A Review of Hatchery Release Strategies

This review of hatchery release strategies was undertaken by the Pacific Salmon Foundation as part of a larger Hatchery Effectiveness Review funded by the British Columbia Salmon Restoration and Innovation Fund.

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Photo by Snootli Creek Hatchery. Cover photos: top and middle by Mirko Diaz, left and right by Sam James

BACKGROUND

Hatcheries are facilities designed to increase the freshwater survival of salmon. To do this, adult salmon are bred and their young are reared in the hatchery and ultimately released back into the river. The goal of this work is to rebuild vulnerable salmon stocks, provide economic opportunities for fisheries along our coast (commercial, sport, and Indigenous), and to engage the broader community in salmon stewardship. Hatcheries also support stock assessment and international treaty requirements. Approximately 300 million salmon are released from hatcheries in British Columbia every year, which makes up roughly 6% of the total number of hatchery fish released into the North Pacific (Table 1).

While hatcheries can support healthy salmon populations, they can also have negative impacts on wild salmon. These include negative effects on the genetics of wild populations, overharvesting of wild salmon that travel alongside hatchery salmon, and competition for food and habitat. While the **Salmonid Enhancement Program (SEP)** has frameworks and best practices in place for addressing risk, the interactions between hatchery and wild salmon, and ultimately the effectiveness of hatcheries, remains uncertain. Therefore, as our government continues to invest in salmon hatcheries, it is important we understand the factors that influence the survival of hatchery fish and their interactions with wild salmon.

Building upon previous research into hatchery survivals conducted during the Salish Sea Marine Survival Project (www.marinesurvivalproject.com), the Pacific Salmon Foundation (PSF) initiated a province-wide, science-based, and independent hatchery review. This review was funded by the BC Salmon Restoration and Innovation Fund in 2019 and will run until the summer of 2022. The three main objectives of this work are to:

1. Identify scientific advancements and cutting-edge genetics tools that could improve hatchery performance
2. Evaluate how hatcheries release their salmon and what bearing that has on their survival
3. Conduct a thorough analysis of the effectiveness of hatcheries and their impacts on wild populations

Parts 1 and 2 have been recently completed and Part 3 is still underway.

***Table 1:** The numbers of hatchery fish released from each country in 2019 and % contribution to total releases. Data are from npafc.org.*

Country	Hatchery Releases	%
Canada	339,356,000	6
United States	2,030,883,000	37
Russia	1,237,746,000	22
Japan	1,918,642,000	35
Korea	10,950,000	< 1
Total:	**5,537,577,000**	**100**

The **Salmonid Enhancement Program** is a multi-faceted program within Fisheries and Oceans Canada (DFO) that contributes to the management, conservation, and restoration of Pacific salmon.

Here, we share with you what we learned from Part 2 — our analysis of hatchery release strategies.

Step one was to learn from the past by exploring the existing literature on release strategies. Next, we took a close look at the hatchery experiments conducted in BC over the past 20 years to see what has worked where. We then created a model that pooled all the available data on **coded wire tagged (CWT)** Chinook and Coho since modern-day enhancement began in 1972 to really explore the relationships between release strategies and salmon survival. We focus on Chinook and Coho as they are the two salmon species most commonly reared in hatcheries and many of their releases are marked using CWTs, making it easier to link release strategies to returns.

Coded wire tags are tiny pieces of metal with a code inscribed that is inserted into the juvenile salmon's nose prior to release from the hatchery. This code can then be recovered when the salmon are caught and provide information on the origin, age, growth, run timing, and other characteristics of the salmon.

RELEASE STRATEGIES EXPLAINED

Photo by Snootli Creek Hatchery

Life stage released: Life stages include fry, subyearling smolts, and yearling smolts. Fry are released shortly after emergence from the gravel, subyearlings are reared for a few months and typically released in the spring of the same year they hatched, and yearlings are reared for a full year and typically released in the early spring of the year after hatching. The life stage released from a hatchery usually mimics that of the natural population.

Size at release: Size is influenced by a number of factors, including water temperature, daylight, diet, and how long the salmon is held at the hatchery. Changing the size at release can be done by altering these rearing conditions. For Chinook salmon, fry tend to range from 2-4 grams in size when they are released, subyearling smolts from 5-8 grams, and yearling smolts from 11-20 grams. For Coho, fry tend to range from 2-5 grams and yearlings range from 14-25 grams. Some hatcheries will try releasing other sizes to determine the effects on survival.

Time of release: For many hatcheries, release timing is based on historical records of the timing of the wild outmigration. However, it may be beneficial to time releases to coincide with high food availability in the ocean, or to offset them from the wild salmon to reduce competition. Chinook subyearling and Coho yearling smolts are typically released in late May. Fry releases are often earlier in the spring. Hatcheries may change the timing of release to improve survival rates or reduce competition with wilds.

Volitional versus forced release: A volitional release means that the hatchery gates are opened and the fish are allowed to swim into the river freely. This allows salmon to leave the hatchery when they are physiologically ready. A forced release means the fish are forced out of the hatchery all at once on a pre-determined date. This is often the case when salmon need to be transported to their release location.

Seapens: Sometimes salmon are transferred to a net pen in the ocean near the river mouth and held for a few weeks prior to release. This allows the salmon to adjust to marine conditions while protected from predators, which should, in theory, increase early marine survival. However, seapens are also used to encourage salmon to return to a specific area to support targeted fisheries.

Photo by Sam James

LEARNING FROM THE PAST

To better understand the impacts of rearing and releasing fish in different ways, we first looked to the literature. A lot of research has been conducted on release strategies, particularly in the United States, and we wanted to set the stage before conducting our own analyses on unreported experiments in BC.

We reviewed 76 studies on the effects of release strategies on survival, catch, age at return, proportions of males and females in returns, and size at return of Coho and Chinook salmon. Most research has come from Washington and Oregon with a large focus on Chinook, particularly in recent years. Two of the more commonly studied release strategies are the size at release and time of release (Figure 1). Of the studies that looked at size, about half reported that releasing larger fish resulted in higher survivals. However, several studies also found that larger fish were more likely to return at younger ages. Releasing Chinook later in the season resulted in lower survival in half of the cases, while releasing Coho later resulted in higher survival. Releasing Coho later also led to higher catches and older ages at return but smaller body sizes of adults. **Thus, the body of literature suggests that rearing and release strategies can influence the fate of hatchery fish**.

For more information, check out our full report on the literature: '[Review of Pacific salmon hatchery release strategies in Canada and the United States](#)'.

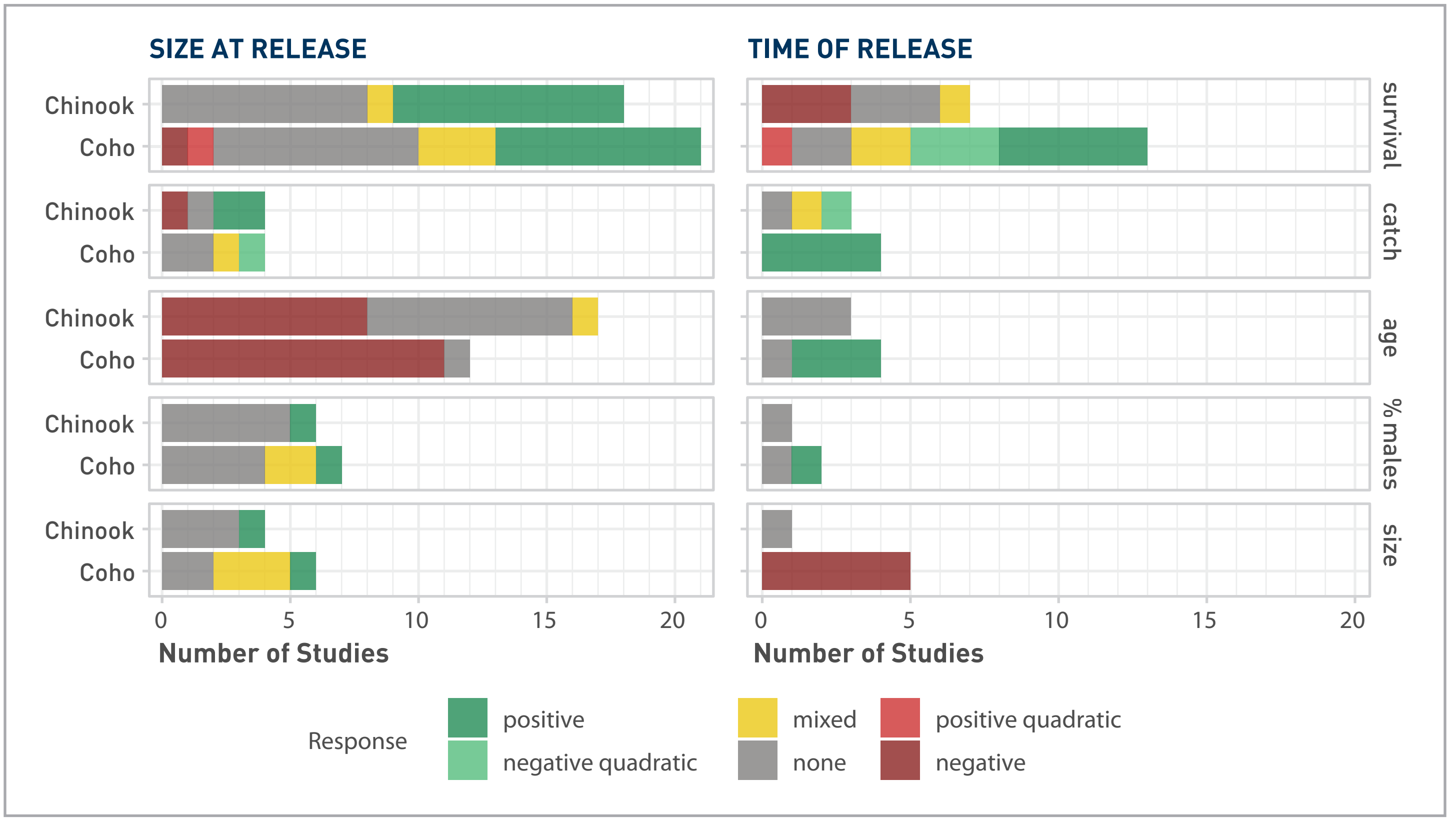

***Figure 1.** The number of studies reporting different effects of size at release and time of release (i.e. the 'treatment') of Chinook and Coho salmon on survival, catch, return age, the proportion of males in the returns, and size at return (i.e. the 'response'). Responses could be either positive (as the treatment increases, so does the response), negative quadratic (as the treatment increases, the response increases to a point, and then decreases), positive quadratic (as the treatment increases, the response decreases to a point and then increases), negative (as the treatment increases, the response decreases), mixed (different responses in different years of the study), or none.*

ANALYTICAL STUDIES

We analysed 25 hatchery experiments conducted in BC over the past 20 years to get a better picture of what strategies might be able to improve hatchery performance today and to add to the lessons learned from our literature review (Table 2 on the following page). The experiments included seven on releases of multiple Chinook life stages, four on Chinook size and time of release, eight on Coho size at and time of release, and six on the effects of seapen releases. Results were variable and details are provided below. We know that salmon ecosystems are highly complex and environmental conditions beyond the hatchery can cause dramatic changes in survival from year to year; additionally, several of the experiments only ran for a few years, which may be why we did not see any effects of release strategies in some cases.

This is where our models come in. By using all CWT Chinook and Coho releases and not just a few years of experimental data, we could paint a clearer picture of how hatchery salmon have responded to changes in release strategies (see the facilities we included in our models in Figure 2). We were also able to look at how the size at release and time of release could influence the age of returns at a few hatcheries where the data were available (Chinook: 4, Coho: 7).

The key findings from both the hatchery experiments and our full data model are summarized below, but you can find more information on each in our final report:: '[Review of Hatchery Release Strategies in British Columbia](#)'.

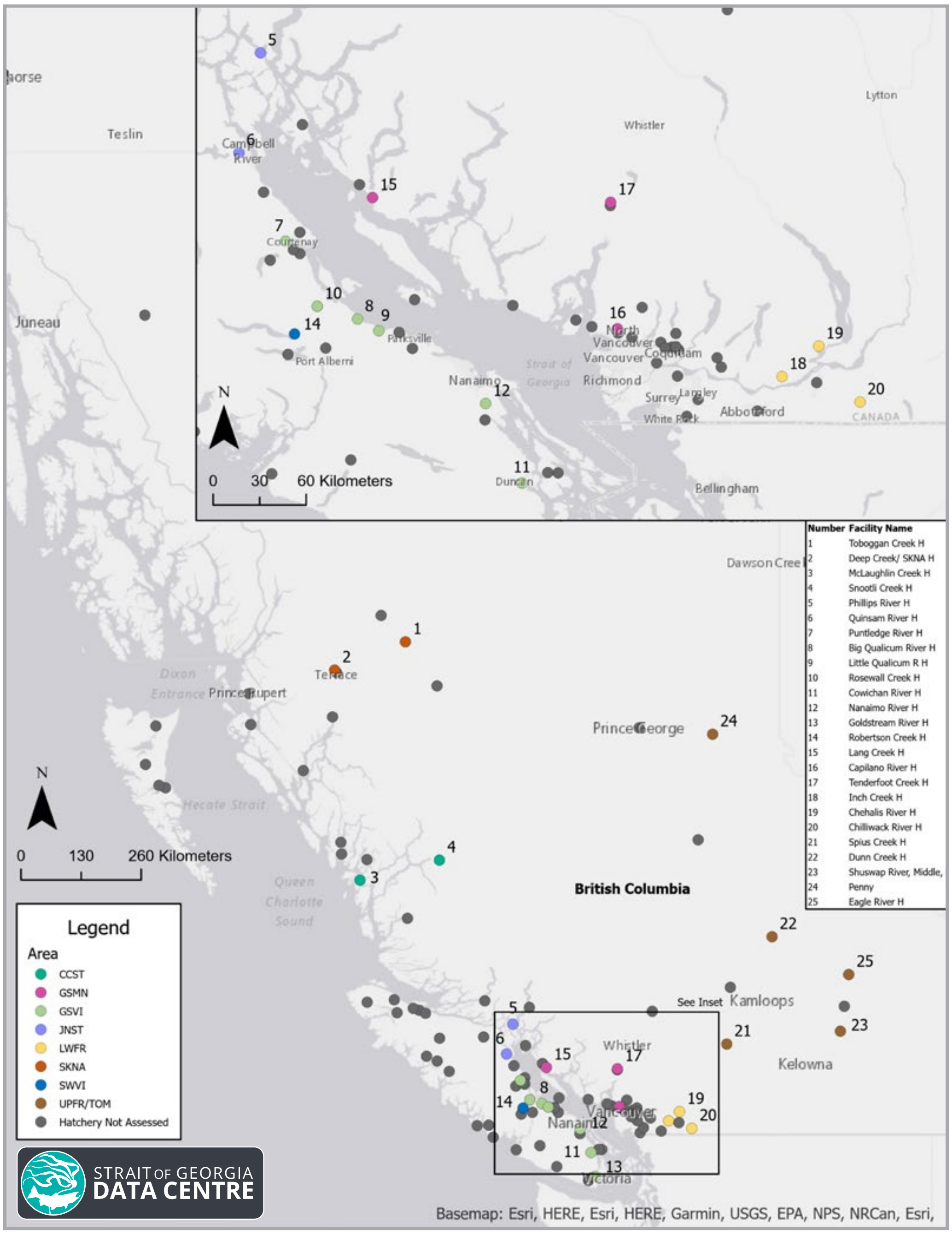

***Figure 2.** Map of salmon hatcheries by production area included in the release strategies model.*

The inset shows the location of hatcheries around the Strait of Georgia.

Production areas are defined by DFO and include:

SKNA = Skeena,
CC = Central Coast,
JNST = Johnstone Strait,
SWVI = Southwest Vancouver Island,
GSMN = Georgia Strait mainland side,
GSVI = Georgia Strait Vancouver Island side,
LWFR = lower Fraser River,
UPFR/TOMM = upper Fraser River and Thompson River

Hatcheries are also listed by program type:

OPS = major DFO hatchery,
CDP = community-led hatchery,
DPI = community-led and public involvement hatchery

Table 2. *Summary of each salmon stock in each region used for each release strategy experiment in specific ocean entry years (OEY)* in BC using CWT'd Chinook and Coho salmon over the past 20 years. Earlier experiments were also included for Chilliwack and Cowichan Rivers.*

Strategy	Region	Stock	Run	Species	OEYs	Experiment
Life Stage	Central Coast (CC)	Atnarko R Low/Up	Summer	CN	2009-2013	smolt vs yearling
	Northeast Vancouver Island (NEVI)	Phillips R	Fall	CN	2011, 2012, 2014	smolt vs yearling
		Quinsam R	Fall	CN	2001-2007 2015-2018	release of fed fry to Quinsam Lk vs smolts from hatchery
	Strait of Georgia (SoG)	Cheakamus R	Summer	CN	2016-2019	fed fry vs yearlings
		Puntledge R	Summer	CN	2002, 2003, 2005	fed fry (released at multiple locations) vs hatchery smolts
		Shuswap R Mid	Summer	CN	2015-2018	smolt vs yearling
	West Coast Vancouver Island (WCVI)	Robertson Cr	Fall	CN	2004-2007 2017-2018	smolts vs yearlings
Size	SoG	Quinsam R	Fall	CO	2010-2012	normal vs large
		Inch Cr	Fall	CO	2012-2014	small vs normal
Time	SoG	Chilliwack R	Fall	CN	1993-1995	early vs late
		Chilliwack R	Fall	CO	1983, 1990-1991, 2000-2001	early vs mid vs late
		Cowichan R	Fall	CN	1990-1995, 1998, 2001-2004, 2006, 2008-2009, 2011-2016	early and late, at two release locations
		Inch Cr	Fall	CO	2006-2008	early vs normal
		Quinsam R	Fall	CO	2002-2012	early vs normal vs late
Time & Size	NEVI	Quinsam R	Fall	CN	2015-2017, 2019	normal vs late/large
		Quinsam R	Fall	CO	2016-2020	normal vs late/large
	SoG	Big Qualicum R	Fall	CN	2011-2013, 2015-2017	normal vs late/large
		Big Qualicum R	Fall	CO	2016-2018	normal vs late/large
		Inch Cr	Fall	CO	2015-2017	normal vs late/large
Seapens	CC	Wannock R	Fall	CN	2010-2011, 2014-2015, 2018-2019	hatchery (freshwater) vs seapen (marine) releases
	NEVI	Quinsam R	Fall	CN	2000-2018	hatchery (freshwater) vs seapen (marine) releases
	WCVI	Robertson Cr	Fall	CN	2002-2004, 2014-2018	hatchery (freshwater) vs seapen (marine) releases
	SoG	Puntledge R	Summer	CN	2000, 2002-2003, 2006-2009	hatchery (freshwater) vs seapen (marine) releases
		Cowichan R	Fall	CN	1992-2004, 2006-2009	hatchery (freshwater) vs seapen (marine) releases
		Chilliwack R	Fall	CN	2014-2017	hatchery (freshwater) vs seapen (marine) releases

*Ocean entry year (OEY) refers to the year in which salmon are released from the hatchery.

KEY FINDINGS

Life stage: Of the experiments we reviewed that released multiple life stages, we found that **the older stage often had higher survival rates.** For instance, yearling Chinook smolts released into the Atnarko River had higher survival rates than the subyearling smolts they released. However, the effects of a salmon's life stage at release are hard to tease apart from its size at release or when it's released. For example, a yearling Chinook may have higher survival because it was a larger size when released, or because it was released earlier in the year. This was more apparent in our model, in which release strategies like size and time were more important in determining survival than the life stage itself.

Size: There were only two short-term experiments in BC that explored the influence of size at release (both on Coho) and neither found any effect on survival rates, exploitation rates, or return ages. Yet in our full data models, we found that **almost all hatcheries in BC can expect to see higher survival rates if they release both their Chinook and Coho smolts at a larger size than they have historically**. How much larger depends on the hatchery, but the best release weights ranged from 5-16 grams for Chinook subyearling smolts and from 17-33 grams for Coho yearling smolts (the most commonly released life stages for each species) (Figure 3). McLaughlin Creek, Robertson Creek, and Puntledge River were the exceptions, where smaller Coho releases are expected to have higher survival rates.

We only found effects of the size at release on a salmon's age at return at 1 of 4 Chinook hatcheries and 3 of 7 Coho hatcheries. For Puntledge River Chinook, increasing the size at release from 3 grams up to 7 grams was related to a decrease in the age at which the salmon returned. Interestingly however, increasing the size at release beyond 7 grams was related to an increase in the age at return. Coho also expressed mixed responses. Coho typically return as 3 year old salmon, with 2 year old returns known as 'jacks'. The number of jacks coming back increased as the size at release increased up to a point, but fewer jacks came back from the largest fish at both Big Qualicum and Quinsam Rivers. Meanwhile for Puntledge River Coho, the larger the size at release, the more jacks that came back. **Thus, from our limited data on return ages the general trend is that we can expect salmon released at a larger size to return younger, although there is some variation in trends across hatcheries**.

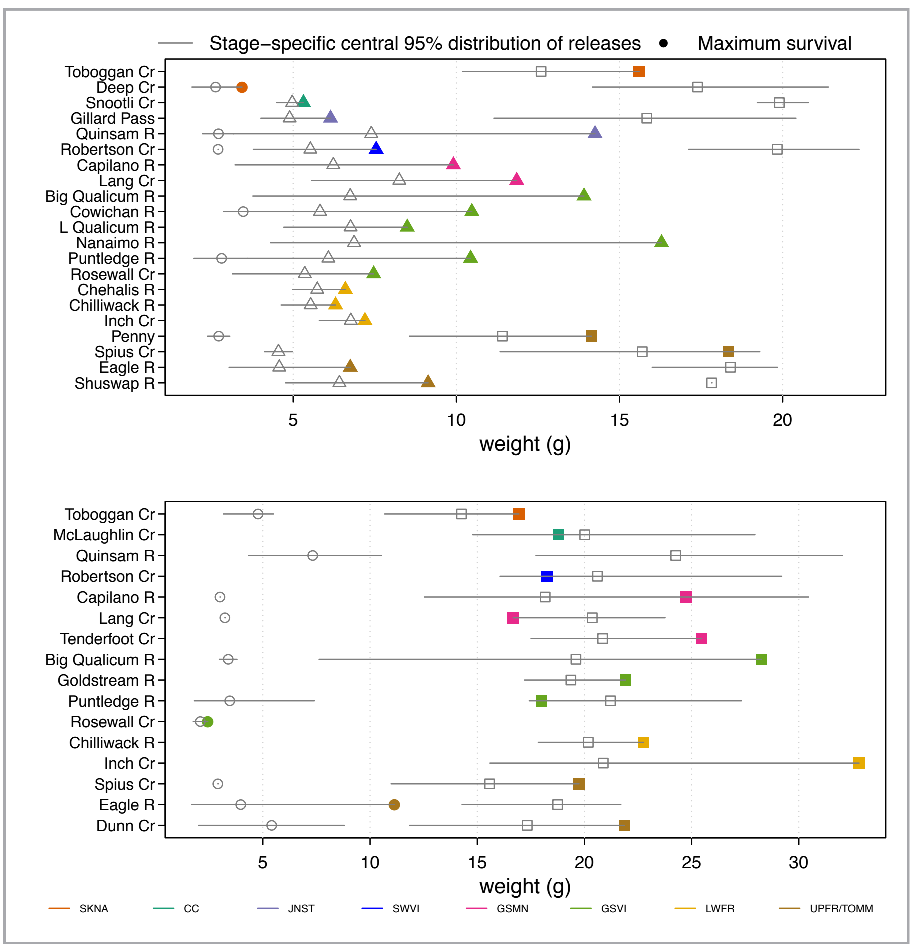

Figure 3. *The range of release sizes at each hatchery releasing CWT Chinook (top) and Coho salmon (bottom). The black hollow symbols/lines show the typical range of fish weights, while the coloured symbol shows the weight that is expected to yield the highest survival rates for that hatchery. The shapes of the symbols represent different life stages: fry (○), subyearling (△) and yearling smolts (□).*

The best release size is only shown for the main life stage released at each hatchery.

Colours represent the different production areas:
(SKNA (orange) = Skeena,
CC (turquoise) = Central Coast,
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UPFR/TOMM (brown) = upper Fraser River and Thompson River

Time: We found that the few experiments on the time of release had mixed results. Late releases of Chinook on the Cowichan River had higher survival rates while those at Chilliwack River had lower survival rates. For Coho, later releases had higher survival at Inch Creek, and also at Quinsam River in more recent years.

Our full data model found that **Chinook generally do better when released 6-27 days earlier than the historical average (at 13 of 17 hatcheries), and Coho generally do better when released 8-33 days later than the historical average (at 12 of 13 hatcheries)** (Figure 4).

As for return ages, the time of release did not appear to have any effect.

Size and Time: It can be difficult to separate the effects of size from those of time. In fact, several more recent experiments have been looking at the effects of releasing larger smolts later than usual (Table 2). **This strategy has seen increases in survival, harvest, and return age for Quinsam River Coho**, with early results from other locations showing similar trends.

When we consider both size and time in our full data models, changing the weight at release is expected to be more effective at improving survival rates than changing the time of release alone for most hatcheries (13/21 Chinook and 11/16 Coho hatcheries).

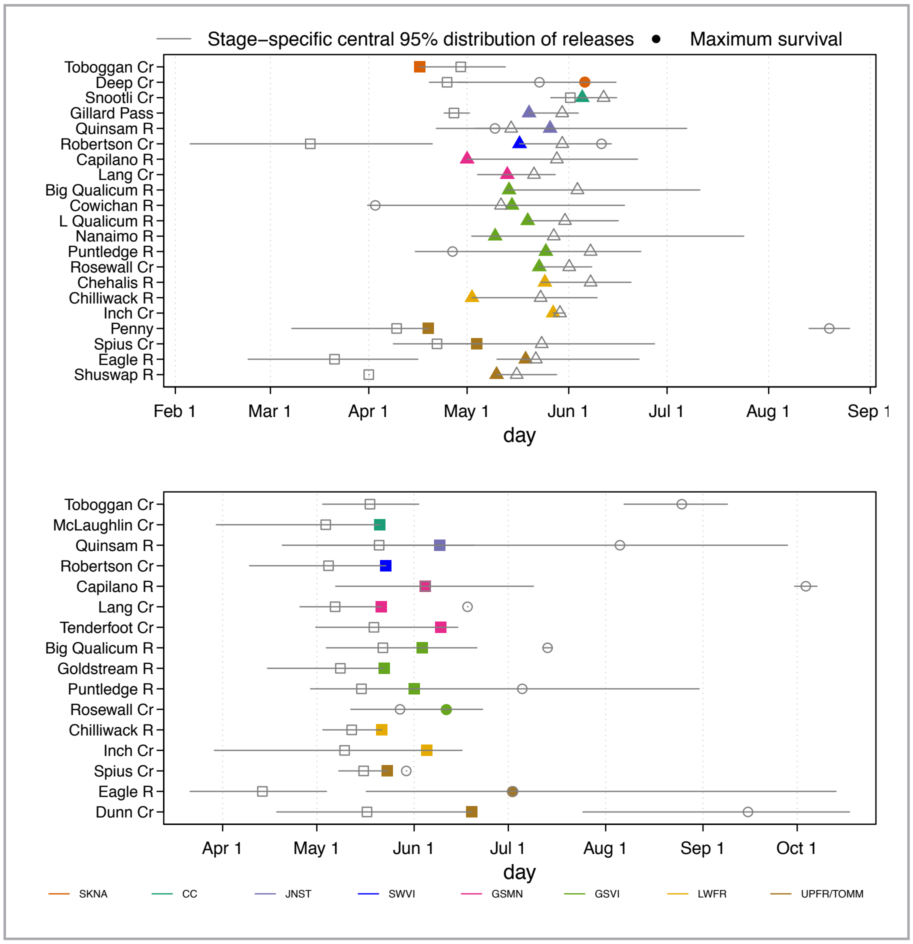

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Photo by Lucy Quayle

For instance, changing the date of Chinook releases at Big Qualicum River is only expected to increase returns by 4% however changing the weight at release could increase returns by up to 229%. But ultimately, both strategies should be considered when designing release strategies to improve hatchery survivals. It is important to note that these improvements only led to a greater than 50% increase in survival for 8 of 21 Chinook hatcheries and 4 of 16 Coho hatcheries, with increases in the number of adult salmon returning ranging from 61-245%. Therefore, **adjusting or experimenting with release strategies will be of greater value to some facilities than others**.

Seapens: In the hatchery experiments releasing salmon from seapens, we were unable to find any benefits to overall survival of releasing salmon from seapens; **salmon transferred to seapens prior to release had similar survival rates to those released directly from the hatchery**. However, seapen fish were more likely to be caught in fisheries for 2 of 4 locations with enough data to allow for analysis. Seapens were not directly assessed in our models.

Photo by Snootli Creek Hatchery

Release biomass: In our full data models, **increasing the total annual biomass of hatchery salmon (of all species) released from a hatchery is expected to cause lower survival rates for Chinook and Coho salmon**. More fish means more competition for resources, like habitat and food. Large pulses of salmon can also attract predators that cue on to large release events. However this negative relationship was only significant at three hatcheries.

Environmental conditions: Harbour seal abundance, killer whale abundance, sea surface temperature in the early marine environment, and the Pacific Decadal Oscillation are all significantly negatively correlated with survival rates — meaning as their values increase, survival of hatchery Chinook and Coho salmon decreases. However, we found that using the more sweeping category of 'random year effects' (anything that could influence survival rates other than the release strategies in our model) was better at explaining patterns in survival than any one of these four environmental parameters on their own. Therefore, we used random year effects to account for the 'unknowns' in our models so that we could focus on the effects of release strategies. In doing so, we found that **10-91% of the variability in hatchery salmon survival rates can be linked to random effects**. This means there are other conditions beyond the control of the hatchery (such as predator abundance and sea surface temperatures) influencing survival rates. Therefore, the best release strategies moving forward could vary over time with climate change or more local dynamics associated with river conditions, predation, or prey availability.

The **Pacific Decadal Oscillation** is a long-term record of ocean-atmosphere climate variability in the Pacific basin.

LOOKING AHEAD

While there are some consistent findings across our three analyses, the conditions at each hatchery are unique and what works best in one location may not work at another. Our 'Review of Hatchery Release Strategies in British Columbia' final report provides hatchery-specific information for managers to consider when planning hatchery releases in the future and identifies locations with the greatest opportunities for improvement. However, environmental conditions are changing, and we may not be able use the past to predict the future. Therefore, **the way in which hatchery salmon are reared and released needs to be adaptive to change**.

To do this, we recommend the development of a thorough, peer-reviewed, experimental design to assess hatchery rearing and release strategies moving forward. This strategy should take into account the following:

- **Experiments need the resources to run for longer periods of time** (>3 years) to be able to pick out release strategy effects amidst the 'noise' of significant environmental variability.
- There also needs to be adequate resources in place for **routine collection, analysis and reporting of data**, allowing for more rigorous experimental designs.
- Not all facilities are expected to see significant improvements from altering release strategies — **efforts should be focused on those that have the greatest potential for improvement**.
- **More information is needed from data-poor areas**, such as the west coast of Vancouver Island, and the central and north coasts, before we can fully understand role of hatchery release strategies in BC.
- Future experiments need to **monitor the impacts of hatchery release strategies on wild salmon**.
- There are **management objectives and limitations** specific to each hatchery that need to be taken into consideration.

Photo by Snootli Creek Hatchery

Photo by Mirko Diaz

This work provides an important first step towards improving our understanding of the complex dynamics of hatchery practices and the performance of the salmon they produce. It also paves the way for future work that was beyond the scope of this review. For instance, how has the effectiveness of different release strategies changed over time? How does diversifying release strategies influence hatcheries in the long run? And what happens when there are significant changes to hatchery practices throughout the province?

This analysis will also inform the other components of PSF's broader hatchery review, which will be looking at the trends in biological traits of Chinook salmon over time, the critical role of community hatcheries, the effectiveness of hatchery production for specific objectives, such as producing fish for harvest or rebuilding, and the impacts of hatcheries of wild salmon.

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