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REVIEW OF GENETCIALLY BASED TARGETS FOR ENHANCED CONTRIBUTIONS TO CANADIAN PACIFIC CHINOOK SALMON POPULATIONS

Chinook Salmon adult spawning phase. (Photo credit: Fisheries and Oceans Canada.

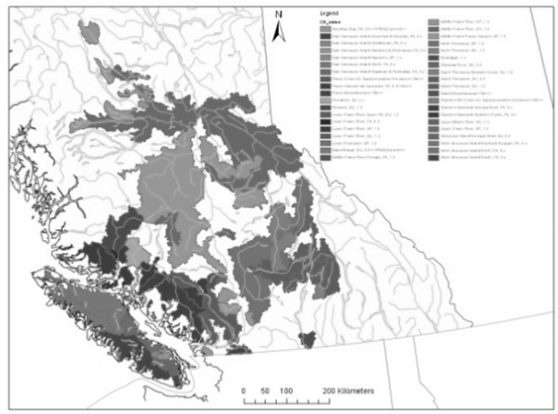

Figure 1. Map of southern BC showing the Chinook Conservation Units.

Context

Existing guidelines for genetic management of Pacific Salmon populations in the Fisheries and Oceans (DFO) Pacific Region Salmonid Enhancement Program (SEP) have been in place for many years and are used within an integrated enhancement planning process to address multiple socioeconomic and biological objectives with hatchery production. Whereas over-arching SEP objectives are framed in broad socioeconomic terms, management of biological risk to natural populations requires a detailed assessment of the nature, degree and duration of enhancement on a species, population and site-specific basis. Updated guidelines are required for management of genetic risk to populations enhanced by hatchery production and Conservation Units containing enhanced populations.

Pertinent developments since the implementation of existing enhancement guidelines include the adoption of Canada's Policy for Conservation of Wild Pacific Salmon (the Wild Salmon Policy or WSP), implementation of SEP's Biological Risk Management Framework (SEP RMF), and increased scientific information on the impact of gene flow between hatchery- and natural-origin fish on the fitness of fish spawning in natural environments. The US Congress supported Hatchery Scientific Review Group (HSRG) highlighted the distinction between 'integrated' and 'segregated' hatchery programs, the need to develop benchmarks for hatchery production consistent with the specific biological objectives set for hatchery programs, and the need to address trade-offs in hatchery productions levels engendered by the simultaneous adoption of conservation and harvest goals for some hatchery programs. The HSRG proposed implementation of the Proportionate Natural Influence (PNI) metric as an indicator of the relative influence of the natural environment on the adaptive status of a natural population influenced by hatchery production. Canadian Chinook Salmon enhancement guidelines that can be applied at the population level are required to ensure that the: (a) relative genetic risk to fitness of natural populations resulting from co-existing hatchery-origin salmon is identified, b) genetic risks of hatchery enhancement are more transparently evaluated against the intended socioeconomic benefits and (c) hatchery

Chinook Salmon programs are planned and managed in a manner to recognize and mitigate genetic risk while achieving socio-economic benefit from enhanced fish.

This report presents new Canadian guidance, new genetic information, assessment tools, and measurement metrics for evaluating the genetic risks of hatchery rearing on wild Pacific Salmon Chinook Salmon.

This Science Advisory Report is from the August 31 - September 1, 2017 Review of genetically based targets for enhanced contributions to Canadian pacific Chinook Salmon populations. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Hatchery production in the Salmon Enhancement Program of DFO is used as a management tool for the conservation of small or endangered natural populations, fish production (harvest), stock assessment, and stewardship/education objectives. The presence of hatchery-origin salmon poses risks to the fitness and genetic diversity of wild fish spawning in the natural environment and therefore has implications for the conservation of wild salmon.
- Canadian enhancement programs have been developed as ‘integrated’ populations in which natural- and hatchery-origin salmon spawn in both the hatchery and wild environments, with the gene flow between the two spawning components slowing the process of domestication (adaptation to the hatchery rather than the wild environment) that would occur in a segregated hatchery system.
- The proportionate natural influence (*PNI*) and associated metrics developed by the U.S. Hatchery Scientific Review Group (HSRG) have been assessed as appropriate metrics to evaluate, classify and monitor levels of hatchery influence and genetic risk to the natural adaptive state in Canadian integrated Chinook Salmon hatchery populations.
- A population classification system informed by the Wild Salmon Policy for Canadian Pacific Salmon has been developed to reflect the adaptive state of integrated hatchery populations based on proportions of natural- and hatchery-origin fish. Increased genetic risk is associated with population designations that have increasing hatchery influence and decreasing proportions of wild and/or naturally-spawned fish.
- The impacts of three management measures (hatchery size, proportion of hatchery fish visually marked, and proportion of marked fish selectively harvested) on the genetic risk metrics for integrated hatcheries were evaluated using a demographic model of a Chinook Salmon population that incorporated genetic impacts on fitness from hatchery spawning and rearing.
- The model demonstrated that each management option can be used to manage genetic risk. Limiting hatchery size was a consistently effective approach to reduce genetic risk and, in some cases, combinations of high rates of visual marking, selective broodstock composition, and selective removal of hatchery-origin fish from the natural environment were also effective in reducing genetic risk.
- Genetic risk associated with higher levels of hatchery production can be lowered by reducing the proportions of hatchery-origin fish included in the hatchery broodstock and/or allowed to spawn in the natural environment. However, selectively increasing the proportion of natural-origin salmon in both environments depends on visual external marking to enable differentiation of fish based on origin prior to spawning.

- Minimizing genetic risk to wild salmon populations to maintain consistency with WSP conservation goals requires limitation of the number of local and stray hatchery-origin fish in natural spawning environments, creating a trade-off between genetic risk and hatchery production for socio-economic purposes. Higher levels of genetic risk may be warranted for populations that are in immediate danger of extirpation as a result of demographic risk.
- Measures proposed to manage risk to fitness and genetic diversity of wild Canadian Chinook Salmon populations are consistent with the hatchery management principles outlined by the HSRG: 1) develop explicit biological goals for hatchery-influenced populations, 2) implement scientifically defensible hatchery programs and 3) undertake adaptive management of hatchery programs within a documented experimental approach.
- Minimizing genetic risk from hatchery production to wild populations requires maintaining the productivity of natural habitat and controlling the presence of hatchery-origin fish therein. This necessitates a comprehensive approach to monitoring and assessment among enhancement, stock assessment, fishery management, and habitat restoration activities.
- There is uncertainty about the degree of, and the mechanisms underlying, loss of fitness in hatchery-influenced Pacific salmon populations. There is no information on the magnitude and timeframe of fitness restoration for a population in which hatchery influences are removed.

INTRODUCTION

The Pacific Region hatchery program is managed by the Salmonid Enhancement Program of Fisheries and Oceans (DFO). The purpose of the program is to support a range of objectives, including harvest augmentation, conservation & rebuilding of depleted stocks, provision of stock assessment information, and support of local stewardship and education programs. There are currently 17 major DFO hatcheries, 6 spawning channels and 94 smaller community-based hatcheries in operation, with a release target of 44 million juvenile Chinook Salmon in 2017. Production of salmon from hatcheries is a major tool employed to achieve the program's final outcome of "*Enhanced salmon and habitat contribute to ecosystem health and economic productivity*", supported by two intermediate program outcomes:

- Enhanced salmon and improved habitat contribute to sustainable economic, social and cultural harvest opportunities
- Citizens engage in a culture of salmon and ecosystem stewardship

DFO's Salmonid Enhancement Program (SEP) guidelines for hatchery program management are used in an integrated enhancement planning process to address multiple socioeconomic and biological objectives. Whereas over-arching SEP objectives are commonly framed in broad socioeconomic terms, management of risk to natural populations requires a detailed assessment of the nature, degree and duration of enhancement on a species, population and site-specific basis.

Canada's hatchery programs are integrated, meaning that local broodstock is used and that hatchery-origin spawners are allowed to spawn with co-migrating natural-origin spawners in both the hatchery and natural environments. This approach allows for gene flow between the hatchery and the natural population components as a means of mitigating potentially negative effects of genetic divergence between naturally- and hatchery-spawned fish in the population (DFO 2013b). However, even in integrated populations, genetic diversity and fitness of the population in the natural environment can be reduced as a result of hatchery production if the level of hatchery production is not managed to constrain the numbers of hatchery fish that return and spawn each year.

Canada's WSP emphasizes the need to maintain wild fish spawning in natural habitats to conserve genetic diversity and fitness in current and future salmon populations. Nevertheless, the WSP indicates that hatcheries may be used to rebuild populations with an unacceptable chance of extirpation and to produce fish for socioeconomic benefit. The WSP defines a wild fish as one born in the natural environment from parents also born in the natural environment. Therefore, under the WSP, three types of salmon can be defined, 'hatchery-origin' that are born in the hatchery, 'natural-origin' that are born in the wild, and 'wild' salmon which are a subset of the natural-origin group for which both parents were also born in the wild.

Conservation Units (CUs) are ecologically- and geographically-defined groups of salmon populations that may include populations in which hatchery programs are operated. WSP Status Assessments are intended to assess status of wild salmon, but a standardized approach to dealing with the presence of hatchery-origin spawners and their non-wild offspring within a population has not been developed. To date, hatchery-influenced populations have been handled in various ways in different WSP Status Assessments of CUs and a standardized approach needs development.

There is inherent difficulty in determining how to properly assess a CU when it is uncertain that a CU (sustained with one or more populations of wild fish) would still exist in the absence of hatchery production for conservation or harvest purposes. The development of a standardized approach to WSP assessment efforts necessitates a method to relate the level and duration of hatchery influence in a salmon population to the level of risk that the hatchery fish pose to the natural adaptive and productive characteristics of the hatchery-influenced and surrounding wild populations. Poor quality and/or limited natural habitat and high harvest levels may also pose genetic risks to wild salmon populations but the focus of this study is to examine risks to genetic diversity arising primarily from enhancement.

Recent advances in scientific understanding of salmon population structure and adaptation, and the effects of gene flow between natural- and hatchery-origin salmon, require incorporation into an updated hatchery planning process as was highlighted in an independent science panel report on southern British Columbia Chinook Salmon that recommended SEP hatchery programs be brought into better alignment with WSP principles. With guidelines that more explicitly identify the potential genetic risk to enhanced populations from hatchery production, managers and stakeholders can make decisions that explicitly align with their risk tolerance during development of hatchery program objectives. A comprehensive program of hatchery review established and funded by the US Congress has been underway since 2000. The Hatchery Scientific Review Group (HSRG) established under this program developed three principles of hatchery management that can also be applied in the Canadian process. These principles with respect to hatcheries are to operate with well-defined goals, scientifically defensible programs, and informed decision making.

ANALYSIS

Chinook Salmon Genetic Structure and the Wild Salmon Policy

Genetic diversity in Chinook Salmon is partitioned among populations on a hierarchal basis, with proximal populations generally more genetically similar than distal ones. Among-population genetic diversity is the result of adaptation to the local freshwater spawning environment and marine migratory patterns, but also reflects patterns of current gene flow, postglacial colonization of freshwater habitats from glacial refugial populations over the past 12,000 years and, potentially, ancient lineages that predate the last glacial period.

The WSP establishes conservation of wild salmon and their habitat as the highest priority for Pacific salmon resource management decision-making. As noted above wild salmon are those that are born in the natural environment from parents that are also of natural origin. By extension, a wild salmon population may be considered to be one that has spawned exclusively in the natural environment, with no local hatchery program, for two or more generations and is at a very low risk of straying from other hatchery-influenced populations. The WSP affirms that the genetic diversity of wild salmon is the basis for their current and future adaptive health in the natural environment and should be safeguarded through the maintenance of habitat and ecosystem integrity, and the management of hatchery enhancement and fisheries for sustainable benefits.

Approximately 60 CUs have been described for Chinook Salmon, and many include populations with integrated hatchery programs. Biological guidelines for hatchery programs should be promulgated on the basis of risk to, and the sustainability of, wild populations in and surrounding the watershed in which enhancement is undertaken.

Genetic interactions between hatchery- and natural-origin Pacific salmon

Current scientific understanding indicates that salmon adapt, sometimes very rapidly, to the hatchery environment in which they are spawned; a process termed domestication. Domestication may result from both genetic and environmentally-mediated mechanisms including epigenetic alteration of the genome. The hatchery environment can change the phenotype of a hatchery-origin fish, and the environmentally-induced phenotypic alteration of hatchery-origin fish may be sustained after their release to the natural environment. As a result of combined genetic, epigenetic and other environmentally-induced alteration (often termed plasticity), hatchery-origin fish are often less reproductively successful (i.e. produce fewer returning adult fish) than natural-origin fish when they spawn in the natural environment.

The use of integrated enhancement programs based on production of the local Chinook Salmon population, in which hatchery- and natural-origin fish spawn in both the hatchery and natural environments, is a risk averse approach to hatchery production for conservation and harvest objectives. In contrast, the genetic risk of fish from segregated hatchery populations, in which only hatchery-origin fish are included in the hatchery broodstock, to wild salmon is higher because of the greater degree of differentiation and domestication that may occur in the segregated hatchery population relative to an integrated one. However, even in integrated populations, management of the domestication process requires implementation of guidelines for the numbers and proportions of fish of hatchery and natural origin to be maintained in both spawning habitats of the integrated population.

The integrated population, including both the hatchery- and natural-origin components, will become most adapted to the more productive spawning environment (i.e. that which produces the majority of spawners in the next generation). Minimizing domestication can be achieved by keeping the hatchery program small and/or reducing the proportion of hatchery-origin fish in the hatchery broodstock and among spawners in the natural environment.

Chinook Salmon hatchery programs pose risk to surrounding wild populations if fish from the integrated hatchery population stray into those populations. The degree of impact on a recipient population is partly due to the proportion of out-of-basin strays to natural local-origin spawners in that population. Modelling results indicate that fitness in the wild population may decline even when the proportion of out-of-basin strays is very low (i.e. <5%).

Reducing genetic risk to wild salmon populations (WSP conservation goals) creates tradeoffs with hatchery production goals. For example, limiting size of hatchery production also limits the production of fish for harvest. Similarly, increasing the proportion of adipose-clipped fish for visual marking and undertaking selective removal of hatchery fish also have costs.

Use of the *PNI* metric to manage genetic risk in Canadian Chinook Salmon Enhancement

Both the hatchery and natural environments exert selection on the fish spawning in their environs, with the rate of adaptation in the population dependent on both the strength of selection and heritability of fitness in both environments. Fish in an integrated hatchery program evolve towards an equilibrium intermediate phenotype and fitness that reflects the relative contributions of the two spawning environments to spawners of the subsequent generation. Thus, fish originating from both spawning locations will be becoming increasingly adapted to the more productive spawning environment. The proportionate natural influence (*PNI*) metric is an index of the relative degree of hatchery influence based on a genetic model that assumes that the optimal phenotype (and fitness) of a salmon differs between the hatchery and the natural environment. *PNI* is computed as:

$$PNI = \frac{pNOB}{pNOB + pHOS_{eff}}$$

Where *pNOB* is the proportion of natural origin spawners in the hatchery broodstock, and $pHOS_{eff}$ is the effective proportion of hatchery origin spawners in the natural habitat. *PNI* is an index of the degree of hatchery influence in a population, and ranges from 0-1, with higher values for populations with a stronger influence of the natural environment.

The *PNI* and associated metrics *pNOB* and $pHOS_{eff}$ are appropriate metrics to use in the classification of genetic risk for Canadian Pacific salmon enhancement programs. A population designation scheme was developed based on the presence/absence of an integrated hatchery program and, for populations with an integrated hatchery component, the degree of hatchery influence (Table 1). Within the scheme there are two categories for populations without an integrated hatchery based on the level of out-of-basin hatchery strays they receive. There are three categories of integrated enhancement programs proposed that align with the proportion of the population comprising wild fish as defined by the WSP (Table 1). The least risk to genetic diversity and natural adaptation is associated with the *Integrated-wild* category of population in which the objective is to attain a *PNI* value >0.80[1]. In these populations, at least[2] 50% of the fish will be *wild* and more than[3] three-quarters of the fish will be of natural origin. Greater risk will be incurred in the *Integrated-transition* category of populations, for which target *PNI* values range from 0.5 to 0.8[1]. In these populations, the majority of fish will be of natural origin but as few as 13%[4] will be *wild*. Greatest genetic risk is associated with the *Integrated-hatchery* category, for which *PNI* values will be <0.5. These populations will be dominated by fish of hatchery origin and few, if any, *wild* fish will be present. The low influence of the natural environment on adaptation in these populations leads to uncertainty regarding their ability to constitute self-sustaining natural populations in the absence of hatchery production.

[1] Erratum: 0.72 corrected to 0.80 to reflect revision of Table 1.

[2] Erratum: “more than” corrected to “at least” to reflect revision of Table 1.

[3] Erratum: “close to” corrected to “more than” to reflect revision of Table 1.

[4] Erratum: 25% corrected to 13% to reflect revision of Table 1.

Table 1. Proposed designations for individual salmon populations that vary in the degree of influence of integrated hatchery programs and the proposed genetic guidelines for hatchery management. PNI is computed using $pHOS_{eff}$. The pWILD column shows the expected proportions of WSP-Wild fish in the spawning population. The remainder of the spawning population is made up of offspring of matings with one or two hatchery parents, and hatchery origin returns, at a rate defined by $pHOS_{census}$.[5]

Designation		$pHOS_{eff}$ $pHOS_{census}$[6]	*pNOB*[6]	*PNI*[6]	*pWILD*[6]	Comments[6]
A	Wild	≤ 0.02 ≤ 0.03	n/a	n/a*	≥ 0.92	Designated wild populations that do not have hatchery programs (for at least two generations); strays from out-of-basin hatchery production are limited to <3% per year.
B	Wild-stray influenced	>0.02 >0.03	n/a	n/a*	*< 0.92*	Population receives strays from an out-of-basin hatchery. A very large fraction of fish may be wild but gene flow modelling suggests a long-term decline in *PNI* as *pHOS* increases.
C	Integrated wild	≤ 0.19 ≤ 0.23	≥ 0.77	≥ 0.80	≥ 0.50	Hatchery production is managed to keep wild fish ≥50% of the spawning population.
D	Integrated-transition	≤ 0.47 ≤ 0.53	≥0.47-<0.77	≥0.50-<0.80	≥0.13-<0.50	*PNI* > 0.5 ensures natural-origin influence predominates but wild fish are in the minority.
E	Integrated-hatchery	> 0.47 > 0.53	< 0.47	< 0.50	< 0.13	Net gene flow from hatchery environment; most fish are hatchery origin. Few fish are wild.

*One-way gene flow (*pNOB*=0) is most likely to take place when hatchery-origin fish spawn in the wild, but wild fish from the recipient population are not used for hatchery broodstock. *PNI* under one-way gene flow is computed from simulations that are not reported here.

Hatchery Management measures to achieve *PNI* targets

The population designations in Table 1 provide guidance for the management of genetic risk in hatchery programs in the form of target *PNI* values. A population model was used to simulate an integrated hatchery population to evaluate the efficacy of management measures for achieving the *PNI* and associated $pHOS_{eff}$ and *pNOB* targets. In general, modelling results suggested the most effective way to increase *PNI* values was by scaling the size of the hatchery program to natural production. This ensured that abundance of hatchery-origin fish on the natural spawning grounds was proportional to the capacity of the watershed to sustain natural production. However, limiting hatchery program size also limits the harvest benefits that can be achieved from an integrated-wild population.

Two other management measures to reduce genetic risk that were evaluated were increasing the proportion of natural-origin spawners in the broodstock or decreasing the return of hatchery-

[5] Erratum: Original text read “The WSP column shows the expected proportions of natural origin-natural origin (NN) matings that would result in production of WSP-wild fish, and hatchery-natural matings (HN) and hatchery-hatchery (HH) matings. Matings are assumed to be random and are computed from $pHOS_{eff}$.”

[6] Erratum: Cells in these columns revised after correcting the computation of the proportion of wild fish in the spawning population.

origin fish to the river by selective harvest, or the use of a weir or similar device. Manipulation of the proportions of natural- and hatchery-origin fish in the broodstock and wild environment is dependent upon some type and level of visual marking that allows differentiation of fish originating from the two spawning environments prior to spawning.

To achieve *PNI* objectives for the "integrated-wild" designation, limiting hatchery size (in terms of the broodstock taken) was found to be the most effective management measure among the three considered. In an integrated-wild population without selection to increase the proportion natural-origin fish in broodstock, the proportion of hatchery-origin fish in the wild was limited to 23%[7] or less. At this level of hatchery production, marking fish to enable selective exclusion of hatchery-origin fish from the broodstock or natural environment had little effect on *PNI* unless the marking rate was very high.

To achieve *PNI* objectives for the "integrated-transition" population designation, partial marking coupled with selection of natural-origin fish for broodstock and, possibly, also with selective removal of hatchery-origin fish from the wild was very effective. When hatchery-origin fish comprised the majority[8] of the population, marking fish and selectively increasing the proportion of natural-origin fish in the broodstock and possibly also in the wild was required in order to maintain *PNI* values consistent with the "integrated-transition" category.

Minimization of the genetic impact of hatchery Chinook Salmon on surrounding non-integrated wild Chinook Salmon populations can be achieved by limiting the size of the hatchery program, and implementing hatchery rearing/release practices to reduce straying levels. Given the expected reductions in fitness in recipient wild populations as the result of even very low numbers of strays from hatchery-influenced populations, marking and monitoring of hatchery fish on a regional scale may be required to evaluate risks to wild populations. Strays from integrated-hatchery populations pose the greatest risk to wild populations because of their low level of adaptation to the natural environment.

Sources Of Uncertainty

Studies demonstrating reduced reproductive success (fitness) in the natural environment of hatchery-origin Pacific salmonids relative to their natural-origin counterparts have been conducted primarily with steelhead, stream-type Chinook Salmon and Coho Salmon. The measured reduction in RRS (adult progeny returning) varies among species, populations and brood years and is not predictable. The components of reduced fitness include genetic variation, environmentally-mediated plasticity and epigenetic alteration to the structure and packaging of DNA that does not alter DNA sequence. The contributions of these influences to reduced fitness cannot be individually quantified in most field studies and the generational time frame in which fitness can be restored in natural populations once hatchery production ceases is not known. In particular, little is known about the magnitude and reversibility of epigenetic change in hatchery-reared salmonids and the contribution of these effects to the rapid reduction in fitness observed in some populations in the early generations of hatchery rearing.

The model to evaluate impact of management actions on indicators of genetic risk considered uncertainties in key parameters: heritability, strength of selection, relative reproductive success of hatchery-origin spawners, and marine survival of hatchery and natural components of the population. The observed trends were robust to uncertainties in key parameters, though the absolute hatchery sizes, marking rates, and selective removals rates that define boundaries in

[7] Erratum: 33% corrected to 23% to reflect revision in Table 1.

[8] Erratum: "more than 60-70%" rephrased to "the majority" to reflect revised modelling results.

genetic impacts among categories of populations (“integrated-wild”, “integrated-transition”, and “integrated-hatchery”) will vary, especially with marine survival rates and productivity.

While model results that show the relation between management actions and the genetic risk index, *PNI,* appear robust, with current knowledge it is not possible to estimate the magnitude of the genetic risk in terms of the loss of fitness or productivity of wild populations as a consequence of hatchery influence.

This model describes long-term, equilibrium impacts on fitness of integrated hatchery system. As such, it can provide strategic guidance on choice of the management levers to reduce genetic impacts on naturally spawning populations, but not short-term or tactical advice that requires information on time-trends or inter-generational variability in population fitness, genetic impacts, and/or *PNI*. Further, the model contains a simplistic consideration of the effects of both the hatchery program, and hatchery measures such as selective removal on regional fishery management planning. Operationally the genetic risk management should be conducted within the context of both watershed and fishery management planning.

CONCLUSIONS AND ADVICE

Conservation of genetic diversity and fitness of Pacific salmon in the natural environment is the highest priority for resource management specified in the WSP. Hatchery production of salmon, while recognized as an appropriate tool for both population conservation and increased harvest opportunity, is a risk factor to genetic diversity in wild populations. A transparent means to balance the trade-off between the potential benefits of increased hatchery fish production and the risks of reduced genetic diversity and fitness in wild salmon is required. This requires a clear definition of a wild salmon population and an understanding of the relative degree of genetic risk to wild populations associated with different types and levels of hatchery production. By extension of the WSP definition of a wild salmon, a wild population is one in which no hatchery releases or brood removals have taken place for at least two generations and that receives few stray fish from hatchery-influenced populations.

Management of the genetic risks associated with hatchery production of Pacific salmon would benefit from implementation of the three principles established in the HSRG process:1) develop explicit biological goals for hatchery-influenced populations, 2) implement scientifically defensible hatchery programs and 3) undertake adaptive management of hatchery programs within a documented experimental approach. In the Canadian context, guidelines should be developed to indicate the appropriate level and distribution of enhancement within a CU that can considered consistent with the WSP designation of a CU as an aggregation of wild salmon adapted to the natural environment and constituting an important element of intraspecific genetic diversity.

A population designation scheme has been developed based upon the biological goals for each population (Table 1) and the associated the proportion of wild fish to be maintained in the population. The scheme enables, for each hatchery-influenced population, designation of a target classification consistent with established goals for both the population itself and the CU to which it may contribute. Achievement of CU level goals necessitates that hatchery-influenced populations be constrained by numbers of hatchery-origin fish both in the enhanced population itself and in surrounding wild populations. Development of the classification targets will involve collaboration among SEP, Stock Assessment and Fishery Management personnel within DFO because of their combined oversight for fish production targets, natural habitat maintenance, visual marking and harvest activities. Documentation supporting each hatchery program should include explicit delineation of the trade-off made between increased genetic risk to wild populations and the expected benefit of increased hatchery-origin abundance to support the enhancement objectives of conservation, harvest, stock assessment and education.

Population designations developed in this process can be used in a standardized approach to WSP status assessments of CUs that contain populations with hatchery contributions. The use of *PNI* and $pHOS_{eff}$ values, combined with estimated proportion of wild fish in integrated hatchery populations, provides the means to differentiate populations expected to maintain genetic diversity and adaptation to the natural environment that should be included in WSP assessments from populations dominated by hatchery production that should be excluded from assessment based on their expected high degree of domestication.

Hatchery programs based on scientifically defensible information provide the best opportunity to achieve benefits from hatchery production while minimizing genetic risks to diversity and fitness in wild salmon. Current scientific understanding supports the existing standard Canadian enhancement practice of developing integrated hatchery populations based on the local wild population to minimize the effects of reduced diversity and domestication in the population. However, high levels of hatchery production, combined with low levels of visual marking of hatchery fish, in large hatchery programs can reduce opportunity for moderating the domestication process by increasing the reproductive contributions of natural-origin fish. Without the ability to identify natural-origin fish for hatchery broodstock, a large hatchery program initiated on an integrated basis may become more similar to a segregated population in which all broodstock are selected from returning hatchery-origin fish. Segregated hatchery populations present an increased risk to wild Canadian Pacific salmon populations given our inability to preclude the presence of stray hatchery fish from the natural environment.

Populations that are designated to have predominately wild characteristics, including the maintenance of genetic diversity and fitness require management as natural, rather than cultured, populations. This involves incorporating information on habitat quantity and quality, natural production and recruitment into hatchery production goals as well as managing the levels of straying from, and exploitation on, the integrated population. In the planning process, options for a hatchery operation to achieve a specified population designation can be evaluated through the application of the proportionate natural influence (*PNI*) and associated metrics based on the numbers and proportions of hatchery- and natural-origin fish expected to return to hatchery and natural spawning environments of the integrated population.

In conservation hatchery programs conducted for persistence and recovery of populations imperiled by low abundance and threats to productivity, the genetic risk of reduced diversity and extirpation due to small population size may exceed the genetic risk of domestication associated with a high level of hatchery production in the early stages of a conservation hatchery program. For these populations, hatchery production should be undertaken as part of a broader recovery program in which the factors leading to low abundance are addressed. The hatchery program itself should be designed as a staged process in which the initially high level of hatchery production decreases throughout the process of population recovery to ultimately achieve *PNI* and $pHOS_{eff}$ values consistent with the desired population designation.

Management of hatchery programs requires a comprehensive approach in which hatchery production, marking, natural habitat maintenance or recovery, exploitation and stock assessment are all coordinated to manage genetic risk to wild populations. Hatchery programs should be assessed against the documented goals established in the planning and implementation processes. This will require marking and monitoring measures to periodically track *PNI* and other relevant parameters in the natural and hatchery environments. Informed assessment should be the basis for hatchery program modification to capitalize on increased biological understanding and/or to adapt to respond to natural variation that may influence the means by which the enhancement goals for the population and the preservation of wild salmon can be best achieved.

SOURCES OF INFORMATION

This Science Advisory Report is from the August 31-September 1, 2017. Evaluation and update of biologically-based targets for enhanced contributions to Chinook populations. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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