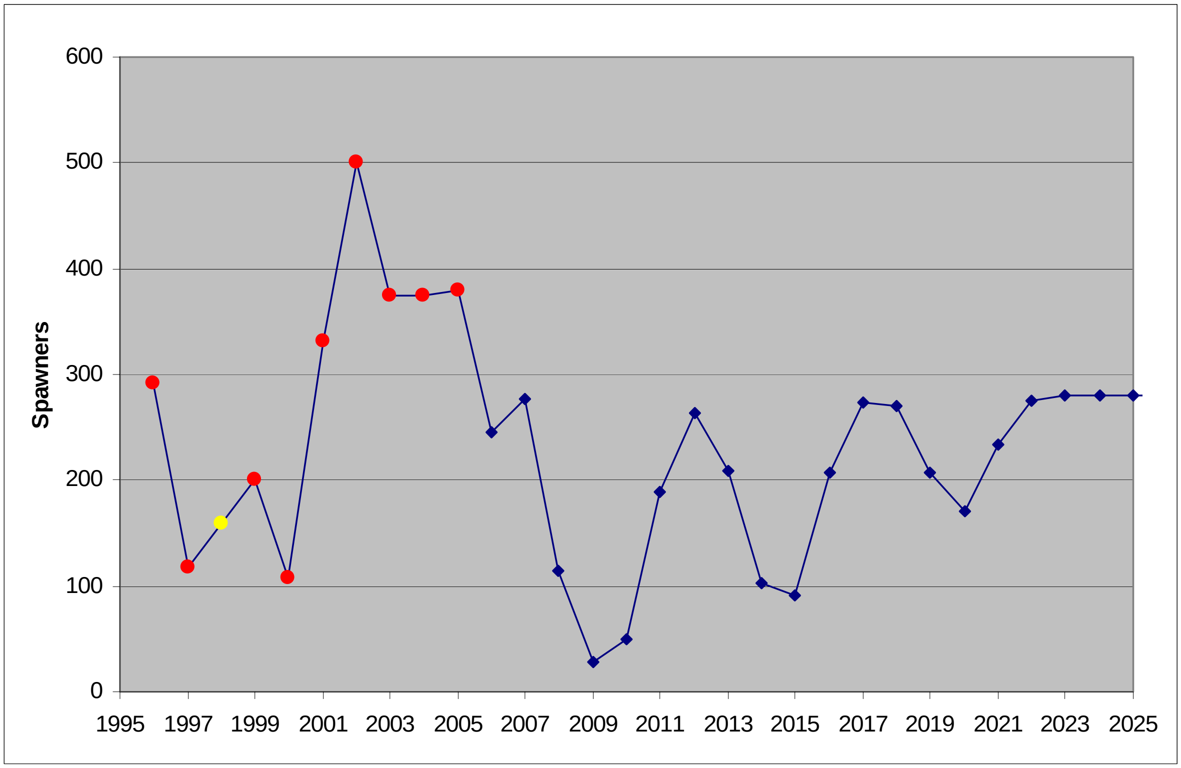

Figure 1. Historical (red circles) and projected (blue circles) steelhead escapement to the Cheakamus River under an intermediate productivity scenario (smolts/spawner = 47, marine survival = 3.5%) and an assumed spill mortality rate of 90% for all freshwater rearing life stages. Escapement in 1998 was not evaluated; the yellow point is the average of adjacent years.

Part II: How do you Know When Enough is Enough? Setting Recovery Targets for Cheakamus Steelhead With and Without Hatchery Supplementation

The problem of setting recovery targets for fish populations is unfortunately not a new one. There is much that can be gleaned from approaches taken in other systems. The recovery objectives for Cultus Lake Sockeye have potential utility for evaluating steelhead recovery in the Cheakamus River. These objectives relate to population size (objective 1) and population growth rate (objective 2) with specific rules to ensure that hatchery supplementation is not used as a substitute for recovering the wild population (Bradford and Wood 2004). The first Cultus Lake Sockeye objective is to:

> "Ensure the genetic integrity of the population by exceeding a four-year arithmetic mean of 1,000 successful adult spawners with no fewer than 500 successful adult spawners on any one cycle."

While the absolute numbers in this objective are likely too high for the steelhead population in the Cheakamus under the current marine survival regime (the highest escapement estimate since 1996 has been approximately 500 fish) and due to overlapping generations (which lowers the required population size), the notion of targets related to both a generational average and cycle-by-cycle abundance has merit in the Cheakamus case, because the spill will very likely create a cyclic population trend. If we assume the average generation time for Cheakamus steelhead is 5 yrs (51% of adult steelhead return as 5 yr olds), we could use the last 5 years of escapement data (2001-2005) to generate a pre-spill generational average of 390 fish. Alternately, the 5-yr. average for the last 5 years prior to the spill impact (2003-2007) could be used as the multi-generational pre-spill benchmark. We could use the lowest escapement over the chosen benchmark period for the brood-by-brood ('cycle-by-cycle' in sockeye terms) evaluation (e.g. 331 between 2001 and 2005). Thus, based on objective 1, the population would be considered recovered at some future date if:

1. The average abundance in the last 5 years exceeds or is equal to 400 spawners.

AND

2. There were no fewer than 325 spawners in any year within the 5-year period used to compute the multi-generational average.

The first year that could be included in the post-spill recovery statistic would be 2009, which is the year when the full impact of the spill will be seen in the numbers of returning fish. We obviously do not want to include returns from broods not affected by the spill into the post-spill statistic.

Objective 2 of the Cultus recovery strategy relates to indexing population growth, both as a generational average (e.g. the average escapement from years 2020-2016 must exceed the average from 2015-2011) and on a brood-by-brood basis (e.g. escapement in

2015 must be greater than 2010). Such a rule has less application to steelhead given the extent of overlapping generations. This rule is designed to avoid excessive harvest of Cultus Lake sockeye in mixed-stock Fraser River fisheries in large return years, which is not relevant to the Cheakamus situation.

The presence of hatchery supplementation adds complexity to the calculation of recovery targets. As is the case for Cultus Lake Sockeye, it is logical to assume that the recovery goals for Cheakamus steelhead will be tied to the return of wild fish only. This obviously needs to be confirmed or refuted by the steering and technical committees. The definition of a ‘wild’ fish provided in the DFO Wild Salmon Policy (DFO 2004) and used in the Cultus Lake Sockeye recovery strategy is:

> “Salmon are considered “wild” if they and their parents are offspring of fish that spawned and grew up in natural surroundings”.

To translate this into the current Cheakamus situation, if adult steelhead brood were taken in 2006 and returned as age 4 fish (2 yr smolts and 2 yrs at sea) in 2010, some of these marked fish would spawn in the wild. Their surviving progeny would return to spawn in 2015 (back to a normal 5 yr. generation time) and would not be clipped, <u>but would not be considered wild</u> under the wild salmon policy because their parents did not grow up in natural surroundings for their entire lives (they spent their juvenile stages in the hatchery). The progeny of these hatchery-origin unclipped fish that return to spawn in 2020, would be considered wild. This example is summarized in the table below.

Event	Year	Generation
Brood Taken	2006	Parents
Clipped fish Return	2010	Children
Unclipped fish return	2015	Grandchildren
‘Wild’ fish return	2020	Great grandchildren

If this approach were taken on the Cheakamus, there would be approximately a 15 yr. lag between the start of hatchery operations and the time when unclipped returning fish that are allowed to spawn in the wild, but with a hatchery lineage, would start to be included in the recovery statistics. Further, as for the Cultus recovery strategy, the number of wild fish removed for broodstock would need to be subtracted from the statistics used to evaluate recovery. Also note that the approach requires DNA pedigree data to determine the lineage of unclipped fish (is it a grandchild or great grandchild of a hatchery-spawned parent?), to determine whether they can be classified as ‘wild’ for recovery statistics.

A much simpler approach, and one that allows hatchery fish to contribute to the recovery statistics in a shorter time period, is to classify any unclipped fish as ‘wild’ (e.g. 2015 in the above example rather than 2020). This might be the only alternative in a situation where a DNA pedigree analysis could not be supported financially or undertaken due to logistic constraints. Many of the leading authorities on salmonid conservation biology and genetics in Canada were involved in the formation of the DFO wild salmon policy described above (Dr.’s Brian Riddell, Chris Wood, Mike Bradford, Blair Holtby and others), which was modeled after the approach taken for Atlantic salmon by the International Conference for the Exploration of the Seas (ICES, B. Riddell, pers. comm.). It would be difficult to scientifically rationalize the simpler/quicker approach (adipose fin = wild fish) if the objective is to restore a wild population, but the values of the steering committee may conflict with the scientific recommendation of the wild salmon policy.

Part III: Recommendation on Whether to User Hatchery Supplementation to Help Recover the Cheakamus River Steelhead Population

I support the use of a hatchery supplementation program to assist in the recovery of the Cheakamus River steelhead population based on the following rationale:

1) The impact of the CN spill on 3 of the last 5 brood years was severe, leading to very low returns beginning in 2008.

2) Under average conditions, it will probably take a minimum of 10 (2 generations) to 20 years (4 generations) for full recovery to occur.

3) Prolonged periods of low abundance pose genetic and demographic risks to the population. Low abundance also reduces fishing opportunities. We must do everything we can to minimize these impacts.

4) The biggest factor that limits the rate of recovery, and that we can control, is the lack of spawning stock from broods directly effected by the spill. Hatchery supplementation is the only way to increase the number of these fish.

5) Hatchery supplementation, if implemented in a responsible (i.e. scientific) manner, will very likely not result in genetic deterioration to the wild stock, or impose greater demographic risks (e.g. through residualization) than the risks associated with a prolonged period of low abundance that would occur if effective action is not taken.

6) Hatchery returns are not included in statistics used to determine when recovery has occurred. The primary objective of hatchery supplementation should be to recover the wild stock.

Hatchery supplementation should be considered a highly experimental option that does impose some risk to the wild population, albeit less of a risk than if nothing is done. I do not support hatchery supplementation in the absence of a rigorous assessment program. The supplementation monitoring program must ensure that:

1) genetic diversity of juveniles produced in the hatchery is maximized through DNA analysis of broodstock.

2) hatchery releases represent a wide range of genetic types, which can be achieved through DNA sampling of releases or separate rearing of individual crosses (or some combination of the two).

3) the number of hatchery-origin fish returning to the Cheakamus is more than would be produced from the broodstock if it were allowed to spawn in the wild. This can be monitored with the existing escapement program supplemented with estimates of the hatchery/wild escapement ratio provided from a volunteer angling program.

4) hatchery-origin fish that spawn in the wild produce viable progeny. This can be monitored by obtaining samples from a volunteer angling program for DNA analysis.

I appreciate the opportunity to provide comments to the technical committee.

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