A Biological Risk Management Framework for Enhancing Salmon in the Pacific Region

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Table of Contents

1 Introduction

This document describes a framework for the assessment and management of biological risks to wild Pacific salmon populations from production originating from Salmonid Enhancement Program (SEP) hatcheries. Its purpose in part is to respond to the need identified in Canada's Wild Salmon Policy (DFO, 2005a) for "a biological risk assessment framework to assess the risk of hatchery production to wild salmon". It is also intended to clarify the nature and application of risk in the SEP operating environment. Although there is considerable literature available on the risks related to hatchery production in general, there has not yet been an assessment of such risks under the specific operating regime utilized by SEP. This document undertakes such an assessment and presents and consolidates in a systematic framework the many enhancement program components that are used to assess and manage risk at SEP facilities. The framework supports structured consideration of risk for improved decision making and will be of use to SEP staff and volunteers, as well as other DFO staff and stakeholders and participants in planning processes.

The practice of risk management involves identification or description of a risk, an assessment of its severity and likelihood, and subsequent approaches for mitigation. This framework describes biological risks associated with enhancement as practiced by SEP, considers their application at each stage of the enhancement process and identifies risk management and mitigation measures. Separate sections address over-arching risk factors that apply more broadly and knowledge gaps and uncertainties. Appendices include supporting material such as pathway-of-effects (PoEs) models and detailed risk mitigation tables.

In acknowledgement of the risks associated with enhancement, SEP has developed an array of risk mitigation and management procedures, guidelines and practices. However, in order for them to be effective, they must be understood and followed. Although there continue to be some uncertainties and knowledge gaps, mitigation strategies and enhancement approaches will evolve as new science emerges and this document and practices will be updated accordingly.

The enhanced salmon risk assessment framework is one of a number of integrated planning tools SEP is preparing to guide future management and decision-making. These include a SEP production planning framework, an infrastructure strategy and a framework guide for SEP biological assessment. These products will be integrated into long-term planning for program-level strategic management.

2 Framework Scope

This framework is designed to address risks to wild salmon populations from salmon enhancement activities carried out or supported by SEP in British Columbia and the Yukon. This includes large facilities operated by SEP staff, smaller community-based facilities managed under contract with SEP and those run by volunteer groups. Other non-SEP enhancement facilities, such as those operated under the Aboriginal Fisheries Strategy and DFO for stock assessment purposes will also benefit from the framework. This framework does not apply to aquaculture sites. Although enhancement, like aquaculture, involves the "cultivation of fish", it differs from aquaculture, in that enhanced fish are released from enhancement facilities as juveniles to grow and migrate naturally.

This framework assesses biological risks for each stage of the enhancement process on a production line basis. Production lines are individual groups of enhanced salmon, identified by a combination of the project, species, run timing (e.g. spring, summer), stock of origin, release strategy (e.g. smolt, fed fry) and release location. This framework characterizes biological risk to wild salmon as risks affecting a *population*[1] of wild salmon. Although some activities may have an effect on *individuals* of a population, those effects begin to be of concern when the population becomes at risk.

SEP uses a variety of enhancement strategies including hatcheries, spawning channels, lake enrichment, fishways, rearing side channels, habitat restoration and water control structures; each of which involves varying degrees of biological intervention. This framework however, is designed for application to hatcheries and spawning channels, with an emphasis on hatcheries due to their complexity, as these strategies carry the most significant level of biological risk. This is consistent with the definition of enhanced salmon in the Wild Salmon Policy, in which enhanced salmon are considered those that originate from hatcheries and managed spawning channels.

Enhancement is undertaken by SEP to support harvest and stock assessment, rebuild depleted stocks, and provide stewardship and education opportunities. The program enhances Chinook, chum, coho, pink, and sockeye salmon throughout the Pacific Region. Steelhead and cutthroat trout are produced at some DFO facilities in partnership with the province of British Columbia, which is responsible for the production planning and management of these species.

Salmon production by SEP averages 386 million juvenile salmon each year. representing approximately 8.6 percent of the 4.5 billion hatchery salmon released to the northeast Pacific Ocean each year by all nations during the 1990s and early 2000s (Ruggerone, et al. 2010). The percentage of stocks enhanced by SEP in BC is small. The Wild Salmon Policy notes that *"in 1996, a study for the American Fisheries Society identified 8,171 natural spawning locations throughout BC and the Yukon"*[2] *;* SEP enhances less than 4 percent of these in any given year. There are about 150 hatcheries and managed spawning channels in British Columbia and the Yukon that are part of SEP. Figure 1 illustrates that most hatcheries release small numbers of fish such that the approximately 130 facilities operated by community groups and First Nations organizations in partnership with SEP, together release less than 10 percent of total annual releases.

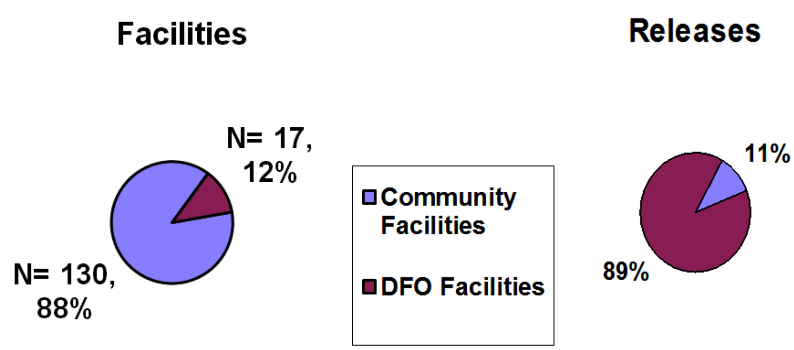

Figure 1. Proportion of SEP facilities and releases by program area.

[1] The Wild Salmon Policy defines a population as "A group of interbreeding organisms that is relatively isolated (i.e. demographically uncoupled) from other such groups and is likely adapted to the local habitat."
[2] Steelhead are excluded from this number.

The majority of enhanced production originates from 17 large facilities operated directly by DFO. Some risks are commensurate with the numbers of fish released. Because of their size, complexity and more material fish production, these facilities have the most stringent risk management practices and protocols, including Fish Health Management Plans for each site.

This framework does not consider risks due to physical failure of a hatchery since such failures do not directly present risks to wild populations, although in some circumstances loss of production could affect likelihood and rate of population recovery. The framework also does not consider risks associated with choosing *not* to enhance a severely depleted population. Although such risks can be substantial, including catastrophic loss of the population through natural or human events or severe loss of genetic diversity, they are outside the scope of impacts of enhanced salmon on wild salmon

3 Background

3.1 Risks and Benefits of Enhancing Salmon

The risks of enhancement to wild salmon populations conventionally cited in the literature (Gardner et al. 2004; HSRG, 2004; and NOAA, 2006) include undesirable genetic effects, disease implications, ecological interactions, harvest impacts and marine carrying capacity, each of which is described in greater detail in subsequent sections of this framework.

However, decisions respecting enhancement require consideration not only of the risks, but of the benefits relative to those risks. These benefits and risks have been subject to debate (e.g. Hilborn, 1992; Meffe, 1992; Lackey, 1999; Lichatowich et al. 1999; Waples, 1999; Brannon et. al., 2004) for some time. Agencies, however, may determine that the resultant benefits from enhancement activities outweigh potential risks, in spite of uncertainties about likelihood or severity. For DFO, the role of enhancement was confirmed in the Wild Salmon Policy as contributing to the rebuilding of depleted conservation units (CU[3]) and providing harvest opportunities as part of integrated strategic management plans. The objective of a proposed enhancement initiative can also be a factor in weighting the risk/benefit equation. Significant risk may be tolerated if enhancement is the only avenue available to address high value outcomes that deliver key departmental priorities, such as supporting the recovery of an at-risk conservation unit. For example, the Sakinaw sockeye CU had declined from 15,000 returning spawners in the 1970s to a low of 24 in 2003 (Sakinaw Sockeye Recovery Team, 2005) and was at risk of extirpation, as well as severely constraining fisheries. Enhancement, together with habitat and harvest management measures was deemed to be the only feasible means of preventing extirpation of the CU and addressing departmental harvest management priorities. Similarly, the production and marking of Chinook salmon indicator stocks is of key importance to DFO as it addresses commitments in the Pacific Salmon Treaty, and current international and domestic harvest management approaches could not be utilized in the absence of SEP data.

Overall, the benefits of enhancement carried out by SEP have been documented in (MacKinlay et al. 2004), (DFO, 2005a) and (DFO, 2009) and include: conservation by enhancement of vulnerable salmon populations provision of harvest opportunities, a focus for cooperative fisheries, partnerships

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[3] A conservation unit is defined in the Wild Salmon Policy as: "…a group of wild salmon sufficiently isolated from other groups that, if extirpated is very unlikely to recolonize naturally within and acceptable timeframe, such as a human lifetime or a specified number of salmon generations." DFO intends to maintain genetic diversity through protection of conservation unit integrity.

and watershed stewardship activities with First Nations and local communities, public education about salmon resources; restored fish habitat and essential` stock assessment information.

Enhancement is a complex process, and has evolved over time in response to both a changing environment and an accumulating knowledge base. Biological risk was recognized at the inception of the program, drawing on the knowledge and experience of other agencies that had already undertaken hatchery programs. Measures were implemented at the outset to address known risks, with a particular focus on planning and assessment in order to support adaptive management for risks that might emerge as knowledge increased. For example, a rigorous facility planning and design process for federal enhancement facilities was developed and implemented during the initial phase of the program (Shepherd, 1984). Facilities were then assessed by means of a biological report card compiled from a survey of senior DFO technical staff (Shepherd and McLeod, 1986) and changes for future facility design incorporated. Similarly, practical studies on components of enhancement operations were undertaken and results used to improve procedures. Work by DFO geneticists indicated that spawning practices could better maintain genetic diversity by changing the spawning ratio of males to females (Information Memorandum, Nos. 1-100 republished in Canadian data report of Fisheries and Aquatic Sciences; No.496). In response, DFO developed and implemented genetic management guidelines in 1986 (DFO, 2005c) for broodstock collection and spawning. These have been in continuous use and are updated as new knowledge becomes available. Assessment information from marking programs has also been critical to adaptive management and results have been incorporated in the risk management process. Perry (1995), for example, describes how release strategies were modified for interior Fraser River coho when analysis of survival rate and recruitment data from marking programs indicated a potential impact of hatchery fry releases on wild coho fry.

SEP has also been guided by formal program reviews and evaluations carried out within the federal government in 1976, 1984, 1985, 1988, 1993, 1994, 2005, 2009, and 2012 (Cohen Commission).

3.2 Management of Biological Risks to Wild Salmon from Hatchery Production by Other Pacific Northwest Agencies

British Columbia, the Yukon and the states of Alaska, Washington, Oregon and California all enhance Pacific salmon and have gained experience in researching, assessing and managing related biological risks, to the extent that assessment and production commitments have formed a part of the Pacific Salmon Treaty since 1985. Although this framework applies to salmon enhancement activities in British Columbia and the Yukon, awareness of enhanced salmon risk management approaches in adjacent jurisdictions provides a useful perspective.

In the US, risk management has involved extensive risk review and development of policies and operational management plans. The National Oceanic and Atmospheric Administration (NOAA), a significant oversight agency, has provided a comprehensive review of risks to wild populations from hatchery fish through its Fisheries Science Center, considering genetic, ecological, behavioral, overfishing and fish health[4] aspects. NOAA has established policies through the National Marine Fisheries Service (NMFS), primarily in relation to its administrative responsibilities for the Endangered Species Act. Of these, the most pertinent with respect to federal and state hatcheries are the requirement for Hatchery and Genetic

[4] To review the NOAA Northwest Fisheries Science Center description of risks to wild populations from hatchery production go to: http://www.nwfsc.noaa.gov/resources/salmonhatchery/risks.cfm#genetic

Management Plans (HGMPs) as a mechanism for addressing broodstock management in general and "take" of species that may occur as a result of artificial propagation activities (e.g. brood collection) for species listed under the Endangered Species Act.

Perhaps the most comprehensive initiative to consider the assessment and management of risks associated with Pacific salmon hatchery production in recent history was the US Congress-funded Hatchery Reform Project initiated in 2000[5], managed by the Hatchery Scientific Review Group (HSRG), an independent scientific panel. Supported by state and tribal science teams, the HSRG produced reform principles and system-wide and program-specific recommendations for Puget Sound/Coastal Washington hatchery programs (HSRG, 2004) around issues such as brood stock management, hatchery planning, assessment and rearing and release strategies. Congress directed NOAA-NMFS to replicate the project in the Lower Columbia Basin in 2005, and then in California in 2010.

SEP recognized the value of the Hatchery Reform Project and assessed hatchery operations against the HSRG principles and recommendations in 2005 (DFO, 2005b unpublished). Operational practices generally met the recommendations but some gaps were identified (Appendix I) with respect to clear definition of project goals, better communication of guidelines and monitoring of their implementation and re-development of the biological assessment framework. All gaps are now the subject of ongoing initiatives.

Hatcheries in the state of Oregon manage risk through policies such as wild fish management, fish health management, and fish hatchery management, supported by specific operational rules on factors such as fish transport and propagation licensing. Each hatchery also operates according to an operations plan and a Hatchery Genetic Management Plan.

The state of Alaska ocean ranching hatchery programs are unlike those in other jurisdictions, but have the objective to "…enhance fisheries while minimizing wild stock interactions"[6]. While subject to the requirements by the NMFS discussed above, the Alaska Department of Fish and Game (ADF&G) has produced a number of policies related to enhancement risk to wild populations. Hatcheries are guided by regionally based comprehensive salmon enhancement plans and policies related to hatchery management that provide guidance of operation aspects such as stock transport and maintenance of genetic variance.

More detailed examples of risk assessment and management in the Pacific Northwest can be found in Appendix II.

3.3 Existing Risk Management Mechanisms for Enhancing Salmon in British Columbia

Like other agencies, DFO-SEP manages the risks of fish culture to wild salmon populations through a hierarchy of legislation, policies, guidelines, operational and management plans and mitigation measures, as illustrated in Figure 2. Foremost of legislation is the *Fisheries Act* and, flowing from it, the Pacific Aquaculture Regulations (PAR), a new regulation instituted in 2010, and the Fishery (General) Regulations (F(G)R).

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[5] For more information on the Hatchery Reform Project go to: http://www.hatcheryreform.us/hrp/welcome_show.action
[6] From the ADF&G hatcheries website at: http://www.adfg.alaska.gov/index.cfm?adfg=fishingHatcheries.main

The Pacific Aquaculture Regulations require that all SEP related hatchery operations must carry a PAR licence, as the regulations apply to all facilities that 'cultivate fish" even if not for aquaculture. PAR licences are issued annually and include a publicly available production plan, a management plan and prescriptive conditions related to production levels, fish transfers, fish health, mortality events, escape prevention, fish release, adult carcass disposal, predator control, net pen rearing, keeping of records and reporting requirements. A list of significant diseases that must be reported, federally and internationally, is also a part of the licence.

Prior to the introduction of the PAR licence, all releases of fish into fish-bearing waters and transfers of fish between fish-rearing facilities were reviewed by the federal-provincial Introductions and Transfers Committee[7] (ITC) using tools laid out in the National Code on Introductions and Transfers of Aquatic Organisms (Anon, 2003). If approved by the committee, such movements were licensed under Section 55/56 of the F(G)R under the *Fisheries Act*. Most releases and movements of hatchery fish are now covered by the PAR licence but any movements that cross fish health zones still require a S. 55/56 licence and review by the ITC.

Each DFO operated SEP facility has and follows a Fish Health Management Plan (FHMP) that is linked to the PAR licence. SEP-supported facility staff are trained in fish health management and facilities are designed to support a flow of work that enables fish health management and biosecurity. FHMPs provide general principles of fish health management and standard operating procedures for fish culture operations (broodstock, spawning, incubation, rearing, mortality management, use of chemicals and disinfectants, and genetic practices and procedures). For Community Involvement facilities, a Best Management Practices (BMP) document is being prepared to support Community Involvement Program staff and community partners in meeting *PAR* licence conditions.

This framework incorporates goals of existing policies and guidelines to manage and mitigate enhancement risks including guidelines regarding broodstock management, spawning protocols, Guidelines for In-Stream Placement of Hatchery Salmon Carcasses for Nutrient Enrichment (DFO, 2012) and the Alaska Sockeye Salmon Culture Manual (McDaniel et al., 1994) for management of infectious haematopoietic necrosis virus (IHNV) in hatcheries enhancing sockeye.

Foremost among the policy documents for this framework is the Wild Salmon Policy, which includes a process for developing a structured integrated planning approach. SEP in turn utilizes a formal but more limited production planning process to set appropriate production levels for each enhancement facility. This process is described in the SEP Production Planning Framework document (DFO, 2012) and will link to Wild Salmon Policy planning processes as they more fully evolve. The production planning process considers enhancement objectives in light of harvest requirements and impacts, population status and trends, ecological interactions habitat issues and carrying capacity and assessment requirements. Appropriate production levels are a fundamental means of managing all risk aspects and such risks are key considerations in the planning process.

[7] More information on introductions and transfers is available at: http://www.pac.dfo-mpo.gc.ca/science/species-especes/aq-health-sante/intros-eng.htm

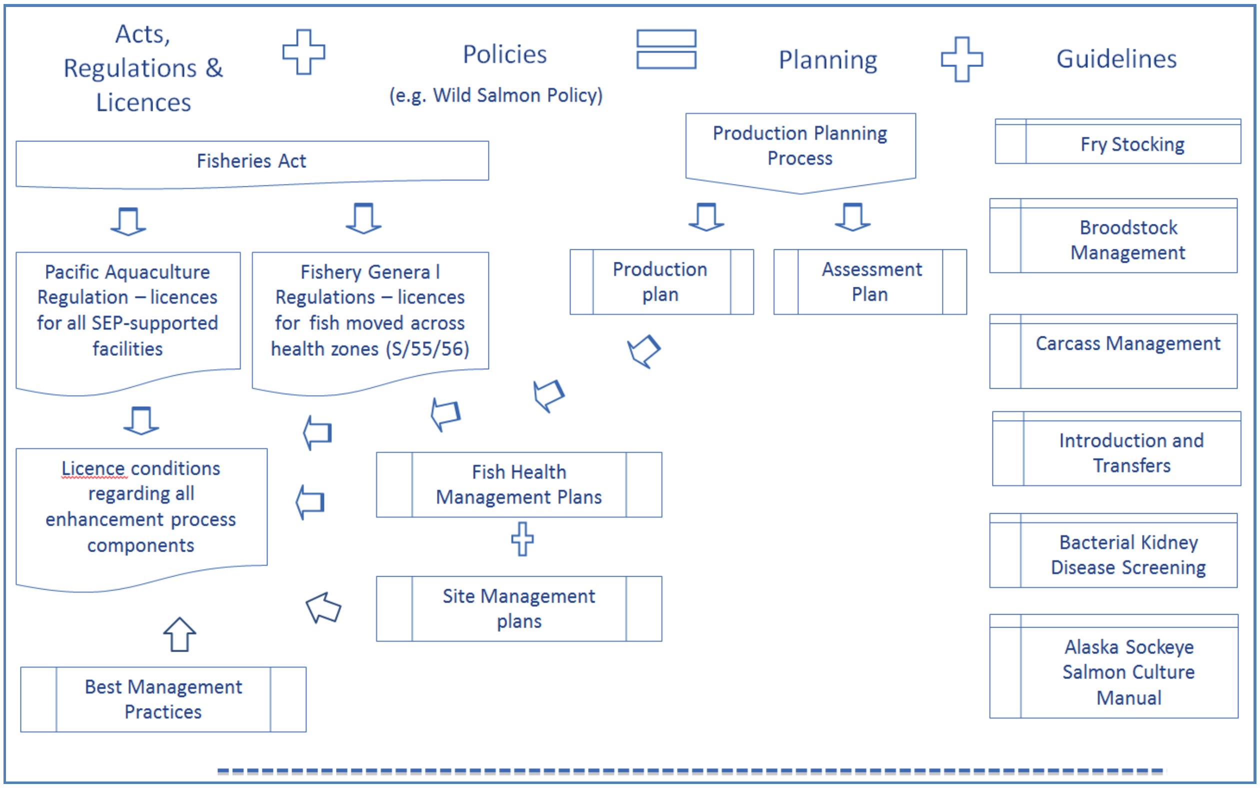

Figure 2. Inter-relationships between legal, policy, planning processes and guidelines that guide SEP production.

All aspects of ongoing production are reviewed during formal production planning, as well as informally on an operational basis. New production or significant changes in existing production are particularly scrutinized using the following approach.

1. Thoroughly assess the need for enhancement, considering both benefits and risks. Enhancement planners work with other DFO staff to explore options to achieve objectives through other means or through lower-risk enhancement strategies, with more minimal intervention. For existing enhancement this may require changing strategies (i.e. location or method or both). For example, when the Cultus sockeye conservation strategy was developed (Cultus Sockeye Recovery Team, 2005), a number of combinations of habitat, harvest and enhancement strategies were considered for recovery of the CU. After assessing the potential for recovery under various scenarios, an enhancement program, including a captive broodstock component, was implemented in concert with harvest and habitat measures.

2. If enhancement proceeds, risk management and mitigation measures are implemented and existing regulations, policies and operational guidelines are applied. With respect to Cultus sockeye, once the decision had been made to implement a captive broodstock program, a technique which has the potential to affect genetic diversity, a rigorous broodstock management program was implemented, including genetic screening (Cultus Sockeye Recovery Team, 2005) and an intensive stock assessment program including juvenile marking and juvenile and adult enumeration.

3. To further mitigate risks, SEP works with DFO scientists to investigate gaps and uncertainties and develop mechanisms for risk management. For Cultus sockeye, data

from genetic screening and survival rate assessments informed a change of enhancement strategies to one that would reduce the risk of genetic change. Additionally, results of genetics work will be used to guide future captive breeding programs.

4 Framework Design and Application

This risk framework is designed to assess the genetic, disease and ecological risks (adapted from NOAA (2006) and the HSRG (2004)) to wild salmon associated with each step of the enhancement process. Risks are considered on a production line basis i.e. a group of fish identified by a combination of their facility, species, stock, spawn timing, release strategy and release site. It is recognized that there are also enhancement related risks associated with harvest effects and marine carrying capacity. These risks apply more broadly than at the level of enhancement processes and are discussed in a separate section.

For the purposes of this framework, the enhancement process has been divided into nine activities; eight operational activities related to hatcheries (adult collection, spawning, etc) and a ninth spawning channel activity that encompasses all aspects of spawning channel operation. Due to their unique differences from fish culture operations, spawning channels are treated differently and risks are discussed in a separate section. The enhancement activities and the procedures relevant to each are described in Table 1

Table 1. Description of Enhancement Activities.

Enhancement Activity	Description
Hatcheries	
1. Adult collection, holding and sorting	Salmon to be spawned for hatchery use (Broodstock) are collected as they swim back to the facility or from off-site locations in the same or a different watershed from the hatchery. Off-site collection involves trapping, netting or otherwise capturing maturing adult salmon for egg-takes on the spot or for holding at an off-site location, usually in net pens, until the adults are mature. Adults captured remotely may also be transported back to the hatchery for holding. Maturing adults at hatcheries are held in ponds or raceways and are examined and sorted periodically to assess state of reproductive readiness. Adult collection for both hatcheries and spawning channels is linked to assessment as fish are counted or estimated by sex, and may be sampled for marks or biological characteristics.
2. Spawning practices	Mature adult salmon are killed, bled, and stripped of gametes (eggs/milt). Gametes are mixed for fertilization then placed in incubation facilities.
3. Adult carcass management	Carcasses of hatchery salmon may be disposed of in a carcass pit or removed off-site to processing plants. Some operations place carcasses in streams to augment or replace nutrients.
4. Incubation	Hatchery incubation involves placing fertilized eggs in containers (e.g. trays or boxes) most suitable to the species for an extended undisturbed period. Eggs, while incubating, are usually treated with anti-fungal agents, and dead eggs are removed, through manual or mechanized means, to manage fungal growth. When hatched fish reach a stage of "button-up", i.e. the yolk is mostly absorbed; the fry are then moved to rearing containers.
5. Rearing	Rearing containers (e.g. tubs or ponds) and duration of rearing are species and hatchery dependent, but the principles are to provide high-quality water and feed to grow fish until they are ready for emigration to the ocean. Fish can also be reared in net pens located in a lake or estuary for part or all of the rearing phase. During rearing, hatcheries control growth rate and rearing conditions, sometimes managing disease outbreaks with antibiotics or chemical therapeutants.
6. Release location	The vast majority of fish enhanced by SEP are released from the facility, but some programs involve releasing fry or smolts to other parts of the same watershed (above or below the hatchery, or in the estuary), or into different watersheds.

7. Release time, size, and condition	Release time, size, and condition are critical factors in determining success. Time and size are related, with time determined by fish physiology and, to some degree, hatchery-controlled growth pattern. Most hatchery fish are released at a size larger than their natural cohorts as hatchery water supplies are often warmer than watershed streams. Condition at release is related to the health history and health at time of release.
8. Assessment	SEP production is assessed to measure performance and to support DFO regional stock assessment requirements. This involves marking fish via fin clips, injecting coded-wire-tags, or applying otolith banding through water temperature manipulation. Other marking methods, such as genetic markers, scale pattern marks, and PIT tagging are rare, and usually only used for specific research projects. Recovery of marked fish is also part of assessment and, as a hatchery activity, occurs through brood stock collection.
Spawning Channels	
9. Spawning channel - all activities	Spawning channels, for purposes of this framework, are channels that SEP operates and manages by controlling spawning densities and actively cleaning spawning gravel substrate, usually with mechanical devices. SEP spawning channels produce mainly sockeye salmon, but chum and pink salmon are also produced in lesser amounts. Adults enter volitionally, or are sometimes directed, into the channel by means of a diversion fence in the river. Fish pair and spawn naturally within the channel, eggs incubate naturally, and fry emerge when ready to migrate. Juveniles migrate out of the channel volitionally to the river of origin without supportive rearing. With respect to assessment, spawning channel adults are counted into channels, and juvenile downstream numbers are estimated by proportional sampling, but rarely are marks or tags applied.

The framework then utilizes a pathway of effects to consider the effects of genetic, disease, and ecological interaction risks for each enhancement activity (Appendix IV). These are graphical presentations of the specific junctures for each enhancement activity and their effects on risk. These are summarized by risk category and activity in Tables 4, 5, and 6 and based on the cause and effects assessment for each risk category, mitigation measures are described. The analysis concludes with an assessment of uncertainties and knowledge gaps for each risk. Figure 3 illustrates the nine activities and the full process.

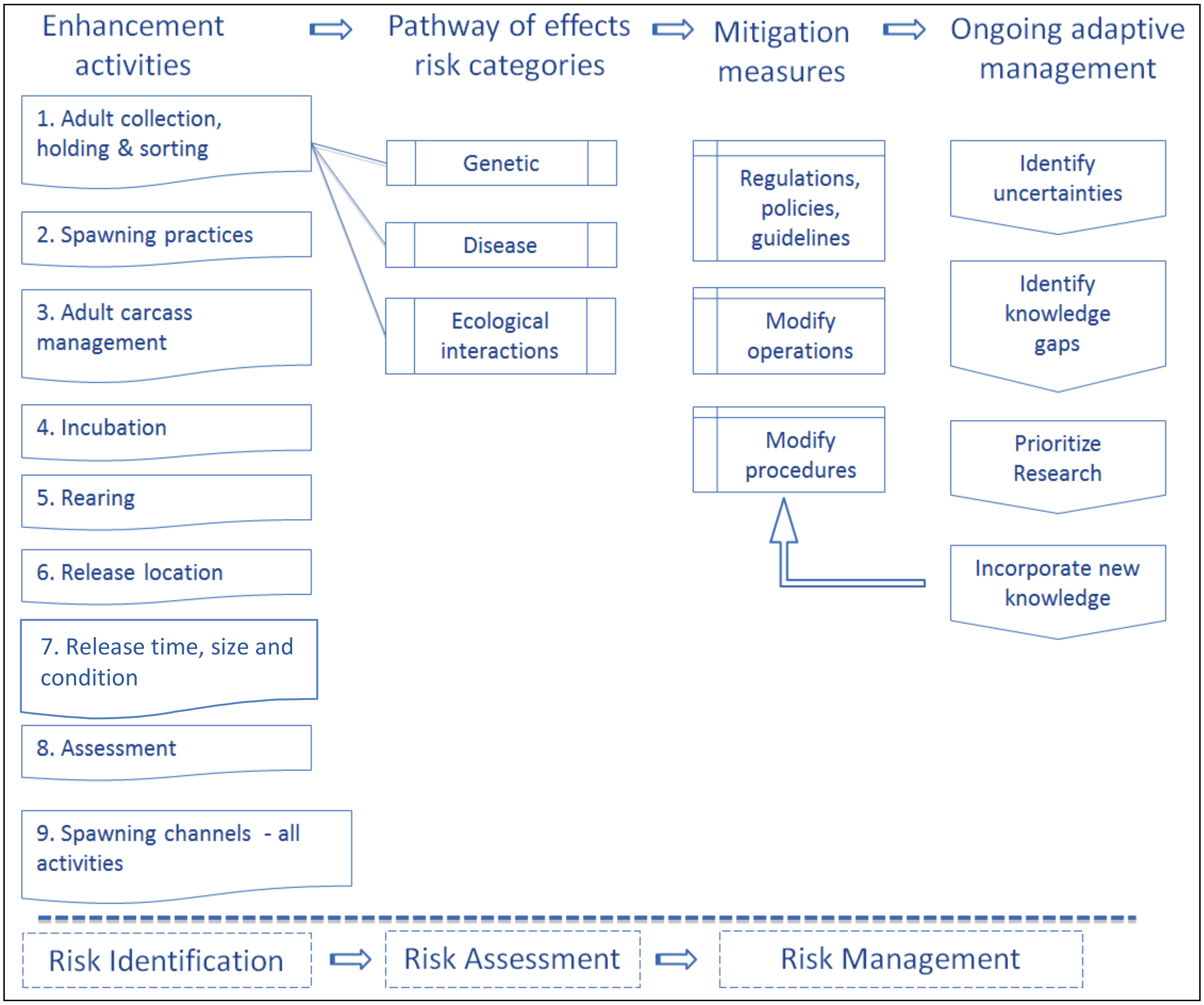

Figure 3: Risk identification, assessment and management process.

4.1 Overview Assessment of Risk by Enhancement Activity

It is important to note that risk factors do not apply equally to all enhancement activities and Table 2 indicates which categories of risk are of primary concern for each activity. This analysis facilitates the focus of risk management where most required. For example, genetic risks are most likely for activities related to adult collection and spawning while ecological interaction risks are centered on juvenile releases – locations, size and time. Tables 4, 5 and 6 further the analysis with a description of the risk mechanisms that are at play for each type of risk and enhancement activity as conducted at SEP facilities and the mitigation measures utilized.

Mitigation measures are specific procedures that can reduce risks e.g the disinfection of eggs to reduce the risk of disease to low levels. SEP has many such measures consolidated in guidelines, Best Management Practices[8], Fish Health Management Plans, and PAR licence conditions and their application forms the basis of this framework. No human activities are

[8] The purpose of this Best Management Practices document is to support Community Involvement Program staff and community partners in meeting *PAR* licence conditions.

risk free but the use of suitable risk management measures can reduce risk to low levels and allow benefits to flow from the activity.

Table 2. Occurrence of risk associated with enhancement activities.

Enhancement Activity	Genetic (see Table 4 for Risk Mechanism)	Disease (see Table 5 for Risk Mechanism)	Ecological Interaction (see Table 6 for Risk Mechanism)
1. Adult collection, holding and sorting	P	S	S
2. Spawning practices	P	P	N/A
3. Adult carcass management	N/A	S	S
4. Incubation	S	S	S
5. Rearing	P	P	S
6. Release time, size and condition	N/A	P	P
7. Release location	P	N/A	P
8. Assessment	S	S	S
9. Spawning channels	S	S	S

N/A – Not Applicable - the risk will not occur with this activity. P - Primary: the risk is associated with the activity under most circumstances. S – Secondary: the risk is associated with the activity under some circumstances e.g. during incubation, although not common, a significant egg mortality in a particular run timing component of the run could result in a genetic impact.

The PoE diagrams (Appendix IV) provide a practical complement to the tables and to the following sections which assess each risk in detail and describe the risk mechanisms and standard mitigation measures for management of the risk. This risk assessment sequence (identification overview, PoEs, and risk mechanism/mitigation analysis) can be applied to a particular production line to audit compliance, or can be used to highlight opportunities for adaptive management.

4.2 Genetic Risks

4.2.1 Risk Description

Since the early 1980s salmon culturists have been aware that artificial production can lead to unwanted or unanticipated genetic changes in wild and enhanced populations (Northwest Power Planning Council, 1998). Recent studies with Pacific Northwest salmon populations indicate that hatchery fish may have a lower fitness in natural environments than do wild fish (Araki, et al. 2008), resulting in lower relative reproductive success. Thériault, et al. (2011) report that evidence in recent years is accumulating that suggests effectiveness of enhancement[9] as a management tool may be less than formerly expected, as a result of reduced fitness in enhanced populations.

[9] For purposes of this discussion about genetic risks the term enhancement is used in reference to producing salmon by hatchery techniques; although there may be genetic effects caused by other enhancement techniques such as spawning channels, fishways and habitat restoration, they are considered to be minimal. Also, enhancement in this context is interchangeable with the term supplementation, which is widely used in the genetics literature.

The increase in production numbers in an enhanced population may compensate for a loss in individual productivity, or even result in a net increase in productivity for the entire population, such that harvest or assessment objectives are achieved. This may be desirable or acceptable in a population for which long-term enhancement for harvest purposes is intended, but the net benefit and increased productivity must be balanced with risks of potentially reduced fitness within the population(s) and genetic risks of outbreeding with fish in nearby wild populations.

When production objectives are for conservation purposes (restoration, rebuilding, extinction/extirpation prevention), reduced effectiveness within a population may be an acceptable risk in the short term, if greater harm is likely to result from a very low population size in the absence of enhancement (inbreeding, loss of rare genetic variants).

The interrelationships between, and relative effects of, genetic and environmental factors on fitness are poorly understood at this time (Tymchuk et al. 2006 and Leggatt et al. 2010) but, where genetic diversity has been preserved, it is anticipated that if enhancement were stopped natural selection would reverse the domestication process in many cases. Vandersteen et al. (2012) found that effects of repeated introduction of a domesticated genotype into a wild genetic background were small, even after only three generations of backcrossing to the wild strain. While more data are needed to study these effects, such observations are important considerations when planning time-limited enhancement initiatives.

An example of successful application of time-limited enhancement for rebuilding of a wild salmon population in British Columbia is the Stave River chum salmon program, begun in 1982 (Bailey et al. 2005). Extensive hatchery augmentation[10], utilizing native broodstock, was combined with harvest reduction, flow control and habitat improvement. As a result of this combination of measures, the population was rebuilt and hatchery augmentation was discontinued in 1998. After three cycles without enhancement, stock abundance continues to be maintained through natural spawning and the stock trends correspond with nearby un-enhanced stocks.

Hatchery practices, if not well managed, may cause unwanted genetic effects that alter run timing and spawning periods. This can occur during several stages of the enhancement process, but is most likely to occur when broodstock is taken from narrow or selected timings of the run period, persistently over several years, resulting in compressed or altered spawning periods or egg-take timing. However, such impacts can be mitigated if appropriate broodstock management protocols are implemented. For example, at Capilano hatchery, a deliberate propagation of early run coho, commencing with the 1982 brood, succeeded in reestablishing the early returning component of the Capilano coho population. (Federenko and Perry, 1991). In some cases, it may be desirable to modify spawning periods to meet operational or harvest objectives, but in general efforts are made to maintain the natural spawning times associated the progenitor wild stock.

Genetic risks may arise from broodstock management practices. There are two general approaches to hatchery broodstock management, segregated or integrated, each with attendant advantages, disadvantages and risks. The segregated approach aims to maintain hatchery stock as reproductively distinct or genetically separated from the naturally spawning population (HSRG, 2004). In contrast, in the integrated approach hatchery brood stock can be viewed as

[10] Although natural chum egg and fry production from the Stave River for the enhancement period is unknown, the resulting adult total return during the post-enhancement period (1990-2003) represented a 4.7 times increase over natural total return during the pre-enhancement period (1960-1984). In 1985 to 2002 return years, hatchery-produced adult escapements estimates averaged 18.4% of the total, and 15.2% for the years 1990 to 2002.

an extension of the natural spawning population, such that hatchery- and naturally-spawned fish reproduce in both the hatchery and wild environment and are considered as a single population.

Segregated broodstock management is expected to generate a population that diverges genetically from the founding natural population, as broodstock are maintained separately and opportunities for hatchery fish to spawn naturally are limited. The population may, after several generations, become domesticated through selective forces or change direction through genetic drift. As well, programs utilizing a segregated approach may sometimes be based on transplanted stocks that must be reproductively isolated from naturally spawning native populations, sometimes through physical removal from the spawning grounds. In contrast, integration maintains a single population in the system, but may result in the population becoming more domesticated (i.e. less adapted to successful reproduction in the wild). The degree to which this occurs in integrated systems is not currently known, but will depend on the degree to which wild spawners are incorporated in the breeding groups and how rapidly domesticated genotypes will be selected against in nature (e.g. in the marine phase of life, or in freshwater on progeny from hatchery-reared parents).

Enhancement programs in SEP are managed on an integrated basis and have generally been based on the native salmon population of interest. This approach facilitated enhancement of a wide range of populations. The program is not considering a change to segregated broodstock management and SEP facility infrastructure and the degree of intermingling of wild and enhanced salmon populations would render no such opportunities. Instead the program approach is to mitigate and minimize genetic risks by balancing and prioritizing production objectives and implementing appropriate in-hatchery practices, as detailed in the following section. Additionally, SEP has adopted a conservative approach to transplanting fish into non-native watersheds in recent years.

A key goal of the integrated approach is to minimize genetic divergence of the integrated population from the existing pre-enhancement local population. Broodstock from both environments (hatchery and natural) are intentionally mixed each year, sometimes with an effort to emphasize contributions from the current generation of fish returning from natural spawning. Use of the local population in an integrated supplementation avoids genetic problems associated with transplantation and alleviates potential problems with low broodstock numbers and outbreeding depression that can occur in segregated programs (through inbred hatchery fish breeding with wild populations). Additionally, in an integrated program, not all hatchery fish need to be marked to be identifiable for subsequent removal, nor is the handling of adult salmon returns at a fence required for the removal of hatchery fish from the wild spawning environment.

However, integrated enhancement is increasingly being linked with changes in the dynamics and genetic structure of the enhanced population, reflected in a lower individual productivity for fish spawning in the natural environment. As such, the genetic risks of enhancement, typically domestication, outbreeding depression, and inbreeding depression, are considered in this framework as having potential to affect the fitness of the integrated enhanced population (comprised of hatchery broodstock and natural spawning enhanced salmon) and surrounding unenhanced (wild) populations (Table 3).

Risks to the enhanced and surrounding wild populations generally are believed to result from domestication selection within the hatchery population and outbreeding effects on surrounding populations. Domestication selection results when selection in the integrated population is driven by a more productive hatchery than natural spawning environment. Typically, the increased survival that hatchery salmon benefit from during incubation and rearing in the hatchery environment results in reduced or altered selection in the integrated population. Whereas natural salmon populations can withstand, or even benefit from a certain influx of genetically distinct individuals which results from natural straying, a great increase in immigration may occur when hatchery fish home poorly or are produced at high abundance and stray. Outbreeding in the surrounding populations occurs when hatchery fish interbreed with local fish in the natural environment

Inbreeding depression, another genetic risk, exists when enhancing small populations. Inbreeding is not generally a risk associated with SEP enhancement initiatives due to the larger size of populations the program works with, but may become a risk in attempts to restore or rebuild at-risk or severely depleted populations.

Appendix III examines these risks in more detail with a review of the genetic effects and risks to hatchery broodstock, naturally spawning integrated enhanced populations, and surrounding unenhanced populations.

Table 3. Genetic risks of enhancement on integrated and surrounding populations.

Genetic Risk	Mechanism	Integrated Enhanced Population Components		Surrounding un-enhanced (wild) populations
		Hatchery broodstock and direct progeny	Naturally spawning enhanced salmon	
Domestication	Altered selection that can result in genetic adaptation of animals to the hatchery environment.	Directly affects progeny.	May affect if domestic selection results in reduced productivity of individuals.	Does not affect.
Outbreeding Depression	Results from hatchery salmon (potentially genetically differentiated/domesticated) breeding with an un-enhanced (wild) population.	Does not affect.	Does not affect when local broodstock are used. May affect if non-local broodstock are transplanted over existing local populations.	May affect if there is significant, long term straying of enhanced population.
Inbreeding Depression	Reduced genetic diversity (bottlenecking) from interbreeding within small effective breeding populations.	Does not affect large broodstock populations. Does not affect small, at risk populations if spawning protocols are utilized. May affect small, at risk populations if spawning protocols are not used.	Does not affect larger populations. May affect if population is small.	Does not affect.

4.3 Genetic Risk by Enhancement Activity - Mechanisms and Management

The previous section describes the nature of genetic risk to wild salmon and its general application under the SEP operational regime. Table 4 describes the specific genetic risk mechanisms that are at play for each enhancement activity as conducted at SEP facilities and the mitigation measures utilized to manage and reduce risk. Genetic risks arise chiefly from broodstock collection and spawning practices so compliance with broodstock collection and spawning protocols is foundational for risk management, although risk to fitness is unquantifiable risk identified in the uncertainties section. Appendix V includes a more detailed description of risk mechanisms and specific material from guideline, planning and fish health management documents.

Table 4. Genetic risk – mechanisms and risk mitigation measures.

Enhancement Activity .	Risk to Wild Salmon (See Appendix V for more detailed descriptions)	Risk Mitigation Measures (See Appendix V for more detailed descriptions)
1. Adult collection, holding and sorting	Loss of genetic diversity can occur if broodstock are not representative of the wild population, or individuals outside the target population are inadvertently included.	Follow Genetic Management Guidelines including broodstock collection protocols appropriate to the population size and enhancement objective. Include wild salmon in broodstock.
2. Spawning practices	Loss of genetic diversity may occur if the entire donor population and its genetic characteristics are not represented.	Follow Genetic Management Guidelines including spawning protocols appropriate to the population size and enhancement objective. Include wild salmon in spawning.
3. Adult carcass management	Not applicable.	Not applicable.
4. Incubation	Minimal Risk. Would only arise is there is disproportionate incubation mortality for specific run timing or size components.	Follow good fish husbandry practices for incubation as laid out in FHMPs and CIP Best Management Practices.
5. Rearing	Domestication effects may occur from rearing practices or container effects. May be some risk to diversity if there is disproportionate mortality in specific time or size components. This may affect representation of population.	Follow good fish husbandry practices for rearing, as laid out in FHMPs and CIP best management practices.
6. Release time, size and condition	Not applicable.	Not applicable.
7. Release location	Risk of outbreeding depression if enhanced fish stray to surrounding un-enhanced stocks.	Follow production plans and release fish in numbers and at life stages and locations that maximize the likelihood of fish returning to the release site – not straying to other systems.
8. Assessment	Minimal Risk. Would only arise if assessment activities (e.g. counting fences, downstream traps) affect genetic composition of population through an effect on spawn area/timing of a particular portion of the run.	Design structures and conduct assessment activities in a manner that does not unduly restrict or affect passage of adults or juveniles.

4.4 Disease Risks

4.4.1 Risk Description

Disease risks are difficult to quantify, in large part due to our limited knowledge of the range of potentially pathogenic organisms and the variable and generally unpredictable nature of the aquatic environment. It is important to keep the nature of microbes in the aquatic environment in perspective. The presence of pathogens is normal; a single millilitre of water can carry as many as one billion viral particles (Suttle, 2005). Certainly not all are pathogenic to fish, but a great number likely have the potential and are a natural component of aquatic ecology. For disease to occur, fish must become susceptible to a particular pathogen and the pathogen needs to be present, viable, and at a sufficient concentration in the water column, at the time the fish is susceptible. The environment is an essential factor in determining the outcome of any encounter between pathogen and potential host as it impacts both the susceptibility of the host and the virulence of the pathogen. It is impossible to over-stress the dynamic nature of the host-pathogen-environment interaction.

Disease may be broadly classified into two categories; infectious and non-infectious. Infectious diseases are those that are transmissible and result from the presence of a pathogenic biological agent that has gained access to a host organism (e.g. the common cold in humans). Non-infectious diseases, often referred to as disorders, are non-transmissible, are brought about by environmental, genetic, physiological, or other factors, and are not known to involve pathogenic organisms (e.g. cancer in humans). In fish culture, infectious diseases are of particular concern as they present a risk of transmission through a number of avenues, and these are the disease risks considered in this document.

Pathogens may be obligate, requiring a host to proliferate, or opportunistic, each presenting a different set of risks. Although obligate pathogens require a host, many are capable of remaining viable for an extended period when a host is absent. Because these pathogens require a host at some stage of their cycle, they will not normally be found in a water supply unless a host population is present to sustain them.

Opportunistic pathogens are those present in natural water supplies, and are not pathogenic under normal circumstances. They are capable of living and reproducing while attached to plant life, substrates, or suspended organic material, and they may also be present on, or in, a host organism, but are not normally pathogenic. These organisms are generally present in natural surface waters and are typically only problematic when fish are compromised.

Disease is not an inevitable outcome of interactions between a fish and a pathogen; under normal circumstances pathogens may be harmless or will affect only the weakest animals in a population. However, the added pressures of physical, chemical, and biological stressors inherent in hatchery situations may tip the balance in favour of the pathogen and allow an infection to occur. As a result of infection, and under a particular set of conditions that compromise the host beyond its ability to cope, disease may occur (Wedemeyer, 1996).

Although risks to enhanced populations while in the hatchery environment are abundantly evident, and released hatchery fish have the potential to affect the health of wild fish, disease transmission to wild salmon populations is considered uncommon (HSRG, 2004). However, such events are possible. A contained population that has become diseased may present a potential risk to wild fish present in the system receiving water from an infected site (Brannon et al. 1999) because it may amplify a normally present pathogen. This is a topic of significant research and current and future studies, primarily in the context of commercial aquaculture, may yield increased knowledge over time.

One of the challenges in identifying disease risks is the widespread nature of many of the pathogens that are problematic in fish culture. Some pathogens are naturally ubiquitous in practically every BC water system in which salmonids are found. Under normal circumstances these pathogens are thought to present minimal risk to wild populations, but in a culture setting their presence can result in large scale losses to hatchery fish.

Hatchery fish are exposed to the same waters as wild fish, and are therefore exposed to the same pathogens. At a hatchery production level, some degree of disease is likely to occur although husbandry practices and biosecurity measures generally mitigate the potential risks. Should a major disease outbreak occur, there is potential for pathogen transfers to and among wild fish, primarily through hatchery effluent (Gardner et al. 2004), or by improper disposal of hatchery adult carcasses or rearing mortalities. The nature of enhancing wild populations using gametes collected from mature salmon returning from the oceans means that it is impossible to prevent introduction of pathogens to the hatchery in all cases, and pathogens, both obligate and opportunistic, may be amplified through intensive culture. While ubiquitous endemic pathogens are often present in the hatchery environment, amplification of non-endemic pathogens imported from other populations may be a potential risk where biosecurity measures fail. Certain hatchery operations and conditions can increase these risks; stress or improper nutrition can reduce disease resistance and increase pathogen shedding, and crowded conditions may increase the transfer of pathogens between individuals (Gardner *et al*. 2004).

Although a concentrated pathogen load in effluent water presents the most likely route of transmission, there is potential for disease transfer to wild populations via infected releases. If the hatchery population is not endemic to the watershed, these risks are elevated for wild populations since they may not possess resistance to particular pathogens. Diseased fish are more likely to fall out of the population through death or predation, presumably the risk of transfer of many pathogens decreases as time passes. Depending on the pathogen, some fish may become carriers and present a risk of introducing disease into a naïve population through straying.

Salmon carcasses from some hatchery operations are distributed within the watershed as a mechanism for delivery of marine nutrients into the freshwater ecosystem (HSRG, 2004). While potentially conveying positive effects, the practice may also pose a risk to wild salmon via pathogen transmission through sediments or the water column, or via direct consumption (HSRG, 2004). Studies on carcasses placement in riparian areas as opposed to in-stream may be of merit.

Routine disease screening and vaccination programs may improve survival rates such that adult production can be maintained with reduced juvenile output.

In summary, the risk of disease resulting from interactions between fish and a pathogen is increased when individuals are exposed to physical, chemical or biological pressures that may compromise their resistance, but little evidence currently exists to support the risk of routine transmissions from hatchery to wild populations, although some risk likely exists.

4.4.2 Disease Risk by Enhancement Activity - Mechanisms and Mitigation Measures

The previous section describes the nature of disease risk to wild salmon and its general application under the SEP operational regime. Table 5 describes the specific disease risk mechanisms that are at play for each enhancement activity as conducted at SEP facilities and the mitigation measures utilized to manage and reduce risk. Compliance with Fish Health Management Plans, Best Management Practices and PAR licence conditions relevant to fish health management, are fundamental to mitigating disease risks to wild salmon. Appendix V includes a more detailed description of risk mechanisms and specific material from the documents.

Table 5. Disease risks - mechanisms and risk mitigation measures.

Enhancement Activity .	Risk to Wild Salmon (See Appendix V for more detailed descriptions)	Mitigation Measures (See Appendix V for more detailed descriptions)
1. Adult collection, holding and sorting	Minimal Risk. Pathogens could be transferred from the facility to off-site collection locations if collection equipment are not properly disinfected.	Equipment must be kept clean at all times, properly disinfected and as far as possible, not shared between sites as per FHMPs and BMPs
2. Spawning practices	No direct risk to wild salmon from spawning practices but Infectious Hematopoietic necrosis (IHN) virus in sockeye can be shed and recycled in incubation and rearing if infected brood stock are brought on site. IHN virus is present in many wild sockeye stocks.	Alaska protocols must be followed for sockeye culture; virus free water supply, stringent disinfection of equipment, containment during incubation and rearing – small containers and isolation from other stocks.
3. Adult carcass management	Minimal risk. Pathogens transfer through carcasses placed in natal streams for nutrient enrichment is possible but unlikely. only untreated carcasses (i.e. no therapeutants) from the native stock are utilized for placement.	Follow Carcass Placement Guidelines and FHMP for carcass disposal. Use only local carcasses for placement as these will not introduce pathogens new to the system.
4. Incubation	Minimal risk. The practice of egg surface disinfection renders disease risks from incubation very low.	Follow FHMP and BMPs for egg disinfection.
5. Rearing	Transportation of fish for rearing off-site can carry a risk of disease transference to receiving water populations. Effluent may impart near field and localized pathogen effects.	Follow FHMPs and BMPs for husbandry practices during disease outbreaks and for non-release transportation of fish. Comply with fish health management conditions in PAR particularly with respect to monitoring fish condition, mortality rates and consultation with vets as required.
6. Release time, size and condition	Hatchery fish may carry pathogen loads that could impact wild fish.	Follow FHMP protocols and comply with PAR licence conditions with respect to disease screening and treatments.
7. Release location	Not applicable – disease risk is associated with time, size and condition..	Not applicable

8. Assessment	Handling of spawners, or, activities that alter or delay spawn timing. may render spawners more susceptible to pathogen and disease occurrence.	Follow FHMP with respect to assessment activities – locate and manage structure and conduct activities in a way that minimizes handling and disruption of migratory activities.

4.5 Ecological Interaction Risks

4.5.1 Risk Description

Brannon et al. (1999) focus on five main ecological interaction issues related to salmon ecosystems: carrying capacity, competition, predation, disease and behavior (as a consequence of genetic domestication). Since the risk factors of carrying capacity in the marine environment, disease and domestication are addressed in separate discussions, this section will describe the effects of carrying capacity, competition and predation in the freshwater environment.

Carrying capacity can be defined as:

> *"The maximum biomass of a population that can be sustained within a defined area throughout a specified period of time (Willis et al. 2008)."*

Risks associated with carrying capacity in the freshwater environment are most likely to occur when juvenile enhanced salmon are released and remain resident within the watershed, either by design as part of an enhancement strategy (e.g. coho fry planting) or as an unintentional outcome of a strategy. The latter may occur if juveniles are released at too large a size or too late a time relative to wild fish. When hatchery fish remain resident within the watershed or near-shore environment, negative effects can occur if carrying capacity limits have been reached and hatchery fish displace wild resident juveniles. In most cases, juvenile salmon released as smolts from enhancement facilities migrate relatively rapidly through the freshwater part of the system to the marine environment. Risks to wild salmon during the juvenile migration phase most likely manifest as competition and predation. Research documenting effects of hatchery fish on the freshwater carrying capacity of salmon streams is largely lacking (Brannon et al. 1999), but evidence suggests that large releases of hatchery pre-smolts, particularly at inappropriate times and sizes, can result in significant competition with wild salmon for food and cover (Brannon et al, 1999). In the lower Columbia River, for example, stocking hatchery fry in excess of carrying capacity was identified as one of the factors leading to the collapse of wild coho populations (Flagg et al. 1995).

Willis, et al. (2008) define competition as:

> *"The relationship between two or more organisms living in the same area that have overlapping niche requirements for a resource that is in limited supply."*

As with carrying capacity, the risks of competition are elevated when enhanced fish are released or migrate at a time or in a condition that extends their time in the freshwater environment (Flagg and Nash, 1999). However, hatchery-induced differences can give differing advantages to both hatchery and wild fish (Tatara and Berejikian, 2010). Size differences created by hatchery rearing conditions (e.g. warmer water and higher feed levels) may result in hatchery smolts that are larger than wild smolts, and better able to compete for space or food. Conversely however, if hatchery fish are released after wild fish have established territories, wild fish have the advantage of prior residence when defending resources (Tatara and. Berejikian, 2010).

Brannon et al. (1999) define predation as:

"…an ecological interaction where one individual becomes a food source for another. Predation is one of the fundamental ecological interactions observed between many species."

Hatchery smolts may consume wild juveniles (Gardner, et al. 2004), when there exists a sufficient size differential. Hatchery releases may attract predators to the detriment of local wild populations. Hatchery fish may also become prey of wild fish and predatory birds, in part due to less experience in predator avoidance (Flagg and Nash, 1999). Hatchery fish can, on the other hand, impart some measure of protection for wild fish from other predation effects because of their numbers. In a review of 14 studies in the Pacific Northwest, Naman and Sharpe (2010) found that, in most instances, predation by hatchery yearlings on wild subyearlings occurred at low levels, except when multiple contributing factors, such as lowered prey population abundance, were present. Rearing in hatchery environments can make hatchery fish more susceptible to predation than wild salmon due to less well developed capabilities in basic survival strategies, feeding deficits in the shift from hatchery-supplied food, and behaviour alterations from handling and transportation (Olla et al. 1998).

4.5.2 Ecological Interactions - Risk Mechanisms and Mitigation Measures.

The previous section describes the nature of the risk of ecological interactions to wild salmon and its general application under the SEP operational regime. Table 6 describes the specific ecological interaction mechanisms that are at play for each enhancement activity as conducted at SEP facilities and the mitigation measures utilized to manage and reduce risk. Production planning process and compliance with production targets supported by stock assessment and habitat capacity information are pivotal to managing ecological interactions as are compliance with Fish Health Management Plans, Best Management Practices and PAR licence conditions relevant to time and size of fish release. Appendix V includes a more detailed description of risk mechanisms and specific material from the documents.

Table 6. Ecological interaction risks - mechanisms and risk mitigation measures.

Enhancement Activity	Risk to Wild Salmon (See Appendix V for more detailed descriptions)	Mitigation Measures (See Appendix V for more detailed descriptions)
1. Adult collection, holding and sorting	Minimal Risk. Excessive removal of spawners affecting ecosystem nutrient availability is possible but unlikely.	Follow Broodstock Management Guidelines.
2. Spawning practices	Not applicable.	Not applicable.
3. Adult carcass management	Minimal Risk Ecological disruption resulting from carcass loading density or distribution that is incompatible with system capacity is possible but unlikely.	Follow Carcass Placement Guidelines and FHMP/BMPs for carcass disposal.
4. Incubation	Minimal Risk. If chemical therapeutants are utilized there is a possible risk of localized impacts in effluent.	Follow FHMP and BMPs for incubation and therapeutants management.
5. Rearing	Minimal Risk.	Follow FHMP and BMPs for rearing and

	If chemical therapeutants are utilized there is a possible risk of localized impacts in effluent.	therapeutants management.
6. Release time, size and condition	Juveniles released prematurely or too large may stay in freshwater to compete or predate on wild fish.	Comply with FHMP and PAR licence conditions with respect to releases. Comply with production plan for release numbers and strategies.
7. Release location	Coho fry releases may affect resident fish if habitat is fully subscribed. Fish released in or near non-natal watersheds may stray to other locations and compete with wild populations.	Comply with production plans for release numbers and release locations
8. Assessment	Downstream juvenile assessment programs may disrupt migration or behavior.	Follow FHMP with respect to assessment. Operate programs to minimize the likelihood of mortalities or migration timing alterations.

5 Spawning Channel Operations

5.1 Risk Description

Spawning channel production involves more minimal intervention than hatcheries and risks are managed and mitigated differently. Operation of spawning channels presents risk of genetic, disease and ecological interaction to wild salmon populations through the mechanisms shown in the PoE diagram in Appendix IV.

Genetic risks to wild populations may result from the exclusion of certain components of the wild stock from the spawning channel due to non-representative channel loading, as well as of genetic outbreeding effects due to mixing of stocks in a spawning channel that would have been separated spatially in spawning in the natural environment. This risk is present primarily when use of diversion or exclusion fences for channel loading result in non-representative loading of the spawning channel, which can alter run timing in the natural stock.

With respect to disease risks, some sockeye spawning channel operations have experienced pre-spawn mortalities associated with the parasite *Ichthyophthirius multifiliis* (*Ich*) in instances where spawners returning to fresh water were subject to high densities over extended periods of time in elevated water temperatures (Traxler, et al. 1998). Light infections of *Ich* were found in resident fish populations, and are considered the likely source of 1994 and 1995 epizootic events in the Babine Lake spawning channels (Traxler, et al. 1998). At least one such high pre-spawn mortality event has occurred in wild Chinook salmon not exposed to spawning channel sockeye. (Pers. comm. D. Lofthouse, 2012).

Ecological interaction risks may result in some instances from gravel cleaning effluent. The gravel in the majority of surface water-fed spawning channels is mechanically cleaned on either a yearly or biannual basis. In some cases, the effluent containing silt and organics is pumped "to ground" where it is naturally filtered. However, this is not possible for all sites due to geography or practicality and results in the release of suspended sediments in effluent which may have an impact on water quality or spawning gravel. The impact of such effluent on lake-fed sites that collect mainly glacial silt and organics is likely minimal. At sites that operate on river water, the discharge of silts and sands may have more impact, but since cleaning takes place in summer, the only effect on wild sockeye populations might be that on localized gravel quality for future spawners. Wild juvenile coho or Chinook salmon might be impacted at the time of cleaning, but the effects would be localized and the risks likely low (pers. comm. D. Lofthouse, 2012).

Risk	Mechanism	Mitigation Measures
Genetic Effects	Loss of genetic diversity in wild salmon populations can occur if loading of spawning channels using man-made diversion structures prevent access of all run timing components.	Operate diversion structures in a manner that allows access of all run components as far as possible.
Disease Effects	Wild populations may sometimes be exposed to elevated levels of disease-causing pathogens organisms from occasional occurrences of high pre-spawn mortalities below spawning channels. This result from pathogen presence combined with elevated water temperatures and with high densities of pre-spawner.	Operation practices to manage risk include: • Reduce adult numbers at project fence through terminal harvest • Reduce holding time by loading the channel rapidly • Reduce adult loading levels • Optimize gravel quality to ensure prompt spawning • Reduce water temperature where possible
Ecological Interactions	Wild populations may be affected through localized effects of silt and organics in effluent and its deposition on spawning gravel downstream of spawning channel cleaning operations.	**Reference:** FHMP **General Measures:** Effluent from cleaning spawning channels is pumped to "ground" where feasible.

5.2 Risk Assessment and Management

6 Broader Risk Factors

In addition to the genetic, disease and ecological interaction risks that comprise this framework, hatchery production has also been associated with harvest and marine carrying capacity risks. These are over-arching risks not associated with a specific enhancement process component and can be a function of scale of production. Harvest and marine carrying capacity effects are described as follows and illustrated with PoE diagrams in Appendix IV.

An inherent challenge in fisheries management is the harvest of co-migrating mixtures of strong and weak salmon populations, whether wild or enhanced. In such fisheries, there are risks of overfishing reproductively weaker or lower-numbered wild salmon populations that are mixed with stronger or larger-numbered wild or enhanced populations. These challenges are present in fisheries without enhanced populations, but production of large numbers of returning adult salmon through enhancement can create or exacerbate the challenges.

Harvest risks and production scale are considered as part of the integrated production planning process that is utilized to develop annual production plans for SEP facilities. Described in the SEP Production Planning Framework (DFO, 2012) the process considers enhancement objectives and appropriate production numbers, fishing plans (harvest location, timing, expected catch, etc.) and harvest requirements, stock assessment planning and information and terminal and selective fishery opportunities. Scale of production has been adjusted in cases where there are undesirable harvest outcomes, or when objectives have been met; for example, chum production in the lower Fraser River and coho production at Robertson Creek Hatchery have both been reduced significantly over the past 20 years. A balanced enhancement approach is taken to enhance weaker stocks that might be harvested in fisheries on nearby enhanced stocks (e.g. Nahmint Chinook salmon are enhanced to balance impacts from Robertson Creek Chinook production). Harvest risks are also addressed through management of fisheries to harvest levels sustainable by co-migrating wild populations, harvest of surplus returns at the production facility or in terminal areas, or through selective fishing practices such as hatchery mark only selective fisheries.

It should be noted that the stock assessment information provided from the marking of hatchery salmon *reduces* harvest risks to wild salmon overall as harvest management for Chinook salmon and to some extent, coho salmon is based on hatchery derived stock assessment information.

The framework considers carrying capacity in the marine environment as an effect beyond the scope of SEP. SEP accounts for only a small portion of the total number of enhanced salmon released to the Pacific Ocean by all nations (Ruggerone et al. 2010) and is expected to have a minor influence on the offshore marine environment. With respect to the near-shore environment, Georgia Strait is influenced by hatchery releases and wild salmon from both Canada and the United States, at levels that fluctuate significantly from year to year. SEP hatchery releases have been reduced in some areas, and for some species (e.g. Fraser River chum), but the complexity of the system makes it difficult to isolate the contribution of hatchery salmon to effects on carrying capacity. Ongoing work, and studies such as those by Beamish et al. (2007, 2008, and 2011) and the Georgia Strait Ecosystem initiative will inform future analysis.

7 Knowledge Gaps and Adaptive Management

The framework identifies biological risks to wild salmon populations from enhancement activities, and describes existing mitigation measures to manage those risks. However, there continue to be uncertainties and knowledge gaps associated with many of the risk factors and mitigation measures. For example, for genetic risks, there are uncertainties about interrelationships between, and the relative effects of, genetic and environmental factors on fitness. In light of the emerging science on fitness changes that can occur in integrated enhanced populations, there are also uncertainties about the optimal balance between increasing the number of spawners and possibly decreasing reproductive fitness i.e. what should the maximum target enhanced contribution be for conservation-based enhancement? Moreover, there are also early indications that if enhancement is stopped, natural selection may reverse any genetic changes but the number of generations of natural spawning that would be required for population to revert back to natural genotype and phenotype is unknown.

With respect to disease risks, studies under consideration to address uncertainties relate to the effects of targeted disease screening and vaccination programs on juvenile to adult survival rates. If there are benefits from such programs, adult production could be maintained with reduced juvenile output. With regard to ecological interactions, examples of knowledge gaps include uncertainties related to carrying capacity in different environments and whether hatchery programs may be contributing to density-dependent effect and predation and competition interactions in freshwater environments during the juvenile and adult spawning phases.

In order to address uncertainties and knowledge gaps, the SEP production planning process and regional processes such as the BC Southern Chinook Planning Initiative are key to identifying and refining research requirements. As requirements emerge from these processes, SEP works with Science staff to focus research priorities on the most important risk areas and where the potential for results are highest. Where appropriate, requests are submitted for formal science advice through the Canadian Science Advice Secretariat (CSAS). Knowledge gaps are also addressed through informal collaborative working groups within the Department and with other agencies and through the review of domestic and international literature. SEP will continue to adapt its operations and procedures as new knowledge becomes available.

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9 Appendices

Appendix I: Summary of the SEP/HSRG assessment recommended improvements for SEP operations

As noted in the framework, although SEP's operational practices generally met the recommendations, they helped inform the program operational strategies. The following gaps were identified; most of which were acted upon or initiatives are ongoing:

- Goals and objectives for projects need to be reviewed and clearly defined to ensure that they are current, and that they are consistent with broader watershed and departmental goals. Project goals and objectives should be developed and incorporated as far as possible within integrated planning processes. Now addressed through production planning process.
- Program assessment of adult contribution and production has become centered on index projects. Lack of direct assessment of non-index projects affects the capacity of projects to improve and adapt to site-specific conditions. Changes to assessment have resulted from changes in harvest and reduced assessment resources. To address these changes, the overall enhancement assessment framework needs to be reviewed and re-developed. Existing assessment is coordinated with that of wild salmon; the re-developed enhancement assessment framework should also be coordinated with the stock assessment frameworks under development for wild salmon. Development of the assessment framework is underway.
- While SEP has developed guidelines and strategies that should generally result in meeting a number of the recommendations of the HSRG, on-site evaluation and routine monitoring of their implementation is limited. Anecdotal information suggests that guidelines are sometimes not fully implemented either through lack of knowledge or expediency. Development of a systematic monitoring program is required to address this issue. A program is under development.
- Better communication of guidelines and best practices to enhancement staff, contractors, and volunteers is required to ensure all facilities have access to information and are applying it correctly. Greater use of the internet, workshops and other scheduled meetings would be an effective beginning, together with focused technical support. An approach is under development.

Appendix II: Assessment and Management of Risk in the Pacific Northwest – detailed examples

There are a number of other initiatives in the US underway or completed that inform the subject of risk management and assessment related to salmon enhancement. The following briefly describes some of the initiatives undertaken by specific US jurisdictions.

The Oregon Department of Fish and Wildlife operates the Oregon Hatchery Research Center that, in part, studies the differences between wild and hatchery salmon. They also publish hatchery operations plans and hatchery genetic management plans for each hatchery. The Independent Scientific Review Panel for the Northwest Power & Conservation Council of Oregon carried out a review of approximately 150 ODF&W programmatic and project issues (ISRP, 2010) and continues reporting on these and other reviews (ISRP, 2011). More specifically:

- Oregon fish management and hatchery operations are guided, as are all State departments, by Oregon Administrative Rules[11]. These rules include policies for native fish conservation, wild fish management, fish hatchery management and fish health management. Specific rules exist for transgenic fish, fish transport, propagation licensing, surpluses and uses of salmon eggs and fingerlings, scientific taking of fish and sturgeon.
- The Independent Scientific Review Panel (ISRP) for the Northwest Power & Conservation Council of Oregon reviewed approximately 150 Oregon Fish and Wildlife Program project and programmatic issues in three key areas: artificial production; fish passage through main-stem dams, the river and reservoirs; and habitat restoration monitoring (ISRP, 2010). In its Retrospective Report (ISRP 2011), the ISRP reviews relative success of hatchery supplementation programs and make a number of recommendations for future research requirements. Of particular interest to SEP is the ongoing work evaluating relative reproductive success of hatchery-produced spawners.
- The Oregon Department of Fish and Wildlife (ODFW) operates the Oregon Hatchery Research Center, the stated goal of which is "…to answer scientific questions related to fish recovery and hatchery programs, including the differences that may exist between wild and hatchery fish, and how to better manage those differences." The Center is research, rather than policy, based, but the ODFW published a fish health management policy (ODFW, 2003)[12] that sets out an operational basis to manage disease risks.
- The ODFW publishes an operations plan for each hatchery that along with facility descriptions set out goals and objectives, and current practices to achieve

[11] Oregon Administrative Rules for the Oregon Department of Fish and Wildlife are available at: http://arcweb.sos.state.or.us/pages/rules/oars_600/oar_635/635_tofc.html

[12] The ODFW fish health management policy is in need of updating (pers. Comm. T. Amandi, ODFW Fish Health Services, 2012).

each objective. The ODFW also publishes Hatchery Genetic Management Plans for each hatchery-reared salmon population as fulfillment of a NOAA requirement.

The state of Alaska ocean ranching hatchery programs are unlike those in other jurisdictions, but have the objective to "…enhance fisheries while minimizing wild stock interactions"[13]. While subject to the requirements by the NMFS discussed above, the Alaska Department of Fish and Game (ADF&G) has produced a number of policies related to enhancement risk to wild populations.

Directed by Congress in July 1997, the Northwest Power Planning Council conducted a thorough review of all federally funded artificial production programs in the Columbia River Basin (Northwest Power Planning Council, 1998). The Council recommended a coordinated policy for future operation of artificial production programs and provided recommendations for how to obtain such a policy (Northwest Power Planning Council, 1999). More specifically:

- Most Alaskan hatcheries are either private non-profit (PNP) or facilities operated by the Alaska Department of Fish and Game (ADF&G) to enhance sport fish. PNP hatcheries are guided by regionally-based comprehensive salmon enhancement plans; the plans vary significantly in content between areas, addressing for the most part salmon production and fisheries management.
- The ADF&G has produced a number of policies related to hatchery management, the most pertinent to the SEP risk management framework being a genetics policy (ADF&G, 1985) that provides guidance for stock transport, protection of wild stocks and maintenance of genetic variance. The ADG&G has also produced an informative one-page brochure that outlines policy development, hatchery production, regional planning and regulation of hatcheries in Alaska (McGee, S. G., undated).

Other related and significant work in the U.S. includes the following initiatives:

- Craig Busack of the NOAA Fisheries, Salmon Recovery Division, and Todd Pearsons of the Grant County Public Utility District, presented "Assessing and Reducing Ecological Risks of Hatchery Operations PCD Risk 1" at a 2010 State of the Salmon conference[14]. PCD represents the simulation of predation, competition and disease impacts in freshwater on natural origin juveniles caused by those of hatchery origin. The model makes assessments of a single species on a single species basis, reporting on a mortality effect basis. While science/expert based, easy to use and flexible, the model remains untested empirically and does not address ecosystem interactions.
- In July 1997, Congress directed the Northwest Power Planning Council (Council), with the assistance of the Independent Scientific Advisory Board

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[13] From the ADF&G hatcheries website at: http://www.adfg.alaska.gov/index.cfm?adfg=fishingHatcheries.main
[14] Presentations from the conference are available at: http://www.stateofthesalmon.org/conference2010/presentations.html

(a panel of 11 scientists who advise both the Council and the National Marine Fisheries Service on scientific issues related to fish and wildlife), to conduct a thorough review of all federally funded artificial production programs in the Columbia River Basin. Congress directed the Council to recommend a coordinated policy for future operation of artificial production programs and to provide recommendations for how to obtain such a policy (Northwest Power Planning Council, 1999).

Appendix III – Genetic Effects Descriptions

Genetic risks associated with fish hatchery programs generally fall into three categories: inbreeding depression, domestication selection, and outbreeding depression. The following describes each of these mechanisms and provides a summary of general implications. Subsequent sections describe risk affects by population category.

Domestication Selection

Hatchery rearing exerts selective pressures on the subject population, although the magnitude of these is debatable. Christie et al. (2011) reported that domestic selection can explain a precipitous decline in fitness of hatchery steelhead, and that first-generation hatchery steelhead had nearly double the lifetime reproductive success when spawned in captivity compared with wild fish spawned under the same conditions. These results indicate adaption to captivity can occur within one generation. Regardless of how hatchery fish are treated, ultimately there will be differences between hatchery and wild reared fish for the fundamental reason that their early experiences are different.

Many enhancement practices are not random, and are therefore selective. An unintentional imposition of selective pressure for run timing and migration behaviour results from arbitrary timing and choice of location for broodstock collection. Because of rearing conditions such as water temperatures, juveniles are not necessarily released at the same size relative to those in the natural system. Use of artificial feeds and resulting increased fry survival is thought to reduce the advantage of large egg size. Improved juvenile condition in the hatchery, compared to wild, may affect predator selection resulting in selection for traits leading to larger size and faster growth (Goodman 2004).

It has been argued that these differences could result in magnified differences later on in life. Differences could include different migration schedules, different maturation schedules, different growth schedules and different run timing. Although a segregated program can lead to rapid domestication, an integrated program, where some wild fish are incorporated into the hatchery program at each generation, results in disruptive selection and may result in some compromises between the two levels of adaptation. It cannot be known which adaptations will be favoured though.

Inbreeding Depression

Inbreeding depression is reduced fitness through the introduction of deleterious recessive genes in a given population as a result of breeding closely related individuals and can lead to a population bottleneck (Lynch, 1997). Breeding between closely related individuals results in more recessive deleterious traits manifesting themselves. The more closely related a breeding pair is, the more homozygous[15] deleterious genes

[15] Having two identical alleles that code for the same trait. Alleles are one member of a pair (or any of the series) of genes occupying a specific spot on a chromosome (called locus) that controls the same trait.

the offspring may have, resulting in unfit progeny. In general, populations with a greater degree of genetic variation are less at risk of inbreeding depression.

Over-dominance of heterozygous alleles is another mechanism that can lead to a reduction in the fitness of a population with many homozygous genotypes, even if they are not deleterious. Currently it is not known which of the two mechanisms is more important.

Introducing new genes from a different population can potentially reverse inbreeding depression. However, different populations generally have different deleterious traits, and should not result in homozygosity in most loci in the offspring. This introduction of new genetic material is known as outbreeding enhancement and is practiced by conservation managers to prevent homozygosity (Lynch, 1997).

Different isolated populations exist in slightly different habitat and are exposed to variations in environmental conditions. Over time, these conditions result in genetic changes that provide benefits to those animals living in that particular ecosystem (Lynch, 1997). These assist the population into which they have evolved, but may not benefit another, unrelated, population in the same manner and cross-population matings may lead to a reduction in fitness in the offspring known as outbreeding depression.

Outbreeding Depression

Outbreeding depression has been a controversial topic in recent years and has been cited by several authors as a genetic risk to wild populations, particularly in enhancement programs, in some cases considered to be a greater threat that inbreeding depression in the genetic makeup of wild populations. There is a lack of extensive literature to uphold this concept, but there are concerns. Outbreeding depression is defined at a reduction in fitness, either through reduced survival or lowered reproductive success, of progeny from distant parents (Templeton, 1987; Lynch, 1991). Two mechanisms can lead to outbreeding depression, both of which can occur simultaneously.

The first is through a breaking down of the genetic adaptations of a stock by "swamping" any locally adapted genes through displacement by immigration of genes adapted to a different environment of population. For example, large body size may be selected for in a population in one system while small body size is advantageous in another. Gene flow between the two populations could produce an intermediate body size, which could be a disadvantage in both systems.

A second means by which outbreeding depression may occur is through a breakdown of physiological or biochemical compatibilities between genes themselves in different populations.

It has been suggested that both outbreeding depression and outbreeding enhancement may occur simultaneously in a population receiving immigrants (Lynch, 1997), either by straying or introductions of hatchery fish to a non-native system. As individuals in a local population are crossed with individuals that are genetically more and more different, outbreeding depression builds. But outbreeding enhancement, because of the masking of deleterious recessive alleles, may also be occurring at the same time that outbreeding depression is occurring. If these divergent effects are averaged, small amounts of outbreeding may lead to an increase in fitness in a local, randomly mating population. However, it is possible that, at higher levels of outbreeding, outbreeding depression may exceed the beneficial effects of outbreeding enhancement. Lynch (1997) suggests that if populations have not been diverged for a long enough time to acquire separate, co-evolved gene complexes, then it is unlikely that outbreeding depression will occur. It is also possible for a population to suffer from both outbreeding depression and inbreeding depression at the same time.

While there is extensive literature supporting outbreeding depression in plants, there is considerably less literature available for vertebrates. Arguments range from a belief that fish held in freshwater for a year or more genetically adapt to hatchery conditions and reduce overall population fitness (Reisenbichler and Rubin, 1999) to a conclusion that there is a possibility of genetic depression from outbreeding (Gharrett et al. 1999). Although Goodman (2004) argues that, unless a population is so small as to be subject to inbreeding depression and genetic drift, there will not be a spontaneous decline in fitness, it is still advisable that the concept must be considered when making management decisions involving enhancement efforts. Gharrett et al. (1999) note that although hybrid crosses investigated would rarely occur naturally or in practice, results demonstrate that outbreeding depression can occur in salmon populations. It has been contended that such outbreeding depression could occur and that hatchery fish may not perform as well as wild fish, hatchery fish being genetically inferior (Reisenbichler and Rubin, 1999). Goodman suggests that a key concern is whether cessation of a supplementation program after an extensive enhancement could result in a population with a lower genetically determined fitness, which would be extremely serious from a conservation perspective (Goodman, 2004).

Information regarding the consequences of inbreeding and outbreeding depression in salmon is difficult to acquire (Lynch, 1997). While it would be valuable to have concrete evidence of either process to prove that these may or may not be real issues in salmon, the only mechanism to gain this information is through the experimental process with salmon. Inbreeding depression is relatively uncomplicated to produce by monitoring the performance of offspring from full-sib matings, because these matings are genetically the closest possible in a sexually reproducing species. However, this may take over a decade to produce a full data set. Since the decline in fitness shares a linear relationship with the degree of inbreeding, extrapolations to small populations could be made from the results of such experiments.

The demonstration of outbreeding depression also requires a significant investment in time and effort. Hatchery and wild fish must be crossed to make first generation hybrids, which would then be released for normal ocean migration. Second generation offspring would be made from returning hybrid individuals, which may represent only a small fraction of those released (Lynch, 1997). The effects of outbreeding depression, however, may not be apparent in these early generations, so the crosses of further generations are required. Hybridization between odd- and even-year pink salmon made with cryopreserved sperm yielded only a small amount of evidence about outbreeding depression after several years of work (Gharrett and Smoker, 1991). As for inbreeding depression studies, quantitative results would take years to generate.

While there is currently limited knowledge available to support or refute the concept, the potential is a valid consideration, particularly where conservation efforts are concerned. However, the extent of the effects is difficult to predict and the risks are dependent on the program goals. Ultimately the goal is to reach a point where the population again becomes self-sustaining and supplementation may be terminated. If hatchery-reared fish are only one or two generations removed from wild populations, outbreeding depression is unlikely to be a problem. If the hatchery is being used to ensure the survival of large numbers of fry, and if the brood stock is continually taken from wild populations, outbreeding depression is unlikely to occur.

<u>Risks to Hatchery Broodstock and Naturally Spawning Integrated Enhanced Populations</u>

Returning hatchery-produced fish may reproduce poorly when they spawn in the natural environment, resulting in lower productivity (fewer adult returns in the next generation). Over time, if a high proportion of returning fish are hatchery-produced, the population may become more adapted to reproducing successfully in the hatchery than in the natural environment. Genetic alteration of an enhanced population becomes of more concern when populations are depleted and small, such as in a conservation program. In such cases, the intention is for short-term supplementation to maintain or restore spawner abundance in the natural environment and enable further population rebuilding to occur as the result of successful natural spawning. If population depletion is due to low marine survival, the reduced fitness of hatchery-produced fish in the natural environment may be a critical factor in the failure of population recovery.

The process of domestication selection is poorly understood. Hatchery supplementation can result in rapid domestication selection in a population only if the altered selection resulting from the hatchery environment is very strong. There is generally little mortality in hatchery freshwater rearing, leading to reduced selection during this life history period. Once hatchery fish are released to the wild, natural selection occurs on both hatchery- naturally-spawned fish. However, this selection may manifest itself differently on hatchery than natural fish due to genotype-environment interactions if genetically identical hatchery- and naturally-spawned fish are phenotypically distinct (e.g. different size, smoltification readiness, nutritional or disease status). Even so, hatchery-produced fish often have similar marine survival to naturally-spawned fish, and only display reduced fitness upon return and spawning in the wild environment.

The mechanisms leading to reduced reproductive success of hatchery fish in the natural environment may result originally from genotype-environment interactions, as mentioned before. If hatchery-rearing results in an altered age structure or physiological status in some or all genotypes of the adult population, hatchery-produced fish of the affected genotypes may perform more poorly than the same naturally-spawned genotypes. When hatchery production reduces the natural reproductive capability of various genotypes differentially, selection against the most affected genotypes will occur as the result of hatchery-produced fish spawning in natural environment. This selection may lead to a loss of genetic diversity in the overall population, with the risk of genetic change increasing with length and magnitude of hatchery supplementation.

Risks to Surrounding Unenhanced Populations

Pacific salmon stray[16] naturally, as a part of their life history. Typically, fish stray to systems that are nearby the natal stream, in which the populations are normally more genetically similar than distant populations. This strategy allows geographic distribution and colonization of underutilized areas, sometimes by a surplus of spawners or in the event of low water events or direct migration obstruction to native streams. Straying also allows for a process called heterosis, in which fitness of a population is increased the introduction of new genetic material through crossbreeding of strays with the native population (Figure 2).

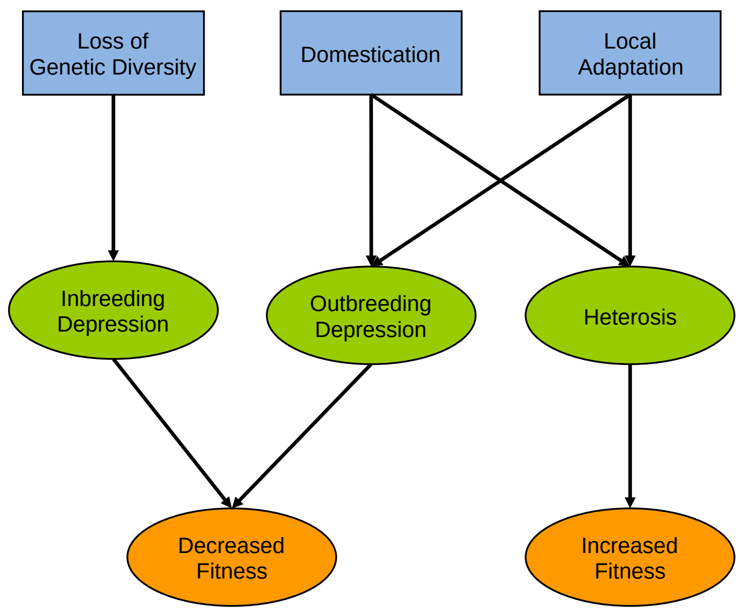


Figure 2. How genetic effects arise.[17]

Straying of enhanced salmon to nearby systems has greater consequence as the animals may originate from an integrated hatchery population with its attendant changes in genetic profile and fitness. This has the potential to disrupt the local gene complexes and reduce the fitness of the wild population through a process called outbreeding depression (Figure 3). However, as with straying between wild populations, the possibility of heterosis exists with the introduction of enhanced fish to a wild population. Additionally, stray hatchery salmon in these systems may physically displace native spawners, and their progeny may compete with wild juveniles for food or cover. There may also be direct predation effects, with hatchery fish preying upon

[16] Straying is when fish return to a stream that is not their stream of origin. This occurs in both wild and enhanced populations.
[17] Adapted from a presentation by W. Vandersteen (DFO) to the Marine Conservation Caucus May 2011.

or providing prey for wild fish – a following section on ecosystem risks explores these effects in more detail.

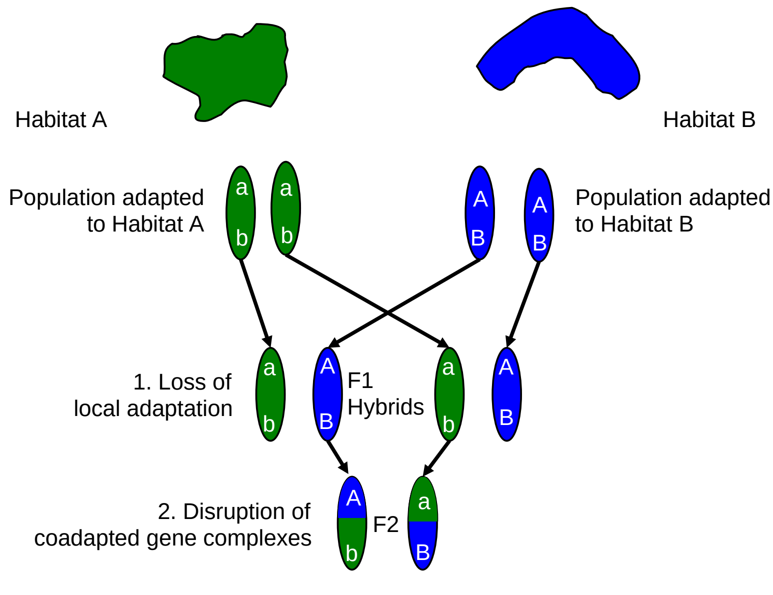


Figure 3. How outbreeding reduces fitness.[18]

Crossbreeding between enhanced and wild populations may have more profound effects when the enhanced population is from a greater distance. This may occur when enhanced fish are transplanted to the stream or watershed, or a transplanted enhanced population has strayed to a non-native stream or watershed. If the population to which animals are straying is naturally small or is depressed, the genetic effect may be more significant.

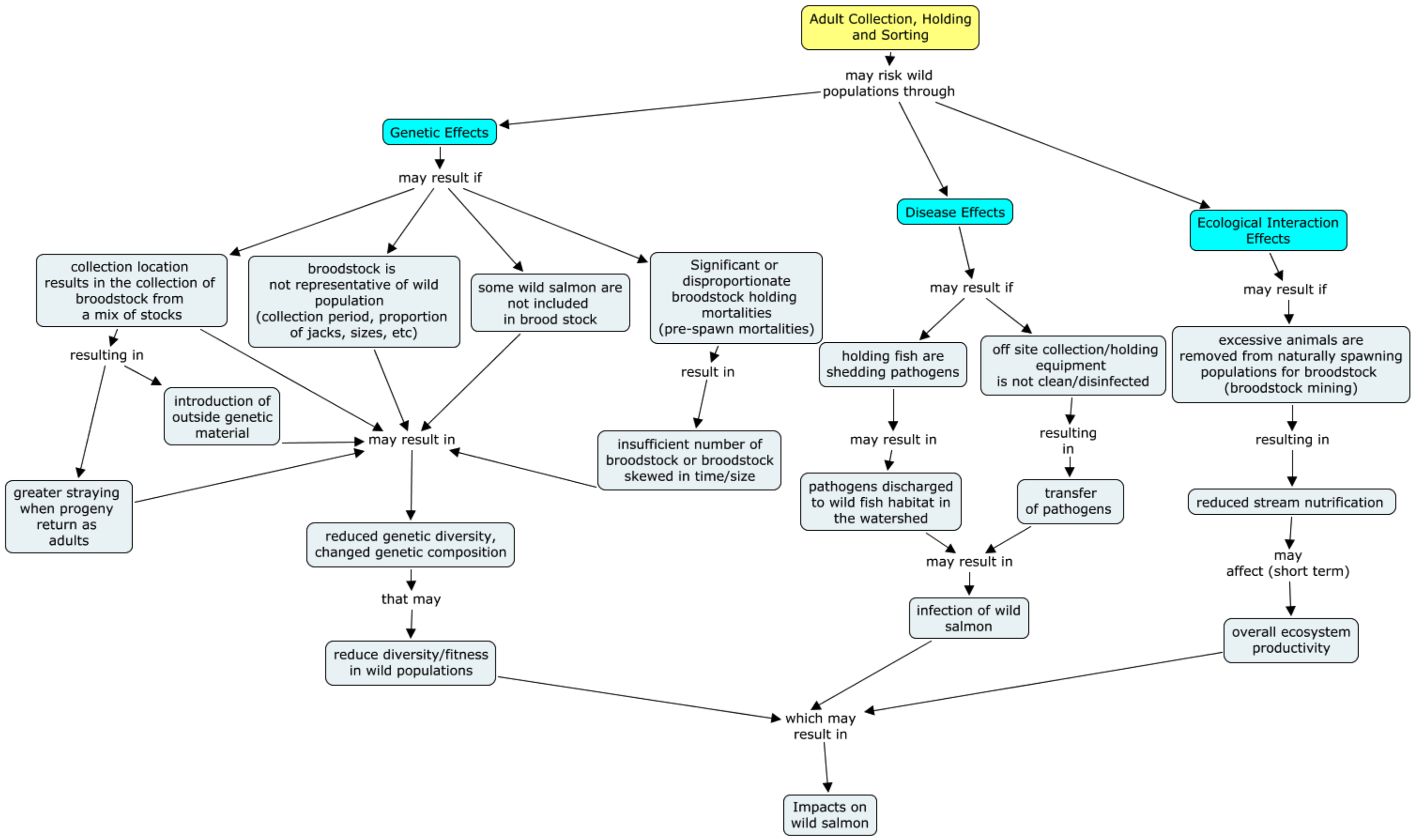
Although the rate of straying for most wild populations is unknown, the rate of straying of hatchery fish is likely not more than wild fish in most instances, but the number of fish that stray relative to wild fish may be greater when the hatchery production is large in scale. For long-term enhancement programs, the ongoing, repetitive input of strays from large-scale enhancement programs is also likely greater than that of wild salmon. Some enhancement strategies, such as temporary rearing of a population at a non-natal hatchery, carry a greater risk of increasing stray rates. In these instances there are specific practices that hatchery staff implement to reduce the likelihood of straying.

Straying of wild or hatchery salmon is not routinely assessed or quantified. The potential exists to examine the stray rates of enhanced fish where large-scale marking programs exist. Assessing the genetic consequences of such straying is far more difficult, has only been recently become possible and only rarely undertaken (e.g. Gold River Chinook).

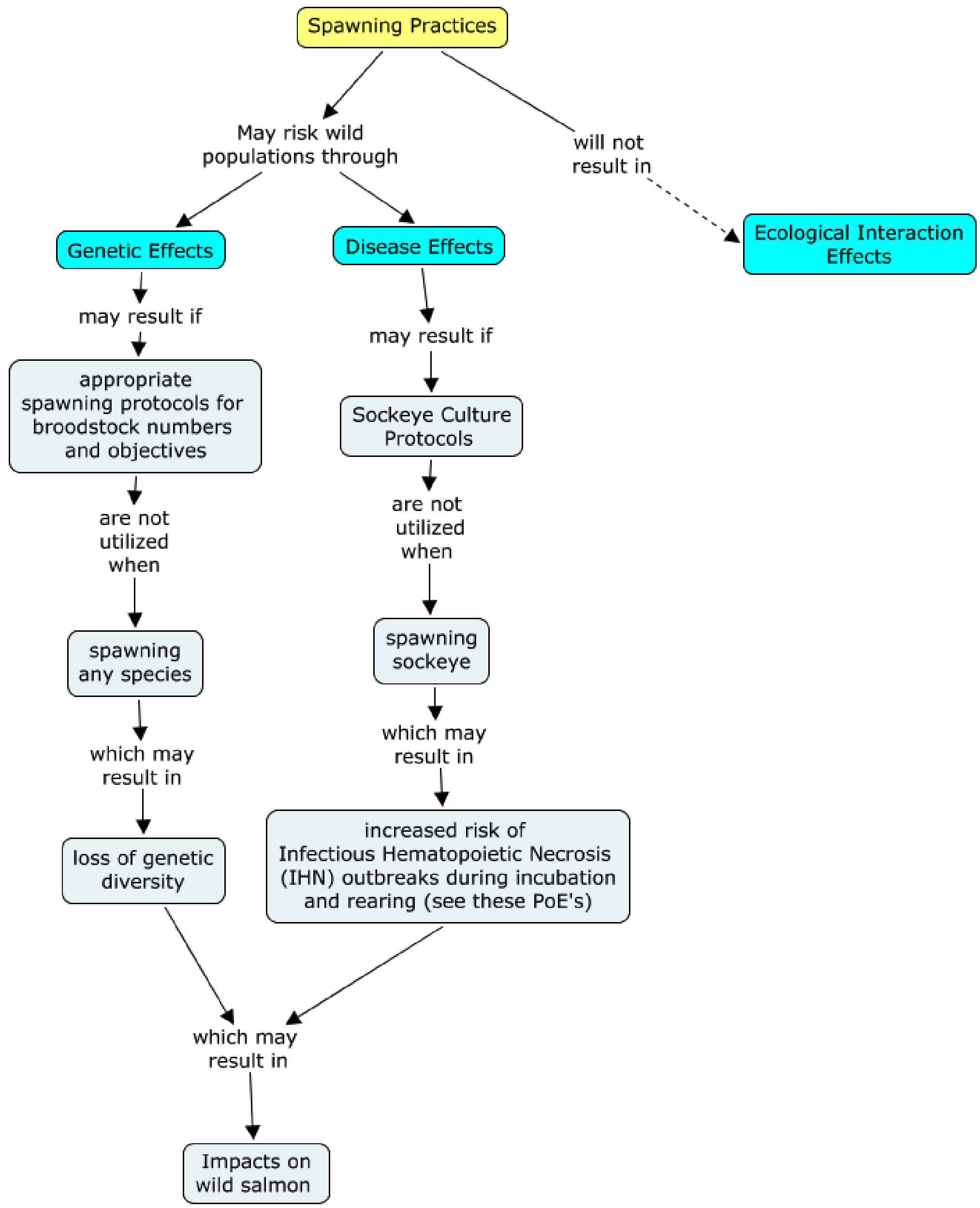
[18] Adapted from a presentation by W. Vandersteen (DFO) to the Marine Conservation Caucus May 2011.

Appendix IV – Pathways of Effects Illustrations

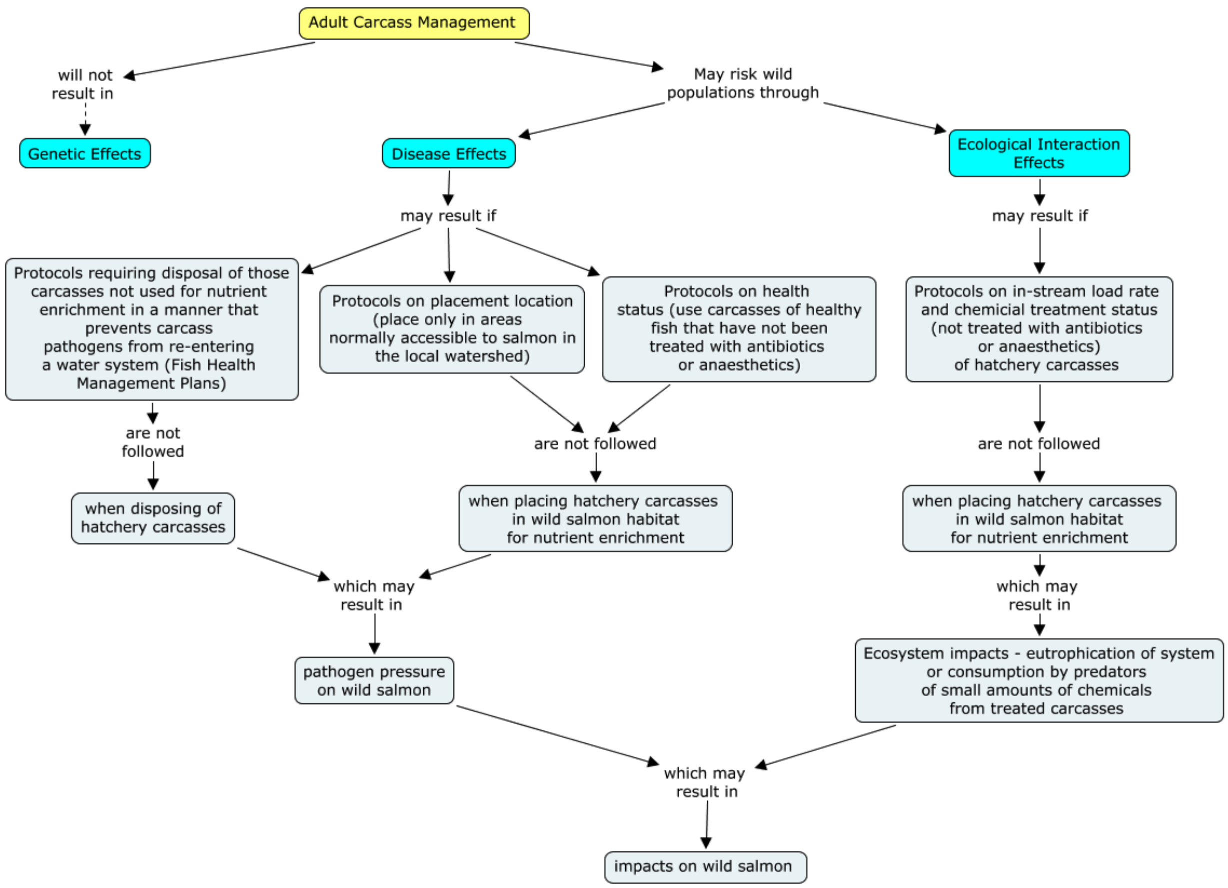
1. Adult Collection, Holding and Sorting



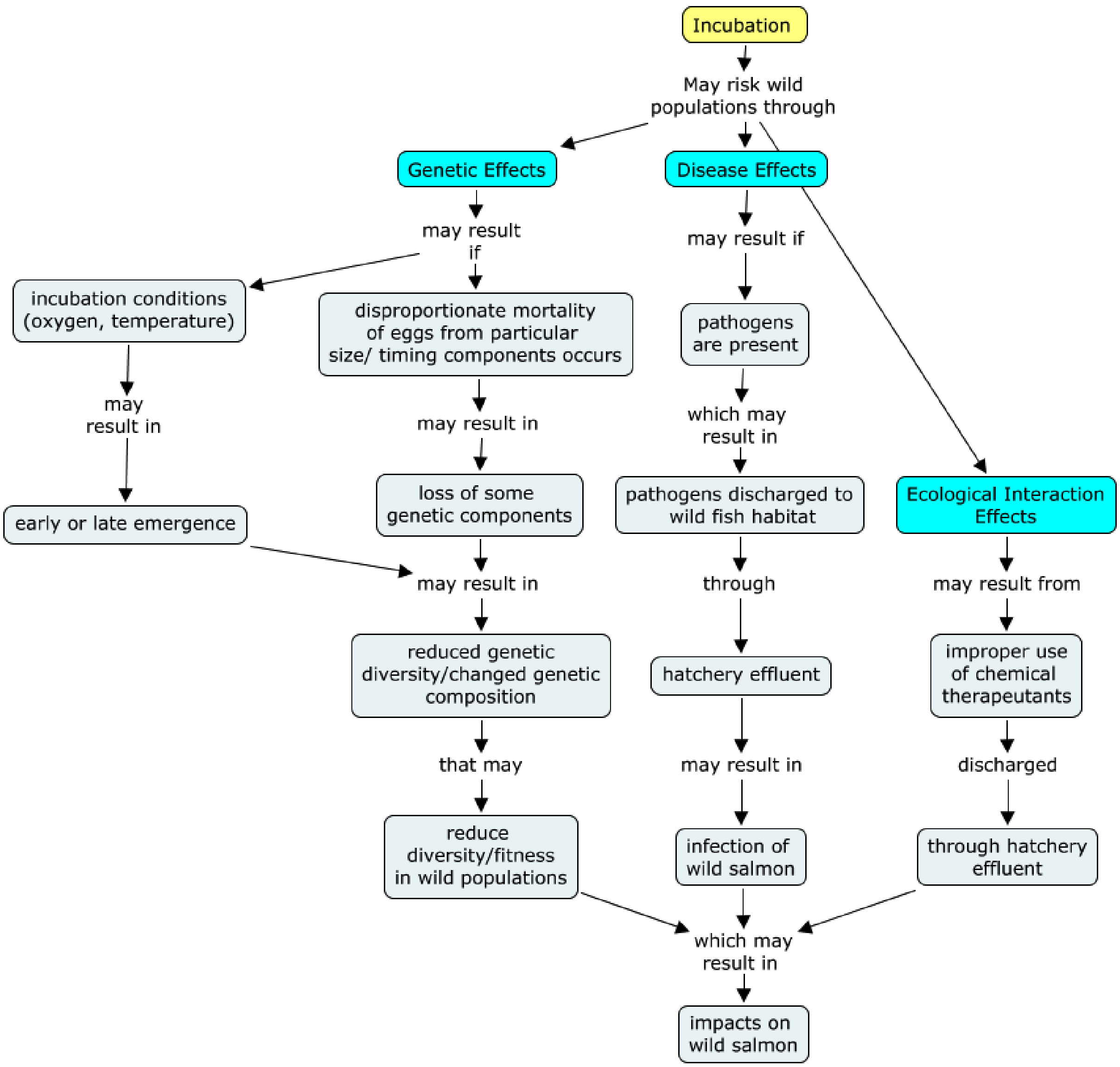
2. Spawning Practices



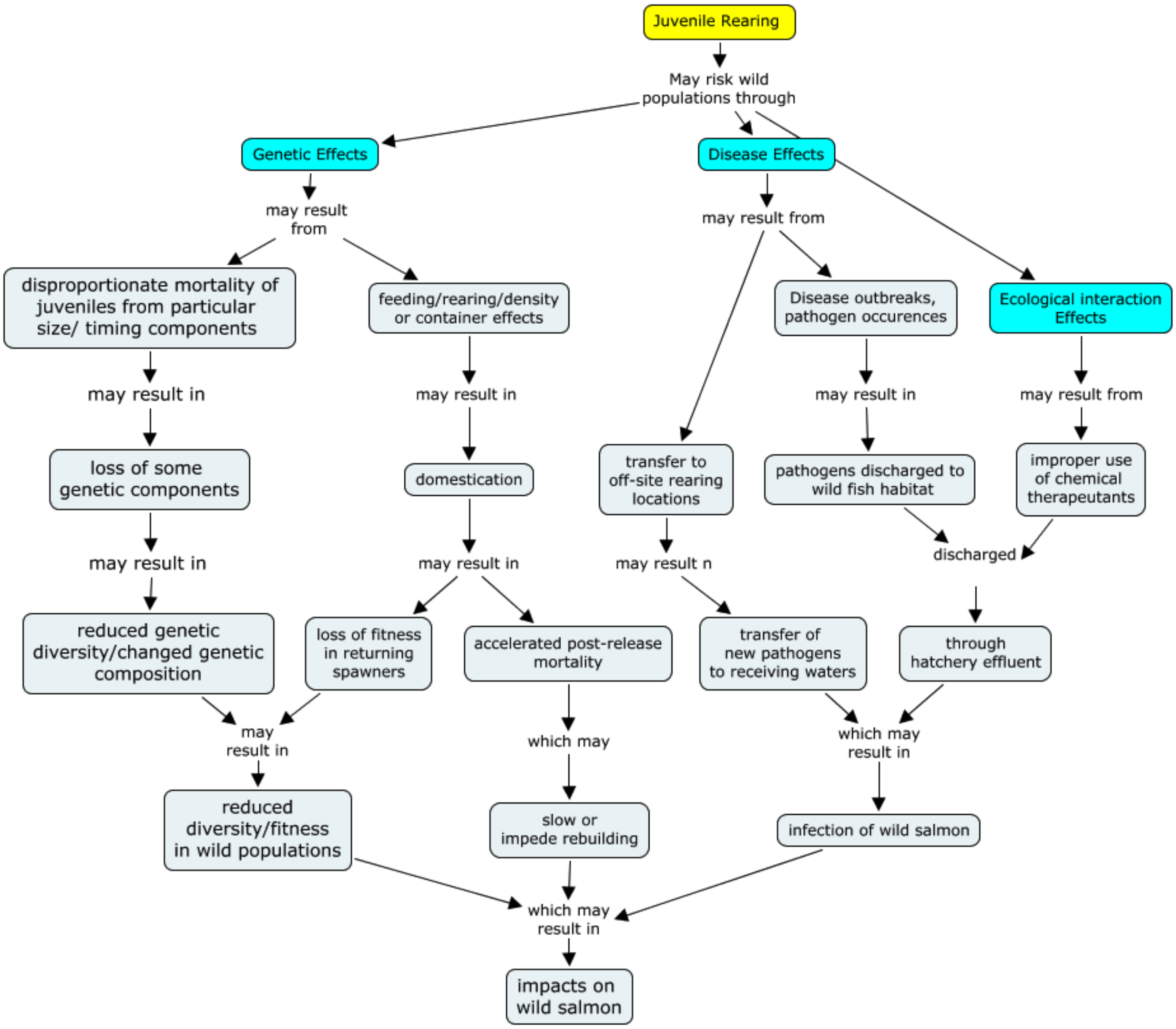
3. Adult Carcass Management



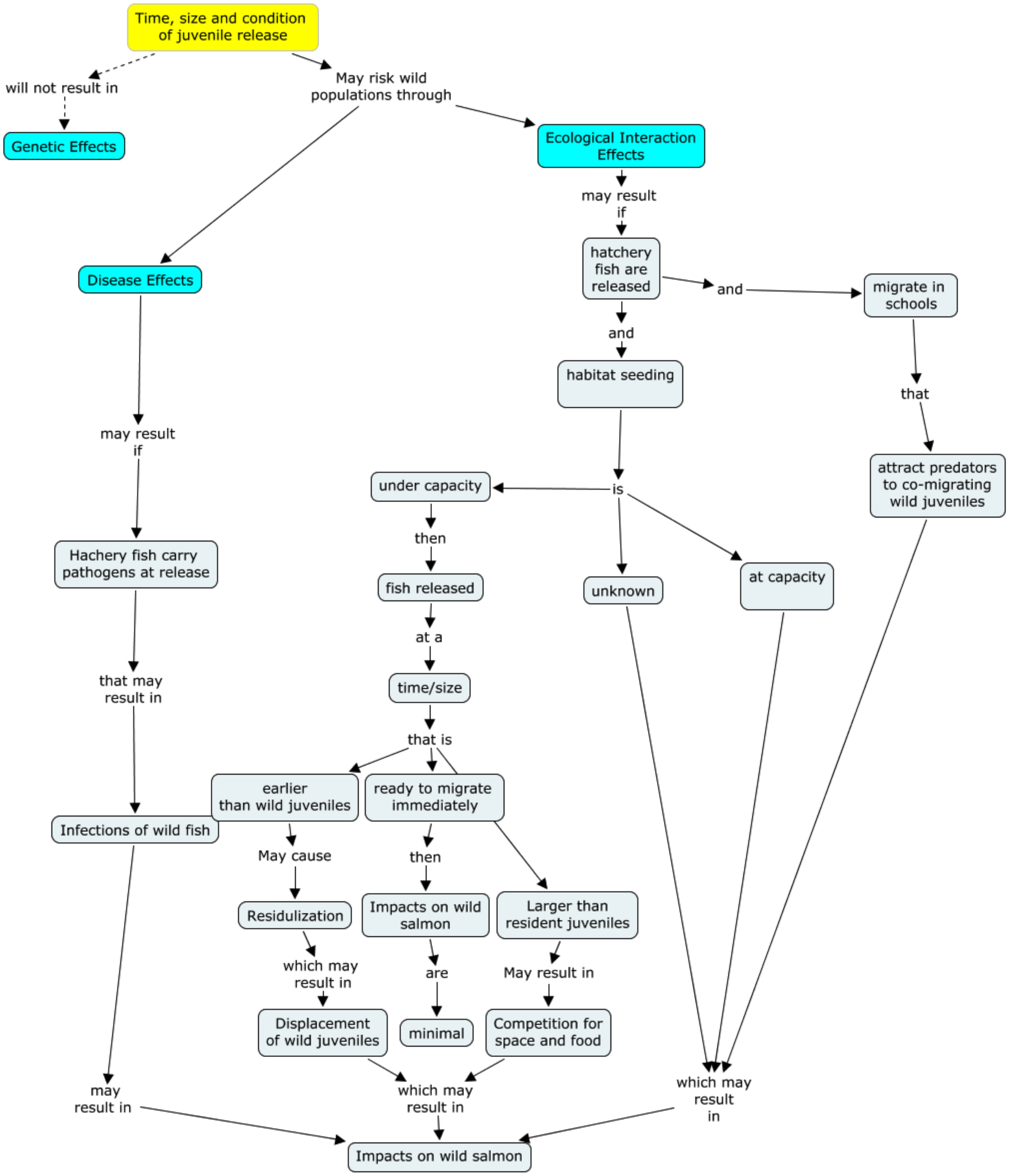
4. Incubation



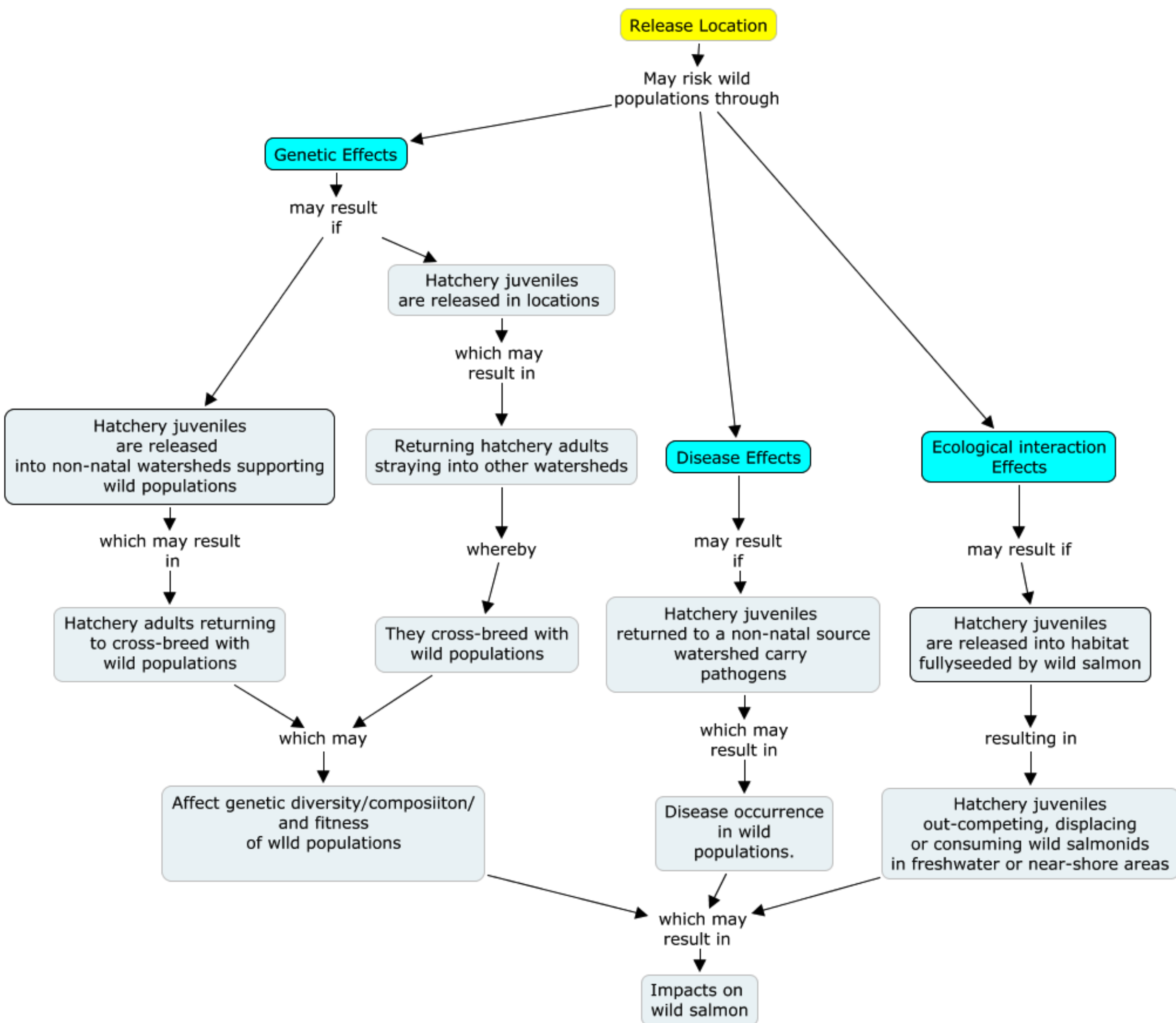
5. Rearing


Juvenile Rearing
May risk wild populations through
Genetic Effects
Disease Effects
may result from
disproportionate mortality of juveniles from particular size/ timing components
feeding/rearing/density or container effects
may result from
Disease outbreaks, pathogen occurences
Ecological interaction Effects
may result in
may result in
may result in
may result from
loss of some genetic components
domestication
transfer to off-site rearing locations
pathogens discharged to wild fish habitat
improper use of chemical therapeutants
may result in
may result in
may result n
discharged
reduced genetic diversity/changed genetic composition
loss of fitness in returning spawners
accelerated post-release mortality
transfer of new pathogens to receiving waters
through hatchery effluent
may result in
which may
which may result in
reduced diversity/fitness in wild populations
slow or impede rebuilding
infection of wild salmon
which may result in
impacts on wild salmon

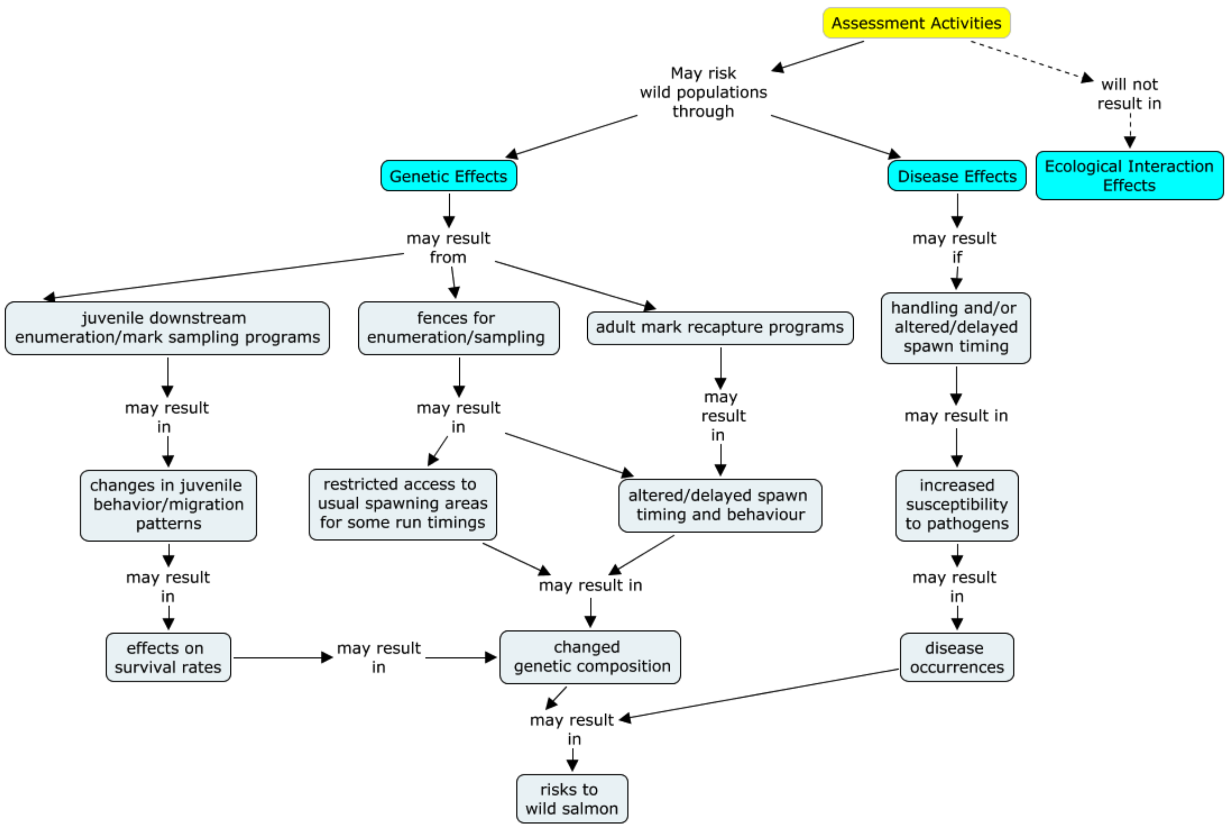
6. Release Time, Size and Condition



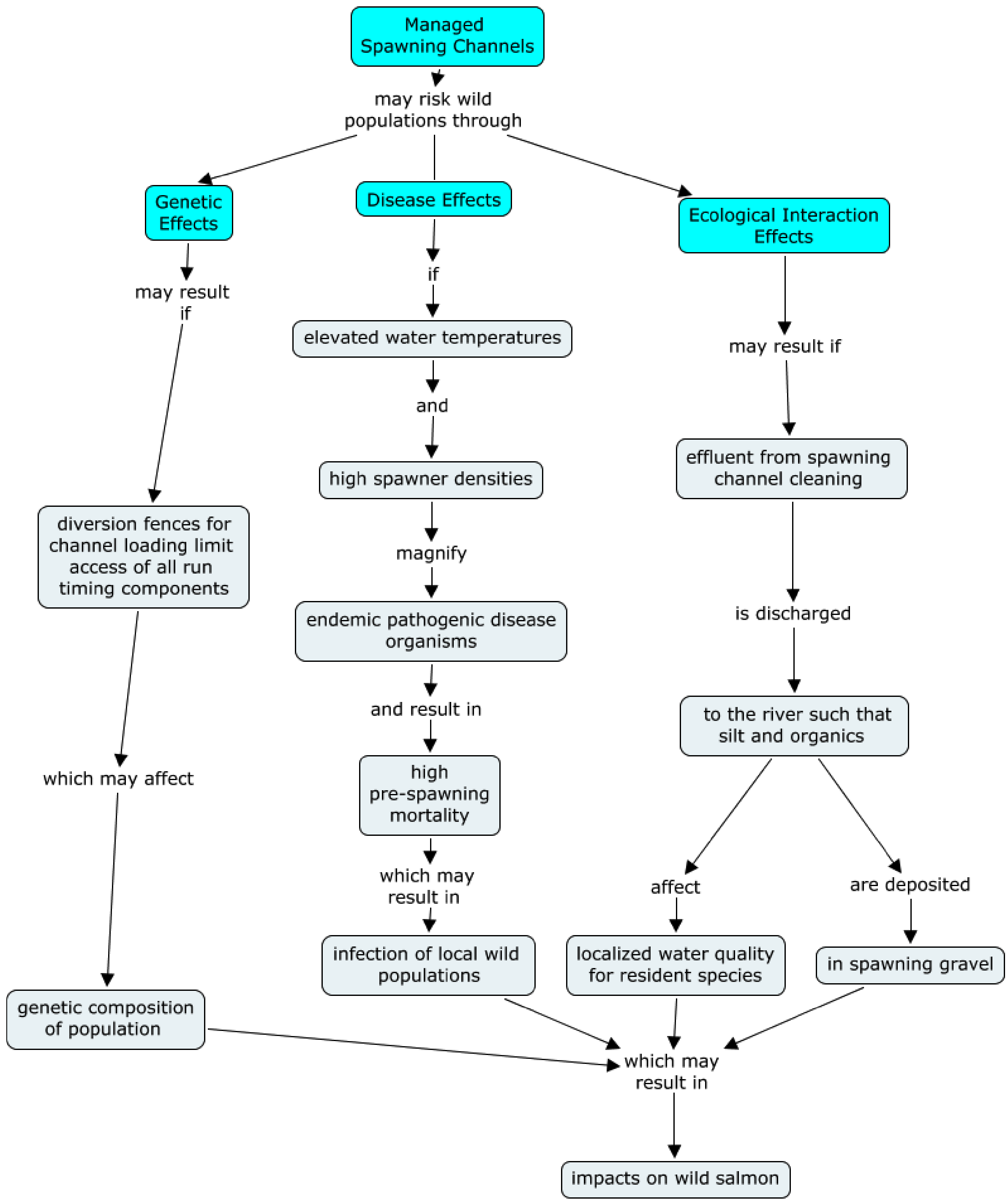
7. Release Location



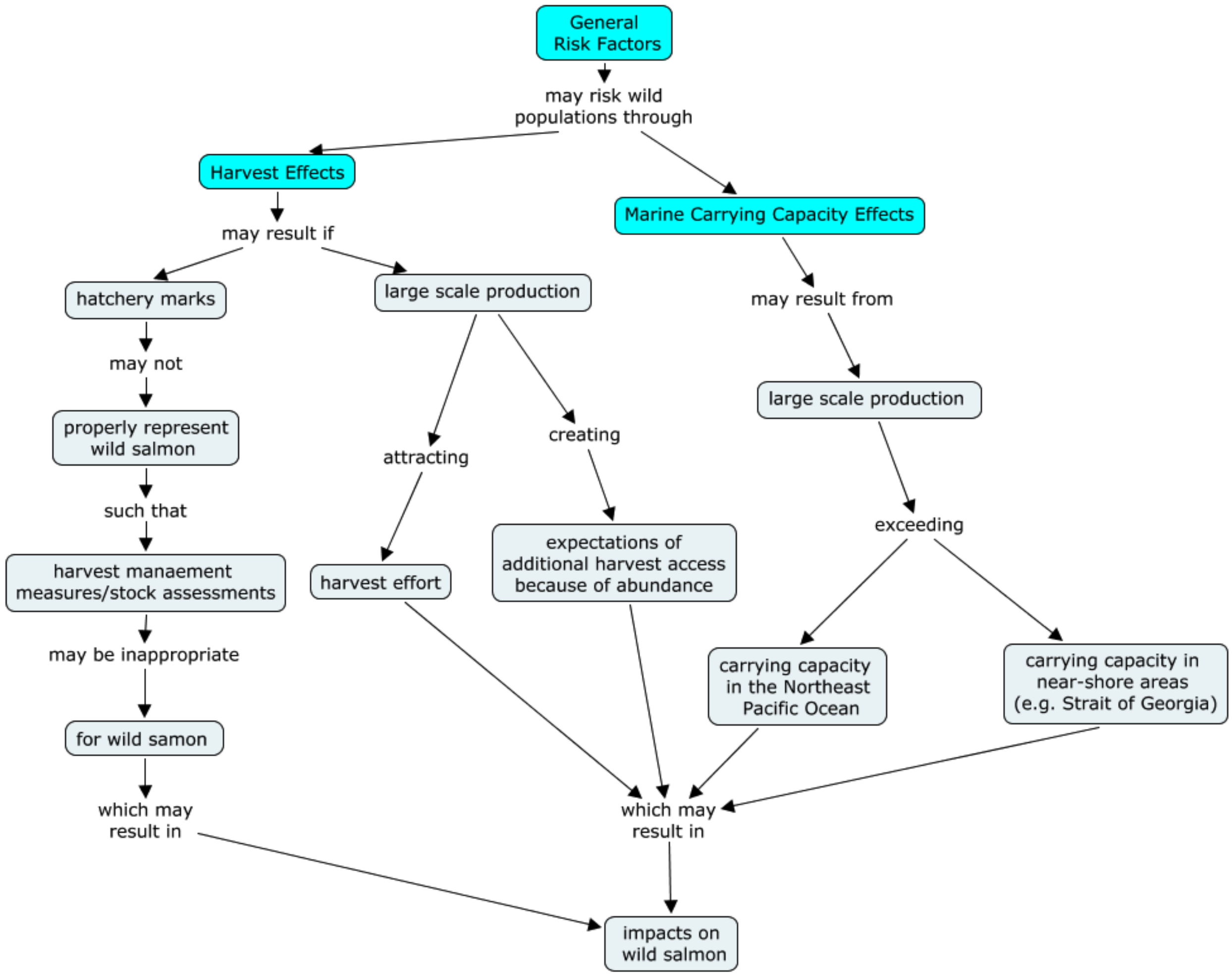
8. Assessment



9. Spawning Channels



10. General Risk Factors



Appendix V – Cause and Effect – Risk Management Tables

Genetic Risk Assessment and Management

1. Adult, Collection Holding and Sorting

Cause and Effect Relationship	Standard Mitigation Measures
• Potential loss in diversity within wild populations through changed genetic composition (the *effect*) may be *caused* if: o broodstock collection is not representative of wild population; o the collection period is inappropriate; o inadequate use of jacks, or inappropriate size selection results in negative in-breeding effects; or o collection location contributes to future straying of adult returns resulting in negative out-breeding effects. • Potential loss of diversity due to small or time/size-skewed donor population resulting from excessive or disproportionate holding pond mortalities.	**Reference**: Operational Guidelines for Pacific Salmon Hatcheries (2005); Fish Health Management Plans **General Measures**: • Maximize effective breeding population, using native populations when possible – a standard SEP practice. • Use fish from the entire run timing, and use wild (unmarked) fish as much as possible. • Collect broodstock randomly from the whole population to represent the full range of physical characteristics, including small or sexually precocious fish. o collect jacks proportionally to their abundance in the escapement o avoid artificial or intentional selection of spawners • Where egg targets are small (< 10,000 eggs) or when weather or logistical circumstances confine broodstock collection to a short period (e.g. one weekend), strategies to improve representativeness should be employed. These could include collecting some broodstock from as many sites as possible within the river and/or collecting broodstock from a different portion of the run timing each year. • Some captured adults may be excluded to achieve a balanced sex or age ratio or to avoid using any fish with apparently questionable health status. • Minimize holding stress/mortalities (e.g. adequate flows/oxygen, fungus treatments as necessary, pond covers) to maximize donor numbers.
•	

2. Spawning Practices

Cause and Effect Relationship	Standard Mitigation Measures
• Natural mating patterns are complex and poorly understood, and unlikely to be maintained in a hatchery environment. • Loss of genetic diversity and undesirable genetic effects may occur if: o Sufficient broodstock that adequately represent the entire donor population and its genetic characteristics are not used for spawning;	**Reference:** Operational Guidelines for Pacific Salmon Hatcheries (2005) **General Measures** (applies to all broodstock population sizes - specific and different procedures are detailed in the guidelines for broodstock of more than 50 pairs versus less than 50 pairs)**:** • Spawn all collected fully mature broodstock, without regard to age, size or other physical characteristics. Do not exclude any individuals for any reason, except for those with overt signs of disease or physical injuries that may compromise gamete viability. • Include donors from the wild population to the extent feasible. • Use fully random mating; avoid selection. • Use one male to one female except as described below. This strategy ensures that each male makes an equal genetic contribution. • Do not mix milt from two or more males and then add it to eggs. This practice is known as "pooling" milt and can result in milt from a single male fertilizing a disproportionate share of the eggs.

	• It is strongly advised that males not be re-used, except as part of specific spawning protocols. In a sequential protocol two males may be used sequentially per female (see specific guidelines for protocols). • Consult a support biologist if planning to re-use males in any way other than the spawning protocols identified in these guidelines. • Generally, do not release live males that have been used for hatchery spawning back to their systems of origin. These males will already have contributed a disproportionate amount of genetic material to the stock compared to wild fish, and, if released, would have the opportunity to contribute even more. Consult a support biologist, however, if there is a very disproportionate sex ratio among natural spawners.

3. Adult Carcass Management

Cause and Effect Relationship	Standard Mitigation Measures
N/A	N/A

4. Incubation

Cause and Effect Relationship	Standard Mitigation Measures
• Potential loss of genetic diversity, particularly if the culture group is small, due to excessive incubation mortalities overall or mortalities that disproportionately affect eggs from specific time or size components. **Note**: Risks of this occurring to a detrimental degree are low	**Reference:** Fish Health Management Plans **General Measures:** • Minimize incubation mortalities through application of good fish culture practices (e.g. water quality/quantity, temperatures, substrate as applicable, densities, effective egg picking and fungus treatments as required).

5. Rearing

Cause and Effect Relationship	Standard Mitigation Measures
• Domestication of rearing population due to feeding or rearing container effects may result in o reduced post-release survival that may impede re-building o loss of fitness/reduced genetic diversity	**Reference:** Fish Health Management Plans; HSRG, 2004; Brannon, 1999 **General Measures:** • Minimize disproportionate rearing mortalities (e.g. size disparities within rearing population and with wild populations) through application of good fish culture practices. • Rear under conditions that maximize probability that all segments of the population contribute equally to the release population. • Where feasible, utilize ambient natal stream habitat temperatures to reinforce genetic compatibility with local environments and provide linkage between stock and habitat that is responsible for population structure of stocks from which hatchery fish are generated.

6. Release Time, Size and Condition

Cause and Effect Relationship	Standard Mitigation Measures
N/A	N/A

7. Release Location

Cause and Effect Relationship	Standard Mitigation Measures
• Loss of diversity and fitness may result from adult hatchery fish mixing and cross-breeding with alternative wild populations due to; o poor homing fidelity within the watershed; or o straying into nearby watersheds.	**Reference:** HSRG, 2004; Production Planning Framework,2012 **General Measures:** • Fish should be released in the locations specified in the annual production plan as developed through the planning process • Fish should be released at life stages and locations that maximize homing fidelity (e.g. in areas with adequate imprinting to the facility or desired stream reach). • Aim to release fish to natal stream(s), but when off-site releases are part of an enhancement program, the production plan should be followed.

8. Assessment

Cause and Effect Relationship	Standard Mitigation Measures
Activities that affect spawning area/timing or behavior can affect genetic composition of a population, particularly if activities have a greater affect on particular run timing components • Fences for enumeration or sampling of returning adult salmon may: o alter spawning behaviour causing hatchery or wild salmon to spawn in unsuitable areas/timing, or with fish of other demes. o delay spawning and cause mortalities of some run timings. o restrict access to intended spawning areas for some run timings. • Adult salmon mark recapture programs may alter or delay spawning behaviour. • Juvenile downstream or mark-recapture number programs may affect juvenile migration patterns or timing. This may affect access to food or territory and subsequently, survival rates.	**Reference:** FHMPs for facilities that have them and operate marking/enumeration programs. **General Measures:** • Fences will be designed and operated, with sufficient effort, to avoid unduly restricting passage of adult migrants. Enumerations may need to be compromised, particularly if there are risks of altering natural wild salmon spawning timing or locations, or skewing run/spawning timing of enhanced fish. • Downstream trapping programs will be designed and operated in a manner that reduces likelihood of mortalities or migration timing alterations (e.g. remove barriers/traps in high-water events, invest sufficient effort in order to prevent back-logs in enumerations and marking, avoid handling of fish in higher than normal temperatures).

Disease Risk Assessment and Management

1. Adult, Collection Holding and Sorting

Cause and Effect Relationship	Standard Mitigation Measures
Potential disease transmission to wild populations may occur if: • broodstock is collected off-site from the hatchery facility, there is a risk of transferring pathogens between the collection location and the facility if collection and holding equipment are not effectively disinfected. • holding fish are shedding pathogens that are discharged into fish habitat with effluent. Note: The risk of these causes/effects is very low.	**Reference:** Fish Health Management Plans **Measures that reduce the risk of transference off-site::** • Transfer permits are required. • Equipment should be kept clean at all times, properly disinfected after each use, and put away in its proper location. • Where possible, equipment will not be shared between sites. This includes pumps, vehicles, and fish handling equipment. Where this is not possible, equipment that must be used at multiple sites should be subject to strict biosecurity and disinfection measures between uses. **Measures that reduce the risk of disease and subsequent transference or pathogen shedding** • Minimize holding stress/mortalities (e.g. adequate flows/oxygen, fungus treatments as necessary, pond covers) to maximize numbers of broodstock to maintain genetic diversity. • If using anaesthetics, the fish should be monitored until they are ready to be handled. • The anaesthetic bath may contain mucus protectants (e.g. Vidalife™) to protect the fish's cuticle from subsequent opportunistic infection. • Water quality should be monitored during anaesthesia. • When easily handled, fish should be removed from the anaesthetic bath and assessed for 'ripeness'. • If antibiotics have been prescribed by the Veterinarian, they may be injected at this point. • Broodstock should be maintained in a separate holding area from other fish (i.e. juveniles). • All broodstock holding areas should be pressure washed and scrubbed and disinfected with Ovadine or other suitable disinfectant, or fully dried in the sun, prior to being used for other life stages. • All equipment used on broodstock should be designated for brood use only. Staff separation should occur whenever possible. • Disinfectant footbath stations should be regularly maintained between adult holding and incubation areas. Spray bottles of Ovadine™, or other topical disinfectant solution, should be available for surface disinfection of hands and rain gear. • Staff must adhere closely to site and staff biosecurity procedures.

2. Spawning Practices

Cause and Effect Relationship	Standard Mitigation Measures
Although infectious hematopoietic necrosis virus (IHNV) is endemic to many fish stocks, successful culture of sockeye salmon can occur as long as specific procedures are adhered to. Without such procedures, transfer IHNV from fish to fish can occur and there can be catastrophic mortalities in hatcheries during incubation and rearing.	**Reference: ALASKA SOCKEYE SALMON CULTURE MANUAL McDaniel et al, 1994** http://www.adfg.alaska.gov/static/fishing/PDFs/hatcheries/sockeye_salmon_culture_manual.pdf **Water Supply** • IHNV-free water supply via wells, depurated, or fishless water

<table>
<tr><td></td><td>is required for all phases of sockeye culture.

Disinfection

• Stringent disinfection of utensils, facilities, external surfaces of brood stock, etc. during and after the egg take. Use of disinfectant footbaths, steam-clean and separate gear (reduces risk of external contamination by virus).

• Separate water hardening of each family of eggs in 100 ppm iodophor for 60 minutes with replenishment and adequate mixing (reduces the potential virus contamination of other eggs by high titer gamete fluids; kills virus on the surface of the egg and in the perivitelline space; allows for more adequate disinfection of the smaller egg mass).

Containment

• Separate fertilization of eggs from each female using 1 or 2 males (reduces the potential virus contamination of other eggs by high virus titer seminal fluid).

• Eggs are pooled into separate incubator units at densities considered as expendable.

• Each sockeye stock physically isolated by barriers and disinfectant footbaths from any non-sockeye species as well as other sockeye stocks (protects other IHNV-susceptible species as well as separate sockeye stocks).

• Rearing containers for fry and fingerlings adequately separated by distance or physical barrier to maintain containment by compartmentalization and isolation.</td></tr>
</table>

3. Adult Carcass Management

<table>
<tr><th>Cause and Effect Relationship</th><th>Standard Mitigation Measures</th></tr>
<tr><td>• Carcasses from hatchery salmon may be placed in streams to provide nutrients as they decay and so contribute to ecosystem productivity. This activity may pose a risk of disease transmission as new pathogens could be introduced if carcasses:
o are moved to areas within the watershed that are normally not accessible to salmon, or
o are moved to streams outside of the local watershed.

There is a risk of pathogen transference to adjacent water systems if those carcasses not used for nutrient enrichment are disposed of in a way that could result in pathogen shedding to local water systems

Note: The risk of disease transfer through carcass placement is very low in most conditions.</td><td>Reference: Fish Health Management Plans; Guidelines for In-Stream Placement of Hatchery Salmon Carcasses for Nutrient Enrichment (also attached to FHMPs)

General Measures:

• Carcasses not used for stream nutrient enrichment will normally be disposed of in a manner that prevents carcass pathogens from re-entering a water system (e.g. landfill or, if not exposed to chemicals, to rendering plants or used for human consumption).
• Placement of carcasses for stream nutrient enrichment is subject to the in-stream placement guidelines, including the following general measures:
o Only those fish killed with CO2 or blunt trauma that show no visible evidence of serious disease should be used for carcass placement.
o Because of drug clearance times, and the length of holding, fish previously treated with an antibiotic or chemical anaesthetic must not be used for carcass placement. However, fish treated with external chemicals that do not require a withdrawal period (e.g. Parasite S or Chloramine T) are considered safe for placement. If in doubt, contact the Fish Pathology Program at PBS.
o In general, no carcasses may be moved outside their natal stream because of concerns regarding disease transmission. However, in specific circumstances,</td></tr>
</table>

	movement of carcasses from the watershed to nearby streams may be considered if **all** of the following conditions are met: ▪ donor and treatment streams are geographically proximate and, ▪ treatment stream is within the zone of influence of the donor stock (i.e. adults may be straying from donor to treatment stream), and ▪ current disease history is available. o Carcasses may be frozen for later use. However, as freezing will not significantly reduce pathogen loads, it should not be considered a disease management tool.

4. Incubation

Cause and Effect Relationship	Standard Mitigation Measures
• Disease occurrence or pathogen presence during incubation may result in the risk of pathogen transfer to: o other groups within the facility; and/or o wild populations within the watershed through the discharge of facility effluent. Note: The risk of these forms of disease transmission is very low due to egg surface disinfection practices.	**Reference:** Fish Health Management Plans; HSRG, 2004 **General Measures:** • Eggs should be dry fertilized to increase fertilization success and reduce introduction of potential water borne pathogens into the egg – a standard SEP procedure. • Where possible, pathogen-free water should be added to the egg/milt mixture to activate the sperm. In general, well water is considered to be the cleanest water source on most facilities. • Following fertilization and washing, eggs should be disinfected to reduce the possibility of external pathogens entering the incubation system.

5. Rearing

Cause and Effect Relationship	Standard Mitigation Measures
• Disease/ pathogen presence during rearing may increase risk of pathogen transfer to: o other groups within the facility; and/or o wild populations within the watershed via the discharge of facility effluent. • Transportation for rearing off-site poses a potential risk of disease transfer to receiving-water populations.	**Reference:** Fish Health Management Plans **General Measures:** • Fish should be observed daily for signs of health, injury, and disease. • Changes in behaviour (decreased feed response, decreased startle response, failure to evade capture, etc.) and physical condition (darkening in colour, failure to gain, external lesions, etc.) should be reported and recorded. Any change should be investigated and the causes identified and corrected. • Mortalities should be picked from the youngest and healthiest groups of fish first. The same sequence for moving between tanks should be followed for routine sample collections. • Each holding unit should have dedicated equipment (nets and buckets) for mortality removal. Equipment used to remove mortalities should be cleaned, disinfected and dried between uses. • All dead and moribund fish should be removed from holding units on a daily basis. Moribund fish should be humanely euthanized prior to disposal. • Where feasible, particularly when a disease outbreak occurs, separation of staff occurs so that staff picking mortalities are not feeding fish or cleaning holding units on the same day. Footbaths and hand wash stations should be used prior to returning to fish holding areas.

	• Mortalities should be counted and classified during collection. • In the event of unexpectedly high morbidity or mortality rates, the frequency of mort collection may be increased. If daily mortalities exceed 0.5%, fish health management should be notified and the veterinarian consulted. • Buckets used to collect mortalities should have secure tight fitting lids that will exclude predators and scavengers. Buckets should be cleaned and disinfected before being returned to the fish rearing area. • After mortalities have been collected they should be stored (they may be frozen) in a central location away from the fish rearing area until they can be removed from the site. • Groups of fish should be tracked from their incubation containers to their rearing containers; those facilities having it, should use the ENPRO Juvenile Manual. • Biological records include: species, stock, length, weight, condition, and comments on appearance. • Groups of fish suspected of having a disease should be sampled according to the Veterinarian's instructions for lab analysis. • In the event of a disease outbreak, detailed guidance and protocols in the FHMP will be followed, including securing the site and isolation procedures as necessary and feasible. • Non-release transportation of fish will follow the following general guidelines: o With a long-standing established program involving annual fish transfers between two sites, with appropriate surveillance data collected and with historical knowledge in endemic disease issues in the two populations, the disease risk assessment may be relatively informal. Any such transfer program should be reviewed during the facility annual production planning process. o Sick fish should not be transferred between sites or knowingly be released without a disease evaluation (an exception for fish in net pens may apply – release often presents the best possible outcome). Depopulation, treatment and release options should be reviewed on a case-by-case basis. o Where new programs are developed or in instances where the rearing population has suffered disease losses and treatment, the Veterinarian may request a sample of either healthy or moribund fish for disease prevalence estimation at least 2 weeks prior to transfer/release. o Transportation of juvenile fish will be guided by the FHMP, including the requirement for all necessary permits/licenses in place prior to movement.

6. Release Time, Size and Condition

Cause and Effect Relationship	Standard Mitigation Measures
• Hatchery reared fish released to the source watershed may carry pathogen loads that could impact wild fish	**Reference**: Fish Health Management Plans; National Code on Introductions and Transfers of Aquatic Organisms (Anon. 2003). **General Measures**: • Fish designated within the same transfer zone that have a history of disease should be checked for health condition prior to release – if a disease is diagnosed, postpone release and treat if flexibility in timing allows – within biological imperatives

	(smolting) and drug clearing periods.

7. Release Location

Cause and Effect Relationship	Standard Mitigation Measures
• Hatchery reared fish returned to the source watershed may have greater pathogen loads than resident populations.	**Reference:** Fish Health Management Plans; National Code on Introductions and Transfers of Aquatic Organisms (Anon. 2003). **General Measures:** • SEP does not transplant fish into non-natal watersheds where viable natal populations exist. • Transplanting fish otherwise requires an approved production plan and Pacific Aquaculture Licence to be in place. • Introduction of fish into fish-bearing waters, i.e. releases and transfer of fish between fish-rearing facilities, are part of a facility Pacific Aquaculture Regulations licence, but the proponent requires a licence from the federal-provincial Introductions and Transfers Committee the first time a transfer is undertaken – that licence then becomes part of the Pacific Aquaculture Regulations licence in future years. • Moving fish across a salmonid transfer zone is not permitted without specific health screening; disease screening and pathogen management will be as per the Introductions and Transfers Committee or veterinarian diagnostic requirements. • Fish designated within the same transfer zone that have a history of disease should be checked for health condition prior to release – if a disease is diagnosed, postpone release and treat if flexibility in timing allows – within biological imperatives (smolting) and drug clearing periods.

8. Assessment

Cause and Effect Relationship	Standard Mitigation Measures
• -Handling of spawners or activities that alter or delay spawn timing may render spawners more susceptible to pathogen and disease occurrence	**Reference:** FHMPs for facilities that have them and operate marking/enumeration programs. **General Measures:** • Fences will be designed and operated, with sufficient effort, to avoid unduly restricting passage of adult migrants. Enumerations may need to be compromised, particularly if there are risks of altering natural wild salmon spawning timing or locations, or skewing run/spawning timing of enhanced fish. Avoid handling of fish in higher than normal temperatures).

Ecological Interaction Risk Assessment and Management

1. Adult, Collection Holding and Sorting

Cause and Effect Relationship	Standard Mitigation Measures
• Decaying spawner carcasses provide nutrients to juvenile salmon and contribute to overall productivity of the system. There is potential for reduction in stream nutrification from decreased number of spawning carcasses if excessive numbers of individuals are removed from the wild population (broodstock mining).	**Reference:** Operational Guidelines for Pacific Salmon Hatcheries (2005) **General Measures:** • No more than one third of the naturally spawning escapement will be removed for hatchery use; up to 50 percent removals may

	be allowed if a project is managed under a formal recovery planning process. These are measures to protect genetic diversity, but also serve to protect ecological integrity within the stream.

2. Spawning Practices

Cause and Effect Relationship	Standard Mitigation Measures
N/A	N/A

3. Adult Carcass Management

Cause and Effect Relationship	Standard Mitigation Measures
• Potential ecological disruption may occur if carcass loading densities, distribution patterns, and timing are not compatible with the objectives of nutrient replacement or supplementation. • Overloading may result in eutrophic conditions leading to negative results such as hypoxia. Note: risk is very low, would require extreme conditions (e.g. large quantities in small water bodies)	**Reference**: Fish Health Management Plans; Guidelines for In-Stream Placement of Hatchery Salmon Carcasses for Nutrient Enrichment (also attached to FHMPs) **General Measures:** • Carcass loading densities and distribution patterns are to be in accordance with the in-stream placement guidelines, including the following general measures: o The temporal and spatial distribution of carcasses should reflect the historic spawn timing and abundance of salmon in the treatment reach. o Carcasses should be placed in stream areas that are normally (or recently historically) accessible to salmon, (i.e., not above barriers). Carcass placement into inaccessible stream segments may be permitted where juvenile salmon of the same stock and species have been previously out-planted (e.g., colonized upper areas above impassable barriers) but consultation with regional MOE staff is necessary.

4. Incubation

Cause and Effect Relationship	Standard Mitigation Measures
• Concentrations of Parasite-S™ (a.k.a. formalin, a liquid solution containing 37% formaldehyde) used for egg treatments, if used improperly could be of a concentration that may irritate gills of juvenile or adult fish in the receiving waters. Note: These effects would be infrequent and very near-field.	**Reference:** Fish Health Management Plans **General Measures:** • Effluent target concentration is < 25 ppm formalin; this dilution should be achieved by combining incubation flows with the discharge from other rearing units prior to release into a natural watercourse.

5. Rearing

Cause and Effect Relationship	Standard Mitigation Measures
• Potential detrimental effects on wild populations and their water quality due to improper use of chemical therapeutants (e.g. antibiotics in feed and Chloramine-T for parasite infections) through hatchery effluent.	• Care must be taken to properly administer antibiotics through feed.

Note: These effects are expected to be very small due to dilution.	

6. Release Time, Size and Condition

Cause and Effect Relationship	Standard Mitigation Measures
• Juvenile fish released prematurely or too large may residualize in the watershed to compete with or predate upon wild populations. • Juvenile fish released before or after smoltification, when imprinting is strongest, may tend to stray to other watersheds or other locations within the watershed and compete or predate upon wild populations.	**Reference:** Production Planning Framework, 2012;Brannon, 1999. **General Measures:** • Fish should be released in the number and at the size and stage specified in the facility production plan as developed through the planning process. Considerations include o Fish should be released at a time and size that minimize the risk of residualization within the watershed. o Fish should be released at life stages and locations that maximize homing fidelity. o Volitional releases during natural out-migration timing should be practiced where feasible. o Fish should be released within the size range of naturally produced fish from which the hatchery population is derived. o Releases should coincide with peak wild migration timing of wild smolts of the same species as indicated by downstream enumerations.

7. Release Location

Cause and Effect Relationship	Standard Mitigation Measures
• Hatchery fish released in or near non-natal watersheds may compete with or predate upon wild populations in the freshwater or near-shore areas. • Returning adults of hatchery fish released in or near non-natal watersheds may stray and compete with or displace wild populations on the spawning grounds.	**Reference:** HSRG, 2004 **General Measures:** • Fish should be released to the location specified in the facility production plan as developed through the formal production planning process. This process takes risk into account

8. Assessment

Cause and Effect Relationship	Standard Mitigation Measures
• Downstream juvenile enumeration and marking programs may cause mortalities of wild juvenile salmon or changes in wild juvenile salmon behaviour or migration patterns, thereby reducing wild salmon production.	**Reference:** FHMPs for facilities that have them and operate marking/enumeration programs. **General Measures:** • Downstream trapping programs will be designed and operated in a manner that reduces likelihood of mortalities or migration timing alterations (e.g. remove barriers/traps in high-water events, invest sufficient effort in order to prevent back-logs in enumerations and marking, avoid handling of fish in higher than normal temperatures).