SFU

Speaking for the Salmon

Reconciling the conservation of wild salmon and the production of enhanced salmon under Canada's Wild Pacific Salmon Policy: A discussion

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PREFACE

Salmon enhancement has a long history in British Columbia. The use of hatcheries and other enhancement tools has also generated much controversy, especially as we learned more about real and potentially negative interactions of enhanced and wild salmon (Hatcheries and the Protection of Wild Salmon; http://www.sfu.ca/cstudies/science/hatcheries.htm).

Despite the positive introduction of a federal Wild Salmon Policy in 2005, it remains unclear how the artificial enhancement of salmon "fits" with Canada's commitment to protect and conserve wild salmon and wild salmon diversity. A think tank was thus held on February 23 and 24, 2009, at the Simon Fraser University Harbour Centre campus, with the explicit purpose of prompting dialogue on how the conservation of wild salmon and the production of enhanced salmon might be reconciled under Canada's Wild Salmon Policy. Three expert presenters outlined key issues and concerns, and participants from several interests addressed the key themes of the workshop. This report is a conveners' summary of the two days of deliberation.

ACKNOWLEDGEMENTS

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Cover Image: *Fulton Spawning Channel, Babine Lake, August 5, 2009*

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SESSION 1: OPENING PRESENTATIONS

The Role of the Salmon Enhancement Program under Canada's Wild Salmon Policy

Brian Riddell, Wild Salmon Policy coauthor, and Pacific Salmon Foundation CEO

Fundamentally, Canada's Wild Salmon Policy (WSP) is a management framework to conserve wild Pacific salmon for the future and for the benefit of Canadians. Its essence is captured in the stated definition of 'conservation':

> *"Conservation is the protection, maintenance, and rehabilitation of genetic diversity, species, and ecosystems to sustain biodiversity and the continuance of evolutionary and natural production processes."* (Page 8, WSP)

Is the Salmon Enhancement Program's (SEP) production of enhanced fish in conflict with this definition? Hatcheries (and to a lesser extent, managed spawning channels) involve unnatural control of spawning and juvenile stages, but with intentional release to the wild. It is difficult to generalize among various enhancement projects, because activities have changed over time and enhancement outcomes are site-specific, providing little basis for comparison. Some level of genetic change and risk is inevitable, but to what extent? Fish produced in artificially-controlled environments are released into natural (uncontrolled) environments, invariably leading to both ecological and fisheries interactions. A chronic lack of longer-term assessment has limited understanding of these ecological and fisheries interactions. There are no controls on production, research on interactions has been limited, and the scale of releases alone generates concern. The existence of interactions is unquestionable, but outcomes are unpredictable.

The WSP deals with SEP as thus (page 36, side bar):

- *The enhancement program will continue to evolve towards greater emphasis on community stewardship, habitat restoration, and rebuilding of priority Conservation Units (CUs).*
- *Enhancement may be used to provide harvest opportunities and fishery benefits as part of an integrated strategic plan.*
- *The risk of hatchery production to wild salmon will be assessed through the development of a biological risk assessment framework.*

Developing a Risk Management Framework

> "*It is easy to identify risks that hatcheries pose for natural populations; it is not so easy to predict whether deleterious effects will occur in any given situation, or, if they do, how serious the consequence will be.*" [1]

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[1] Waples, R.S. 1991. Genetic interactions between hatchery and wild salmonids: lessons from the Pacific Northwest. *Canadian Journal of Fisheries and Aquatic Sciences.* 48(Suppl. 1):124-133.

It is unclear at this point exactly who is developing the risk assessment framework that is prescribed in the WSP, or what parameters it will include. Regardless, the following key risk-determining factors should be considered:

- The scale of production, particularly relative to local natural salmon abundance;
- The level of intervention (type of enhancement activity, from incubation only to intensive culture to maturity);
- The species involved (least intensive culture for pink and chum, greater for the other species);
- Strategy and practices applied in the culture programs;
- Types of interactions (from genetic bottlenecks to ecological interactions);
- Level of understanding and assessment—is there a technical basis for assessment and management of risk? (page 11, WSP).

Why should SEP change?

The debate over the merits and risks of salmon enhancement has been going on for decades. Nothing said now really seems to be new so delving further into the issues may seem futile. However, several outstanding and new questions need to be addressed:

- Ocean conditions for BC's salmon populations are generally deteriorating—are deleterious interactions between enhanced and wild fish being amplified?
- Our current economic situation stimulates questions on the value of the public's investment; while ecological studies in the Strait of Georgia in the early years of SEP showed good productivity for hatchery fish, the production and survival of wild fish has been higher than for hatchery fish in recent years. Is the costs of intensive culture worth it?
- Extensive reviews and dialogue in the United States have shed much light on hatchery/wild interactions and policy solutions—what could we learn from those and which lessons are most applicable?
- Strategy 4 of the WSP necessitates strategic planning and leadership in the development of regionally-integrated planning.
    - Is there a conflict between social support and biological expectations?
    - What is an appropriate role for mass marking and mark-selective fisheries in Pacific Canada?
- Development of ecosystem-based management (EBM) is now a federal priority.
    - Is there a conflict between diversity and production?
    - Are "silos" within government undermining the development of EBM?

The most compelling reason for reconsidering how we "enhance" our salmon populations may be the prevention of potential deleterious wild/enhanced interactions, and increased total production; however, the risk of unintended outcomes will be related to the level and relative scale of enhancement production relative to local natural populations. Risks of genetic interactions will increase with the intensity of culture, the source of brood stock and brood management plans, and inter-mating between populations, and will be related directly to the scale of enhanced to wild production and selection differentials. Risks of ecological interactions will increase with the numbers of fish produced, but will vary with habitat capacity and quality, presence of other species, and climate variation (both in freshwater and marine environments). Risks of harvest interactions will increase with numbers of fish produced, status and productivity of wild stocks mixed with enhanced, and opportunities for selective harvest of the enhanced fish. Risk is also related to assessment capability and management objectives (e.g. ocean mixed-stock abundance). Lastly, issues of disease transmission between wild and hatchery fish are again becoming topical.

Future suggestions and questions

1. Learn first, change later (a period of evaluation/review recommended).
    a. Do the necessary research—we have suffered from limited science investment.
    b. Plan for the future with an adaptive management framework where the burden of proof is the responsibility of the proponent, not wild salmon.
    c. Practice humility, acknowledge uncertainty, and take precautions[2].
2. Does application of the four WSP principles change priorities for "enhanced fish" and SEP processes?
    a. Who determines future objectives and decision processes? How do we identify risks and respond? (Strategy 4 requires region-based integrated strategic plans.)
    b. Who determines priority responses to Conservation Units and how can that process be integrated in to SEP planning?
    c. Public response to change is anticipated to be negative but Fisheries and Oceans Canada (DFO) also knows it needs to maintain public support, can they accomplish both?
    d. The WSP commits DFO to an open and transparent decision-making process, but the process must end with decisions being made, including when to terminate programs.
3. How does DFO address two major national priorities?
    a. What does production of "enhanced fish" look like under ecosystem-based management? Will there be new species priorities, different balance of species mixes, or new species in fresh and/or marine waters? Will there be a role for steelhead within SEP?
    b. Based on the experience in SEP, what opportunities exist to mitigate impacts of climate change? What are the most likely actions to succeed, and where should they be carried out?
4. Is it reasonable to place the onus for change on SEP? The answer is 'no'. At least not fully*.* Salmon enhancement has more than forty years of history in BC and SEP is a fully committed program but public input can aid future direction. How can we build on the core of expertise in this program and provide funding to support the WSP?

Review of Session 1: What have we learned?

- *What were the critical assumptions, what worked and what didn't, what were the surprises?*
- *What has an empirical basis of evidence versus belief?*
- *What questions or objectives weren't explicitly framed in the original program?*

[2] Riddell, B.E. and A.F. Tautz. 2003. State of Pacific salmon and their habitats: Canada and the United States. World Summit on Salmon, Vancouver. 10-13.

- *What experiences from other areas complement or contradict lessons from the BC experience?*

DFO employees provided some answers to these questions and confirmed that the original goal of the salmon enhancement program was to double the commercial salmon catch, with a focus on chum and pink. Pressure came from stakeholders in the 1980s to increase production of recreational species, i.e. Chinook and coho. Juvenile-to-adult survival rates were higher at the time the program began (15% for coho and 5% for Chinook) so marine survival for these species was not considered to be an issue. A former DFO employee noted that another major assumption was that enhancement could mitigate for lost or degraded salmon habitat.

DFO confirmed that scientific work was intensive at the beginning of the program (e.g. investigations on optimal time and size of release and optimal diets), but because SEP was already an operational project, and funding became more limited, scientific research was curtailed. The Treasury Board approved phase 2 funding for SEP in 1987, but the focus of the funding was again operational which limited the ability of the program to fund research projects such as large-scale comparisons between treated and untreated systems. A strong management benefit from SEP for decades was stock assessment data; however, concerns have been raised that the quantity and quality of more recent SEP-related stock data have declined due in part to declines in marine survival and fishing mortality rates, thus leading to lower tag-recovery rates (lower power in study designs).

An audience member suggested that funding for essential research and stock assessment is an increasing concern for DFO (not just SEP).

Mixed-stock fishing effects were also underestimated according to some participants. An unexpected commercial and social dependence grew up around harvest on production hatcheries and spawning channels and that continues to this day, along with overharvest of weak co-migrating stocks[3].

Initial cost/benefit assumptions were based on high survival rates and the large fisheries of the 1970s. It became apparent after about 4 years that projects might not be as successful as had been hoped, but the program had so much momentum it did not have the capacity to change based on early results. As survival rates dropped, SEP has to a large degree remained a static program in a dynamic environment (though a number of hatcheries in the interior of BC have been closed based on cost-benefit analysis, and chum releases in the lower Fraser were reduced about 10 years ago and have stayed lower in response to significant amounts of off - channel habitat that has been created/restored; this habitat provides stable spawning /incubation/rearing areas, even during major flood events).

The focal point of much enhancement work is single species in single areas, and ecological interactions, at least initially, were often assumed to be insignificant. Fisheries and Oceans has developed a design process, transfer guidelines, and a number of field studies to inform hatchery location, strategy and considerations of other stocks (see sidebar).

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[3] Walters, C.J., Lichatowich, J.A., Peterman, R.M. and Reynolds, J.D. 2008. Report of the Skeena Independent Science Review Panel. A report to the Canadian Department of Fisheries and Oceans and the British Columbia Ministry of the Environment. May 15, 2008, 144 p. http://skeenawild.org/resources/archive/report-of-the-skeena-independent-science-review-panel/

Hatcheries were part of the array of tools that the department was using in the 1980s to address the objectives laid out in a series of documents, Salmon Stock Management Plans, prepared for each area. While SEP gave some consideration to demographics, genetic implications for interactions between wild and hatchery fish were underestimated and not well understood (based on the knowledge of the day). Genetics workshops were held using the best information of the day to develop guidelines and practices and these were updated as information became available (see sidebar references); precautionary practices (e.g. wild broodstock wherever possible) have been in place from the beginning to protect localized variation and minimize domestication of wild stocks.

Analogous to the single-species approach, the economic assumptions around SEP focused on direct costs of the program compared to landed value of the fisheries.

A US-based participant pointed out that this experience is not unique to BC[4]. The "shocking" Puget Sound Chinook decline was cited as but one of many examples. The problem was that, when considering the merits and risks of new hatcheries, everyone's reference point was based on limited past experience. Hatcheries were viewed as having inherent benefits, rather than inherent risks. It was viewed as money in the bank or stock market. Despite the profound costs of large-scale enhancement, and the failure of SEP to achieve its original goal of doubling the commercial catch, it was noted that in some cases it has been effective in recovering at-risk stocks. Upper Adams sockeye and Stave River chum were cited as two documented examples[5].

Two participants suggested that, while enhancement may have played a role in the decline of Cultus Lake sockeye through mixed-stock fishing impacts, enhancement may now be the only thing keeping this stock from extinction. Enhancement efforts on Cultus are part of an overall recovery strategy that involves harvest, habitat, and predator control measures (Cultus conservation strategy[6]). This also prompted a question of financial priorities—how do you decide where to put the money? Should the financial priorities for enhancement be aligned with the

Fisheries and Oceans' Studies

Fedorenko, A.Y. and B.G. Shepherd. 1986. Review of Salmon Transplant Procedures and Suggested Transplant Guidelines. Can. Tech. Rept. Fish. Aquat. Sci. No. 1479. 152p. www.dfo-mpo.gc.ca/Library/27111.pdf

Shepherd, B.G., J.E. Hillaby, and R.J. Hutton. 1986. Studies on Pacific Salmon (Oncorhynchus spp.) in Phase 1 of the salmonid enhancement program. Volume I: Summary. Can. Tech. Rept. Fish. Aquat. Sci. No. 1482. 187p. www.dfo-mpo.gc.ca/Library/14474.pdf

Shepherd, B.G., J.E. Hillaby, and R.J. Hutton. 1986. Studies on Pacific Salmon (Oncorhynchus spp.) in Phase 1 of the salmonid enhancement program. Volume II: Data appendices. Can. Tech. Rept. Fish. Aquat. Sci.No. 1482. 205p. www.dfo-mpo.gc.ca/Library/246013.pdf

Shepherd, B.G. 1984. The Biological Design Process Used in the Development of Federal Government Facilities During Phase I of the Salmonid Enhancement Program. Can. Tech. Rept. Fish. Aquat. Sci. No. 1275. 196p. www.dfo-mpo.gc.ca/Library/70021.pdf

Cross, C.L., L. Lapi, and E.A. Perry. 1991. Production of Chinook and Coho Salmon From British Columbia Hatcheries, 1971 Through 1989. Can. Tech. Rept. Fish. Aquat. Sci. No. 1816. 55p. www.dfo-mpo.gc.ca/Library/120409.pdf

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[4] For example, see Taylor 1999. *Making Salmon: An Environmental History of the Northwest Fisheries Crisis*. University of Washington Press: Seattle.
[5] Upper Adams sockeye restoration report: www.dfo-mpo.gc.ca/Library/274927.pdf
[6] National Conservation Strategy for Cultus Lake Sockeye Salmon (*Oncorhynchus Nerka*) www.dfo-mpo.gc.ca/Library/337479.pdf

conservation priorities, based on CU status? In the US, despite operational recovery strategies, very few stocks have been successfully recovered or delisted as a result of enhancement. Ultimately, root causes must be addressed: “If you don’t deal with the original reasons for declines, you’re just painting over rust.”

A final question was raised: Given that hatcheries do in fact pose inherent risks, how do we change the design and implementation framework to adapt to this reality? One participant noted that “critical assumptions” are best avoided in management policies, and the best investment is in preserving the genetic and spatial diversity of wild salmon.

Interactions between wild and enhanced salmon

Carl Walters, University of British Columbia Fisheries Centre

The key issue is not whether enhancement can produce lots of fish, though there is a basic concern about sustainability of enhanced production. The key issue is whether enhancement can generate positive net benefits beyond what wild stocks can produce. This is a no-brainer in situations where wild stocks are no longer viable (dams, etc.); however, it is a fool’s bargain to just replace wild production with costly hatchery production,[7] where healthy wild stocks can be sustained.

Enhanced production can negatively impact wild production in three general ways. The first is through mixed-stock fishery impacts, where hatchery stocks can sustain higher exploitation rates than wild stocks. For example, this has been a major concern for Skeena River sockeye, Georgia Strait coho and Chinook, and to a lesser extent (due to lower enhancement effort), Fraser River sockeye (e.g. Cultus, Weaver). The second category of impact is through competition and/or predation interactions, such as where total production is limited by marine carrying capacity (e.g. Oregon and southern BC coho and Chinook). The third way enhancement may impact wild stocks is through genetic effects.

It is important to remember where the big problems are. Northern stocks are relatively healthy, with high marine survival rates. Data from MALBEC[8]—a synthesis of whole-Pacific historical data, mainly on sockeye, chum, and pink (sidebar)—indicate that total production of sockeye, pink, and chum in the North Pacific is increasing with/despite hatcheries (Figure 1).

Serious declines in production are mainly occurring south of central BC, and mainly with Chinook and coho. The MALBEC project has looked hard for negative interaction effects, but has not yet shown any. While some problems can be attributed to marine carrying capacity, none of the MALBEC indicators say that a cap has been reached. Patterns of food production do not match the survival patterns of fish stocks (Figure 2). Something else is driving the problem.

Declining marine survivals are the biggest risk for wild salmon in southern BC today (Figure 3), and it isn’t just coho. The same problem besets Rivers/Smith Inlet sockeye, Broughton pink, and Vancouver Island Chinook. And while we had confidently predicted that production would double from enhancement, a rapid doubling of coho smolt production through hatcheries in the

[7] The estimated production cost for each hatchery fish caught in the Strait of Georgia is $500.
[8] Mantua, N.J., N.G. Taylor, et al. (2007). "The salmon MALBEC project: a North Pacific-scale study to support salmon conservation planning." North Pacific Anadromous Fish Commission Doc. 1060: 49 pp.

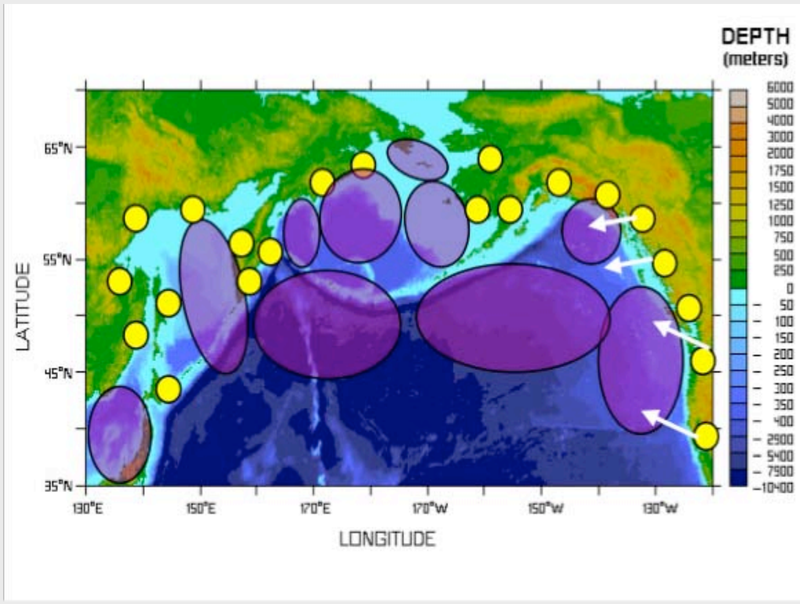
Strait of Georgia (Figure 4) coincided with a general decline in returning adults. Chinook have shown the same basic pattern in southern BC as coho, but with the decline starting earlier.

MALBEC: Model for Assessing Links Between Ecosystems

- Uses model fitting that includes parameters for possible marine interaction effects on growth and survival and allows for comparisons of population trends to models and data on ocean productivity.
- MALBEC predicts the same overall total production pattern as observed data, without including strong negative interaction.

Specific Attributes of Model Input Data

- 146 stocks of hatchery & wild pink (even- & odd year), chum, & sockeye salmon
- 25 freshwater regions
- 13 marine habitats
- 57 years (1950-2006) of total abundance estimates for each regional stock of hatchery & wild salmon used in each simulation as "historical reference period."



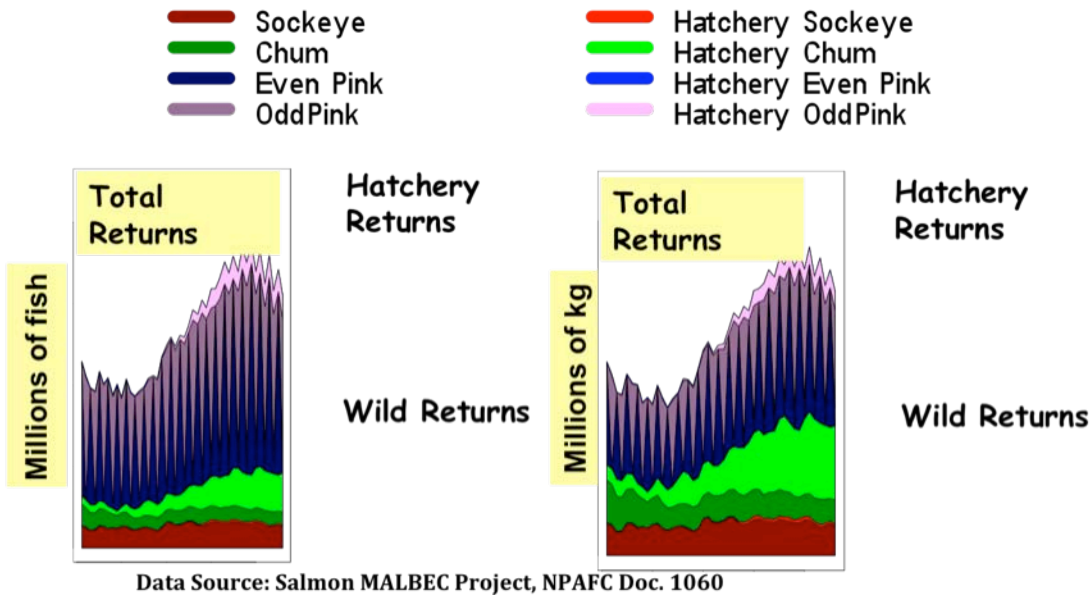


Figure 1. MALBEC Predicts the Same Overall Total Production Pattern as Observed Data, without including strong negative interaction.

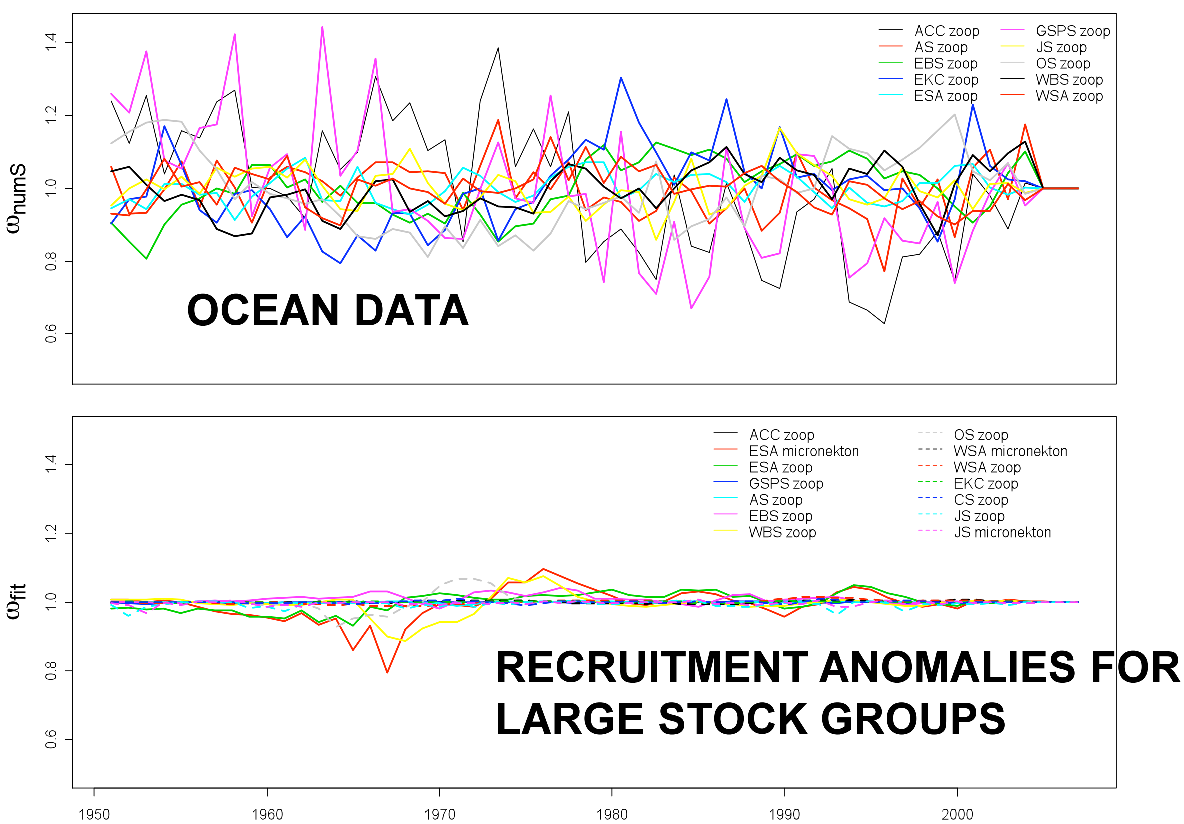


Figure 2. Estimated best fit recruitment anomaly series shows little correlation with ocean productivity indices (zooplankton etc). Top panel ocean data. Bottom panel shows recruitment anomalies for large stock groups.

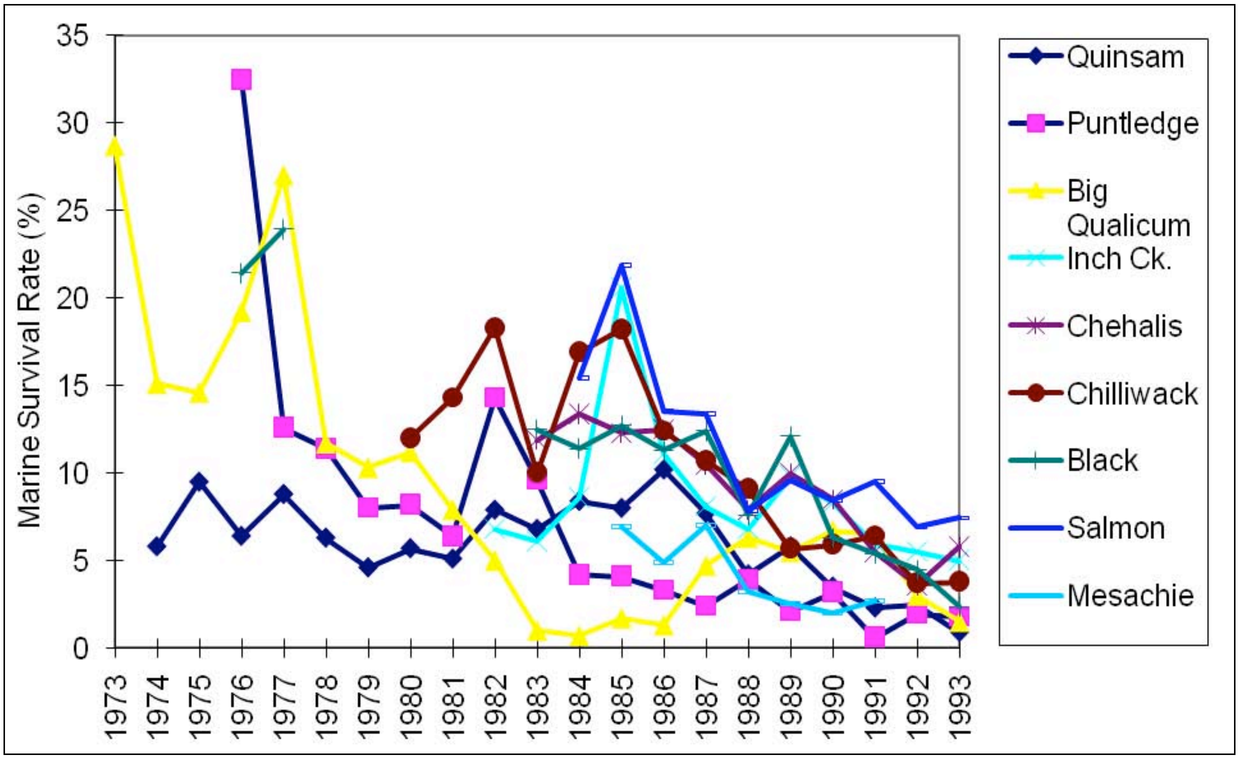


Figure 3. Trends in marine survival rate for Georgia Strait coho stocks (wild and hatchery combined).

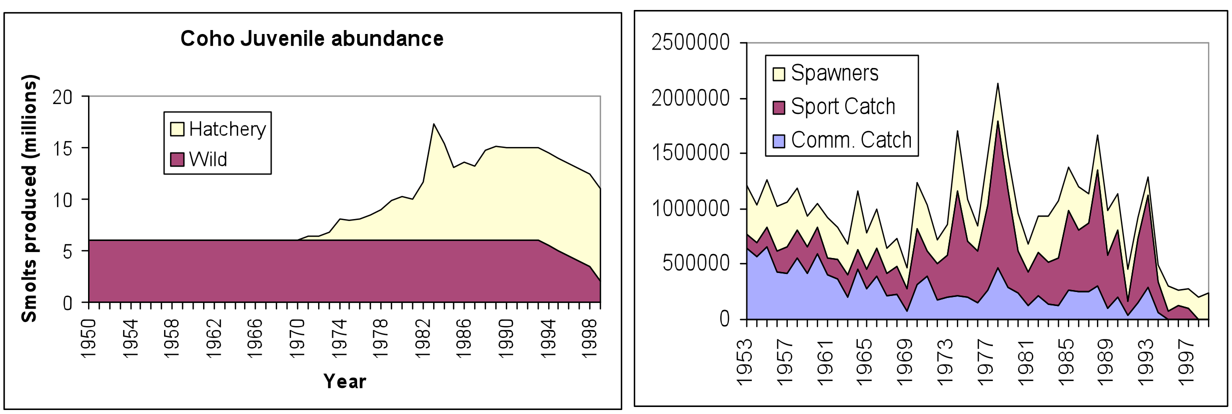


Figure 4. Hatchery and wild smolt production (left) and catch + escapement for statistical areas 13-19, 28, 29 (right).

Declining ocean survival trends could be caused by hatcheries through food competition and/or disease transmission, changing thermal regimes causing a warmer, less windy and hence less productive ocean, and/or mammalian predators (i.e. harbour seals). Severe competition between hatchery and wild Chinook and coho may be occurring due to foraging being restricted largely to the surface arena (top 5-10 m of the water column), combined with a lack of secondary production (food) in this arena. The resulting intense competition may drive increased foraging time and hence exposure to predation risk and disease transmission. Ecosystem models that include the foraging arena structure suggest that wild Chinook and coho are caught in a vise-grip between declining primary production associated with climate change (less wind, warmer surface water), increased abundance of hatchery competitors for that production, and radically increased predation risk from marine mammals while foraging.

Should you believe such models? No more than you should believe any scientist who claims to have the right explanation based on data now available. More important, scientists will never be able to give you the right explanation, unless the proposed causal factors are deliberately manipulated in the field. A critical need exists for an adaptive management experiment to test for competition/disease effects by manipulating total hatchery releases. Extensive simulation studies were conducted to design such an experiment, and they showed that the best design is alternating high and low releases of hatchery smolts. DFO agreed to implement it, but never did. If these grand experiments are not done, the result will be continued "junk" science: models that are derived by fitting numerous environmental variables (10+) until some combination happens to fit well. Such models are not to be relied upon for good predictions. It is probably a good idea not to sit back and wait for scientists to tell you what is going on.

Dialogue following Carl Walters's presentation

Question: You mentioned stakeholders a lot in the presentation. Who are they?

Walter's Response: The general public is the big stakeholder.

Q: So you are saying that things have to happen at the Strait level?

R: Yes, we are not seeing any productive zones, so experiments must be conducted on a large scale. We need experimentation rather than a shutdown.

Q: The challenge is in conducting experiments over a long time frame, and keeping senior managers on side. We also need to consider US hatchery production of coho, and what that would mean for any experiment.

R: Yes, we need to consider a coordinated experiment with Washington and Oregon.

Comment: We wanted to do the same thing on the Columbia with coho, but again the problem is with time. We couldn't get buy-in; however, there may be more stomach for it now.

R: We know where they are dying: In smaller areas around the Strait of Georgia such as Texada Island.

Comment: The same pattern of decline in survival and return beginning in the early 1990s applies to a few other stocks, such as Rivers and Smith Inlets and Barkley Sound.

R: Figures for the Strait show that there is probably something specific affecting survival there. In the Strait, is it something new? No one can figure it out.

Q: What's to prevent the big experiment in the Strait?

R: It's an issue of cost and budget pathology. If you don't spend all of your money on feed one year, you'll never get it back.

Comment: Dick Beamish (DFO) is making the case that pink fry abundance correlates with the productivity of other stocks.

R: This is a widespread issue. Big pink years are not good for other species, and this shows up in scale data from Japanese chum, for example. A potential solution is to run treatments for at least two years each to account for these effects. No adaptive management experiment in the world has ever been maintained to completion.

DFO comment: Resources are only one reason why DFO would not be doing such experiments. We would need US cooperation, and we will explore it.

Comment: In addition to scientific and management benefits, this could pay off for hatcheries as well.

Q: Could ocean acidification be a factor?

R: Georgia Strait waters have low oxygen and high carbon dioxide, and it is a big problem for many organisms that are strictly marine. It is probably not such an issue for pelagic/coastal species like salmon. Disease outbreak may be a much greater threat to salmon. When you have a huge density of hatchery fish the odds or risk of a disease outbreak spreading across the entire population is high. As densities rise, disease transmission increases

Q: How do we deal with the issue of marine mammal biomass?

R: If the experiment fails, then the seals ate them all. The current harbour seal population could eat all the coho pumped into the Strait in 12 days. Seal populations are like a huge fishery.

Q: Why are there so many seals?

Walters's response: No killer whales, and seal protection programs. Think about the potential political fervour if you proposed a cull of seals.

SESSION 2: THE FUTURE OF THE SALMON ENHANCEMENT PROGRAM

What is the foreseeable future of the SEP over the next 20 years, related to:

- *Natural priorities for establishment of ecosystem-based management?*
- *Climate change scenarios and mitigation (tradeoffs between population productivity, diversity, hatcheries, habitat, water, etc.)?*
- *International production issues in the North Pacific and a niche for Canada?*

Dialogue began by an acknowledgement that SEP is at a critical point, a crossroads (due in part to a recent audit), and could go a number of ways in the future. One way would be the status quo—do not fight the existing cultural and institutional inertia; rationalize the existing infrastructure; protect the existing investment and human resources. Yet the cultural inertia is relenting somewhat as stakeholders become increasingly aware of the need for SEP to align with the WSP and to react to the challenges of global climate change. Two participants suggested that hatchery managers are not wed to the status quo, and another suggested that there is general agreement that "business as usual" is the least desirable option; a more desirable approach would be one of "active engineering" and creativity, with a foundation of ecosystem-based management. That said, difficult questions need to be asked around international production and the need for large scale experiments of the type proposed by Carl Walters.

All agreed that stakeholder education and engagement will be critical. More must be done at the community level to make stakeholders aware of the critical issues (e.g. ecological and genetic interaction, and international production issues), and it may be necessary to start a stakeholder engagement process, not only to educate, but to seek public input on these difficult questions. Moreover, the attitudes and mandates of the people on the ground need to be examined to ensure that they comport with both the WSP and SEP's evolving mandate. Existing groups such as the Pacific Fisheries Resource Conservation Council might be best suited to this task, given their recent work[9].

DFO suggested that the key to a higher level of ecological understanding will be a move away from a narrow focus on freshwater survival, and towards a better understanding of nearshore survival bottlenecks and international production patterns. Much has been accomplished on these fronts in recent years, but many questions remain unanswered. Key to understanding North Pacific Production issues will be understanding mortality and carrying capacity over different time and space scales. Another participant noted that Japan must confront this issue as they seek Marine Stewardship Council certification for their fisheries. Canada may have to do the same as the commercial sector seeks certification for sockeye, pink, and chum fisheries. Russia and Alaska—who are enjoying strong returns due to dramatically higher marine survivals—are also critical. Therefore, a hierarchical, cross-jurisdictional approach will be necessary.

Funding and capacity for scientific investigation are an ongoing challenge, especially as the industry becomes less profitable. DFO's Science Branch (which of course overlaps considerably with SEP staff) is facing a large turnaround of staff over the next few years and funding is tight. In the face of these challenges, innovation is necessary in all management sectors, not just Science. A network of no-take areas for harvest, coupled with salmon strongholds[10] was suggested as a potentially more cost-effective alternative to the production enhancement/harvest paradigm.

"International" production issues must also be considered at another, more local scale. The diversity of First Nations' interests regarding enhancement is wide. First Nations have strong interests in natural production and stock diversity in their land claim areas, and their needs and priorities must be given high priority in this regard. A perception exists among some First Nations that SEP was designed as a program for the primary benefit of sport and commercial interests, and that major programs have been retained for this purpose. On the other hand, several First Nations are active participants in, and proponents of, enhancement activities in their territories (e.g. Ditidaht Nation, Nitinat hatchery; Haida Nation, Pallant Creek hatchery); currently, about one-half of community hatcheries are operated by First Nations. Yet, the entire process for incorporating First Nations' interests in SEP activities and cost/benefit consideration could be improved, though the challenge of incorporating cultural benefits is not easily resolved.

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[9] Pacific Fisheries Resource Conservation Council. 2007 Annual Report. www.fish.bc.ca/files/Web_2007AnnualReport_2008_0_Complete.pdf.

[10] Rahr, G.R., III and X. Augerot. 2006. A Proactive Sanctuary Strategy to Anchor and Restore High-Priority Wild Salmon Ecosystems. In: "Salmon 2100: The Future of Wild Pacific Salmon". Edited by R. T. Lackey, D.H. Lach and S.L. Duncan. Bethesda, Maryland, American Fisheries Society: 465-489. www.wildsalmoncenter.org/pdf/Salmon_2100_Rahr_Augerot.pdf.

Genetic Consequences, Conservation Applications, and Uncertainties of Salmon Enhancement in a Changing Climate

Craig Busack, Science Division, Fish Program, Washington Department of Fish & Wildlife (currently with NOAA)

Washington State has a long tradition of hatchery operations and operates one of the largest hatchery programs in the world in terms of number of facilities. Over 75% of the salmon and 95% of the trout harvested in Washington are of hatchery origin, and Chinook and coho populations not influenced by hatchery operations are rare. The Washington Department of Fish and Wildlife (WDFW) operates 89 hatcheries, participates in the operation of 250 cooperative projects, and 40 Regional Fisheries Enhancement Groups (RFEG) projects that produce 25-30 million trout and 175-200 million juvenile salmon annually.

Washington (Figure 5) is also home to several Evolutionarily Significant Units (ESUs) of salmon and Distinct Population Segments (DPSs) of steelhead listed as threatened or endangered under the US Endangered Species Act (ESA); in many cases the hatchery system was listed as one of the threats.

That fact that hatcheries can cause loss of molecular diversity both within and among populations is well established in the literature. While it is widely accepted that the molecular genetic differences between populations in several areas of the state have been eroded because of hatcheries, the concept of domestication—fish losing fitness in the wild because of hatcheries—is more controversial. People tend to accept the idea of fitness loss through domestication when definite artificial selection has been applied, but tend to be resistant to the idea that it happens in normal hatchery operations, or may believe that it does happen, but the effect gets "washed out" if the fish are later allowed to breed in the wild. Recent work on Hood River steelhead[11] supports the idea that fitness effects happen quickly, do not get washed out, and can be dramatic.

Natural selection theory argues that hatchery operations should pose domestication selection risks to natural salmon and steelhead populations. Hatchery rearing environments differ greatly from the natural environment, exerting different selection pressures, including denying fish sexual selection. Cultured populations become more adapted to the hatchery environment and less to the natural environment. Interbreeding between cultured and naturally produced fish cause natural populations to be less fit in the wild environment. The bottom line is that if interbreeding between hatchery-origin and natural-origin fish occurs, hatcheries can be expected to reduce fitness in wild populations. While the domesticating effect of hatcheries has been controversial in the past, it is now considered as fact by a prominent hatchery review process in the US Pacific Northwest: the Hatchery Scientific Review Group (HSRG)[12]. The HSRG has reviewed and made recommendations on all hatchery programs in the state of Washington and in the Columbia-Snake basin. A hatchery reform process is underway in these areas, especially Washington State, where dealing with the genetic risk posed by hatcheries is considered an essential part of activities being undertaken as part of the recovery effort under the Endangered Species Act.

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[11] Araki, H., B. Cooper and M.S. Blouin. 2007. Genetic Effects of Captive Breeding Cause a Rapid, Cumulative Fitness Decline in the Wild. Science 318 (5847): 100-103.

[12] Puget Sound and Coastal Washington Hatchery Reform Project. Hatchery Reform: Principles and Recommendations of the Hatchery Scientific Review Group. www.lltk.org/pages/hatchery_reform_project/HRP_Publications.html

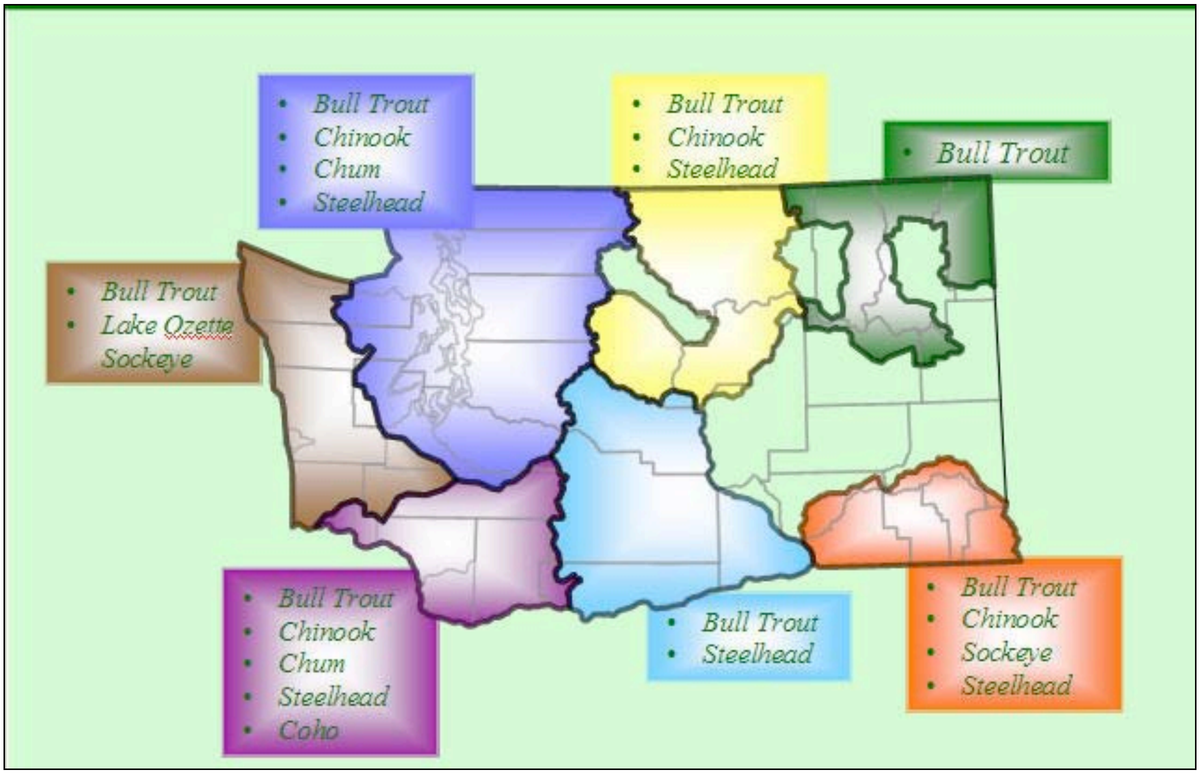

Figure 5. ESA-listed salmonids in Washington.

Domestication effects can essentially be dealt with in two ways: (1) reduce selection pressures imposed by hatchery programs and/or (2) manage interbreeding (gene flow) between cultured and naturally produced fish. Hatchery program types for managing gene flow—based on HSRG recommendations—fall into two categories:

1. *Segregated programs* allow minimal gene flow (ideally none) between cultured and naturally produced fish and they are highly desirable in all cases except where supplementation[13] is occurring. The perfect situation is one in which no hatchery-origin fish spawn in the wild, but this is difficult to achieve. In practice, HSRG recommends that hatchery-origin fish comprise no more than 5% of the natural spawners in a population of high conservation concern.

2. *Integrated programs* attempt to manage gene flow between cultured and naturally produced fish in order to limit domestication. Many existing hatchery programs are "poorly integrated," with much unregulated gene flow. In the HSRG view, the perfect integrated program is one in which natural-origin fish are included as hatchery broodstock to prevent genetic divergence of hatchery and natural production, but no hatchery-origin fish are allowed to spawn naturally. In practice, virtually all integrated programs have gene flow in both directions.

[13] An effort to use artificial propagation to increase the number of natural-origin fish by allowing hatchery-origin fish to spawn in the wild.

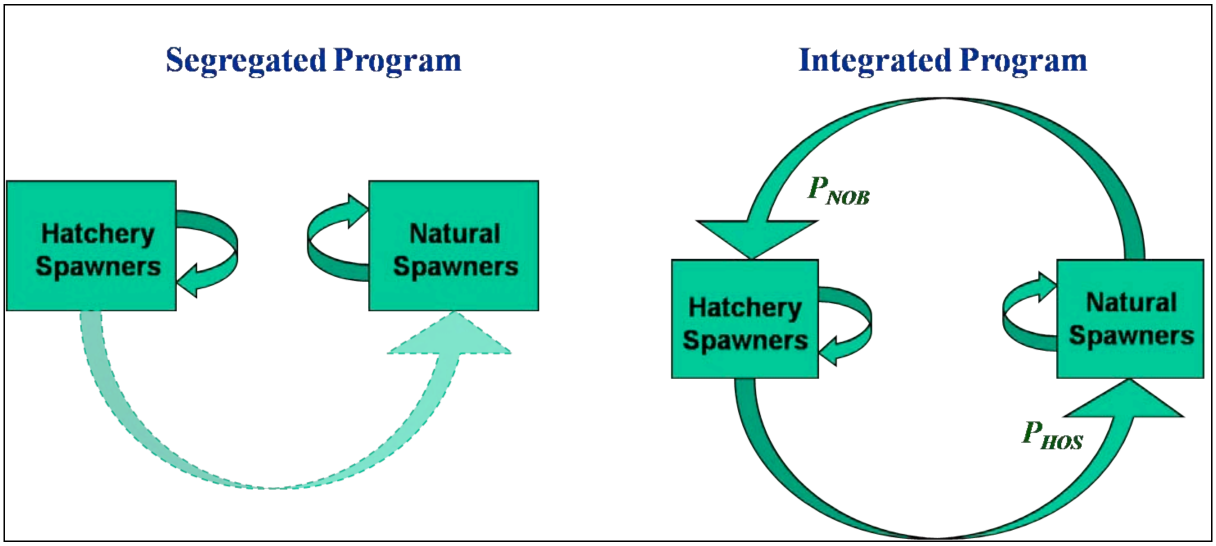

Figure 6: In a segregated program the intent is to have natural and hatchery production types be isolated populations, while in an integrated program gene flow connects the two production types to make a single population. (PNOB = proportion of broodstock consisting of natural-origin fish; PHOS = proportion of fish spawning naturally consisting of hatchery-origin fish).

An "integrated" population lives in two environments, and natural selection in each environment tugs the population towards an optimum for each respective environment. A domestication model developed by Ford (2002)[14] is used to estimate and manage the extent to which hatchery and natural selective forces dominate fish populations in integrated programs. In this management model, the mean of any population trait will eventually equilibrate at a point expressed as a proportion of the distance from the hatchery-origin optimum to the natural-origin optimum, and is called *proportionate natural influence* or PNI. PNI is approximated well by the ratio P_{NOB} / (P_{NOB} + P_{HOS}), where P_{NOB} is the proportion of broodstock consisting of natural-origin fish and P_{HOS} is the proportion of fish spawning naturally consisting of hatchery-origin fish. HSRG recommends a PNI of at least 0.67 for populations on high conservation concern, and further recommends P_{HOS} be less than 30%.

The proper integration of hatchery programs requires the ability to identify fish by origin and the ability to control P_{NOB} and $P_{HOS,}$ which requires some sort of marking and often some method of excluding fish from the spawning ground. Collecting natural-origin fish for broodstock can also be difficult. Proper integration also requires that program size and harvest rates to be scaled to basin productivity and capacity, and that the appropriate population unit is chosen for integration.

The PNI concept has value as a unifying element for the management of integrated hatchery programs, regardless of program purpose. In Washington State, the use of the PNI concept has led to a more holistic approach to hatchery planning, integrating ideas about harvest, hatchery production, and habitat capacity and productivity (an "all-H" approach). However, managers and others seeking to apply the PNI concept should bear in mind that it is based on modeling. Although the model is well-grounded in theory, application of the approach is so new that model

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[14] Ford, M.J. 2002. Selection in captivity during supportive breeding may reduce fitness in the wild. Conservation Biology 16: 815-825.

predictions have not yet been experimentally verified. Further, this approach can only limit domestication but cannot eliminate it. A major additional caveat is that PNI concept does not directly address fitness. A population with PNI of 0.67 should have higher fitness in the wild than one with a PNI of 0.30, but we lack the ability to predict what the fitness will be. Other caveats about this approach are that it is not a complete model of domestication, and that there are other types of genetic risk besides domestication posed by hatcheries. Finally, hatcheries may pose ecological risks as well as genetic risks. Ecological risks of hatchery operations are difficult to study and as a consequence are not well understood.

A partial test of the PNI approach is serendipitously underway in the Yakima River basin of central Washington. As part of the Yakima/Klickitat Fisheries Project (YKFP),[15] the upper Yakima spring Chinook population is part of an integrated program. Only natural-origin fish are used as broodstock (P_{NOB}=1); hatchery-origin spawners on the spawning ground are not controlled, but PNI is above 0.5. A hatchery control line, begun at the same time, is also maintained. These fish never spawn in the wild. The project is now beginning its third generation. Comparisons of first-generation hatchery-origin fish with their counterparts revealed significant differences in life history, reproductive, and morphometric traits, but the genetic signal in these differences is unclear. Striking differences have been seen, however, between the integrated program fish and the hatchery control line fish in juvenile survival in the hatchery, production of precocious males, and allocation of reproductive effort in males, demonstrating that domestication is much more pronounced in the hatchery control line. This is a very interesting project, and I encourage interested readers to check the website, where numerous publications are available.

Dialogue following Craig Busack's presentation

Question: Can you see the effect of backing off of hatchery production?

Busack's response: We haven't done really robust experiments to answer that question. It would be best to conduct a series of graduated experiments to estimate this effect.

Q: Please comment on mass marking of hatchery fish and SEP.

DFO response: The US pushed hard for mass marking in the 1990s. We started with ventral clips, and then switched to adipose, which we have been doing since 1997. In Southern BC, 6 to 7 million (out of about 10 million) hatchery coho are fin-clipped annually in southern BC. The Georgia Strait coho recreational fishery is completely reliant on mark selective fisheries—some areas are mixed bag fisheries and some are mark only. There are also mark selective fisheries in some parts of Vancouver Island and almost all Southern BC terminal recreational fisheries are reliant on hatchery fish and some variant of mark selective fisheries. They are harvested in some mixed-bag recreational fisheries, as well as in some terminal mark-only fisheries.

A final dialogue ensued around current and costly mark-selective fisheries for coho. For example, in Washington State the annual cost of monitoring and enforcement for these fisheries is around $1 million. This does not include the cost of the double-index tagging programs. (As background, this was not SEP's idea, but was done to service the recreational harvest sector, even though there is the potential for using this in commercial fisheries. The department

[15] Yakima/Klickitat Fisheries Project www.ykfp.org

developed a selective fishery policy in the late ‘90s and hatchery mark selective fisheries stem from this. They were also part of the coho response in 1998.)

Having a lot of marked hatchery fish around also generates harvest demand (also consistent with WSP page 36 sidebar—bullet 2). You must either choose harvest rates for those stocks that weak stocks can sustain, or you must figure out how to differentially harvest. Because we have huge mixed-stock fisheries and need to evaluate impacts, allocation, etc. If you can’t differentially harvest, you should not have the hatchery programs, because they are not tenable with diversity and conservation.

Final question to Busack: What are the criteria for measuring fitness and how do you measure the mate selection effect?

R: Fitness is the ability to produce offspring, but the offspring can be measured at many levels from immediate fry production to spawning adults. Currently the most common approach in hatchery research is to measure relative reproduction using DNA, as was done in the Araki et al. study. In this approach prospective adults are genotyped, then the offspring are genotyped and matched back to parents. Regarding the second part of the question, I stated earlier that it is possible that mate selection is a very important selective force in nature, so may be a major area of domestication in a hatchery program. The obvious way to test this would be to have two groups of fish, allow mate choice in one but not in the other, and compare performance of progeny of the two groups. This would be easily done in a laboratory fish species. I have heard of such a study but do not know if it was completed.

SESSION 3: INTEGRATING THE FUTURE SEP WITH WSP PRINCIPLES AND VISION

Biodiversity vs. Production:

- *How much can we have of both biodiversity and production?*
- *Is there a role for mass marking and mark-selective fisheries?*

Habitat restoration and ecosystems:

- *How do we move past major facilities?*

An integrated role for Stock Assessment and monitoring/research:

- *What essential monitoring needs exist to improve hatchery impact assessment (e.g. marking and mark/biological sampling at hatcheries and adjacent natural spawning areas)?*
- *Are there additional needs for hatchery stock monitoring to facilitate wild stock assessment (e.g. exploitation rates)?*

Future tools and approaches needed to evaluate enhancement impacts and strategies:

- *What enhancement impact assessment tools are available and needed to address the biological risk assessment requirements in the WSP?*
- *What overall planning and review approaches are needed?*
- *What policy issues need to be addressed before, or as assisted by, implementing such tools and approaches?*

The discussion began with a participant saying mark-selective fisheries are very important, not only to Canada, but to the US and US tribal fisheries. A question was asked: Can you have fisheries targeting marked fish, and thus maintain biodiversity? It was agreed that costs would likely be significant, and most of them would be unanticipated. Likewise, assumptions regarding the likely benefits should be closely examined: for example, assumptions regarding encounter rates. Mark-selective fisheries will still have direct impacts on wild fish, primarily through hooking mortality. Moreover, fishery benefits gained through continued or expanded mark-selective fisheries will have to be weighed against their larger systemic cost to management efficacy through degradation of the quality of data from the Coded Wire Tag (CWT) program (run by DFO and supported by data from the Pacific Salmon Commission)[16]. While there have been impacts on the CWT program from the coho mass marking program, sampling techniques, equipment and methodologies have now been built into the system to address these so the costs have been well anticipated. There would be additional issues should mass marking of Chinook ever be undertaken.

Ongoing and potential monitoring and stock assessment functions are important benefits from SEP, and must be considered in all deliberations over the future of the program. While monitoring (e.g. CWT program) related to the Pacific Salmon Treaty (PST) provides data valuable to managers despite current challenges, it is still most useful at only a single spatial scale (there are also specific commitments in the PST for Chinook assessment, mostly based on hatchery fish). Monitoring needs also exist across a hierarchy of spatial scales and at present may not be adequately addressed at more local scales where straying and genetic integrity of wild stocks must be tracked.[17] While monitoring and research was conducted at these local scales at the outset of SEP, such activity is now very limited as monitoring and stock assessment have been increasingly limited. Similar concerns exist with the allocation of monitoring effort across sectors and fisheries: Monitoring needs should be addressed across all pertinent fisheries in all sectors.

The development of biological risk assessment tools related to the WSP[18] is a large task and is just beginning. SEP has drafted an *Excel* tool which contains 5 criteria for risk, and provides “relative risk” from stock to stock. So far this tool is being used to assess risks of individual hatchery stocks to nearby wild stocks, but is not yet capable of assessing risk in the context of ecological interactions and carrying capacity. Given that marine survival is now a core issue for SEP and DFO, and BC salmon management in general, additional risk assessment tools are warranted (e.g. MALBEC). In general, we have an array of major questions that should be considered at multiple levels for any risk assessment framework to be effective. At the highest level, where enhanced populations are concerned, it may be worth explicitly asking “how do you monitor hatchery/wild stock interactions?”

The question of socioeconomic benefits—especially of hatchery coho in the commercial recreational sector—was raised in dialogue. The example was given that in recent years the recreational catch of coho in the Strait of Georgia has declined significantly, with about 90% typically hatchery fish. Socioeconomic benefits from production-level hatcheries should be

[16] The Pacific Salmon Commission’s 2005 expert panel on the Coded Wire Tag (CWT) program recommended that despite several shortcomings and challenges, it should continue in perpetuity. The PSC has argued against the use of adipose clips in mass-marking for mark-selective fisheries outside of the CWT program due to degradation of the integrity of the CWT data. (http://www.psc.org/pubs/CWT/EPfinalreport.pdf).
[17] Kim Hyatt used the example of Robertson Creek Chinook showing up in Gold River.
[18] From the WSP (p.36): “The risks of hatchery production to wild salmon will be assessed through the development of a biological risk assessment framework.”

explicitly calculated if they are to persist where conservation/recovery benefits are unclear, survival rates are low, and ecological and genetic risks exist. Robust analysis and review of costs-benefits should be conducted for SEP, and cases identified where socioeconomic benefits could be maintained at or near current levels with significantly fewer hatchery fish produced. The current Barkley Sound pilot process for WSP implementation could provide a good venue for testing such an evaluation.

Ultimately, SEP must comply with the federal government's stated goal in the WSP—to restore and maintain diverse and healthy salmon populations in perpetuity for the benefit and enjoyment of Canadians. All of the WSP strategies are going forward at the same time, making it difficult for sectors within DFO to act in harmony, and also difficult to integrate stakeholders. Many of the issues discussed around risk assessment and resulting decision-making will be dealt with under strategy 4 of the WSP (Integrated Strategic Planning). The WSP contains much guidance on what is required to monitor and rebuild wild salmon populations. DFO participants pointed out that in discussing biodiversity and production it must be recognized that the WSP deals not only with diversity of salmon (i.e., strategy 1), but also with diversity of habitats and ecosystems (i.e., strategies 2 and 3). Of all of the WSP strategies, number 3 is particularly difficult, because while it deals with ecosystem objectives and values, it does not require any real benchmarks.

Ongoing dialogue will be crucial, involving not just the public and stakeholders, but also various government agencies and sectors within DFO. A pressing need exists for this in Barkley Sound where strategy 4 is starting to be implemented, while strategies 1-3 are being "test driven." Ideally, DFO's ongoing multi-stakeholder engagement forums will provide a venue for some of this dialogue to occur regarding the enhancement issue. As part of DFO's current processes for WSP implementation, especially where enhancement and habitat management are concerned, steelhead must be factored in, and the province should be involved. Without meaningful engagement between the federal and provincial governments regarding WSP implementation, the objectives of the WSP will not be met. Diminishing government capacity and resources will present a mounting challenge to multi-agency engagement and coordination and this can only be met by creative and forward-thinking solutions with public and political support.

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