Residualism and precocity in hatchery steelhead programs

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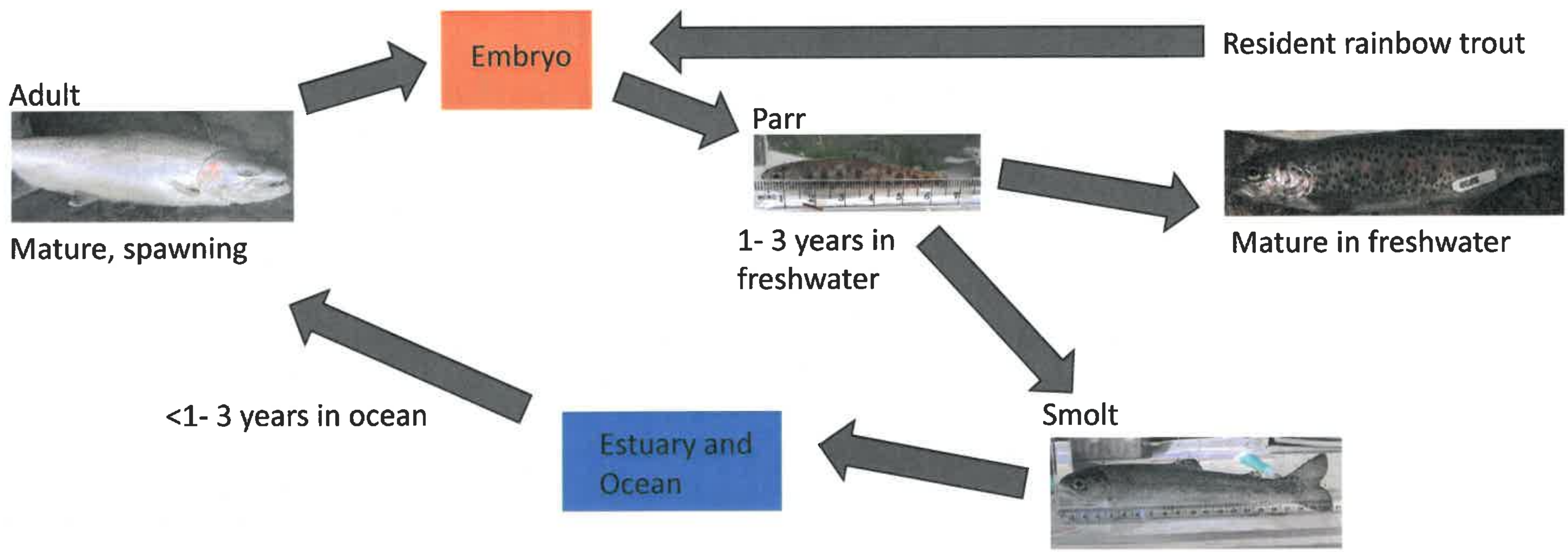
O. mykiss life history diversity



Some *O. mykiss* do not migrate to sea during the primary migration period

- Delay migration for one or more years
- Mature in freshwater

- Residual = hatchery fish that fails to outmigrate with cohort
    - Undersized, immature parr
    - Large, precocious males

Residualization of Hatchery Steelhead: A Meta-Analysis of Hatchery Practices

Stephen J. Hausch[*1] and Michael C. Melnychuk[2]

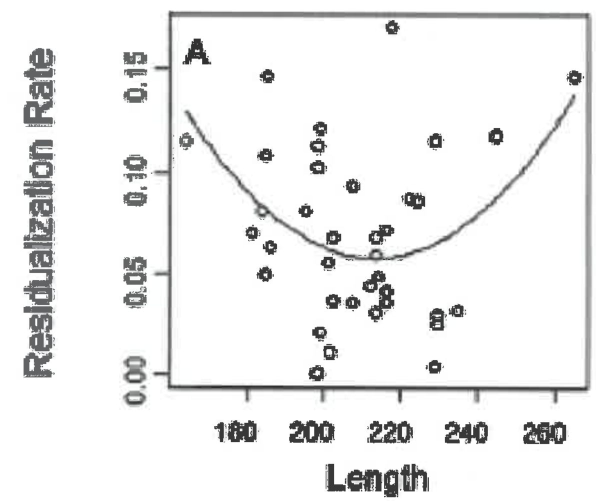


FIGURE 2. (A)-

Hatchery Management Goals

- Maximize adult returns
  - Harvest programs: maximize “full-size” adult returns
  - Conservation programs: maintain natural life history diversity

- Minimize risks to wild populations

Genetic and Ecological Risks

- Evidence that hatchery-origin fish have lower reproductive fitness than natural-origin fish Araki et al. 2008 *Evol App*, Araki et al. 2009 *Biol Letters*, Christie et al. 2014 *Evo Apps*

- Hatchery releases may be associated with decreased survival of wild fish via ecological mechanisms Kostow 2009 *Rev Fish Biol Fisheries*
  - Competition for limited food or rearing territories
  - Predation on smaller-bodied salmonids

Wild broodstock programs (integrated) produce more residuals than hatchery programs (segregated)

- Majority of studies on summer steelhead east of Cascades (inland redband, *O. mykiss gairdneri*)

- Literature review of 16 studies *Hausch and Melnychuk 2012*
  - average 5.6% residualism (0 – 17%)
  - Integrated > segregated (for both inland and coastal lineage)

- Recent studies
  - Methow summers: 6 -23% residualism *Snow et al. 2013*
  - Hood River winters: 3 – 4% residualism *Larsen et al. 2017*

Residualization of Hatchery Steelhead: A Meta-Analysis of Hatchery Practices

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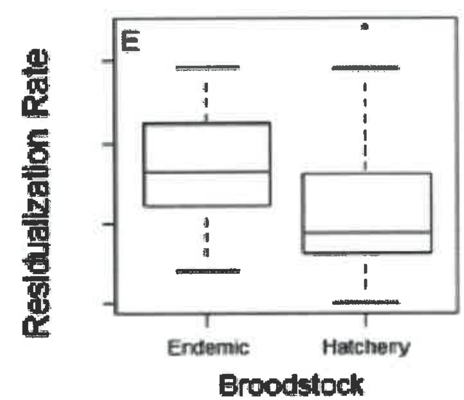


FIGURE 2. (A)-

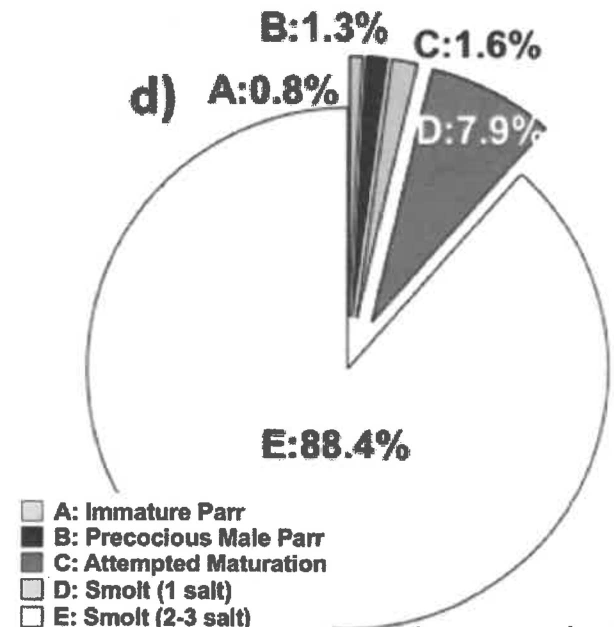
Some hatchery males exhibit sexual maturity prior to release

- Measureable proportion of males are precocious
  - Methow summers: 0 – 18% mature *Tatara et al. 2016*
  - Hood River winters: 1 – 2% mature *Larsen et al. 2017*
  - Hood Canal winters: 2 – 20% mature *Berejikian et al 2012*
  - Puget Sound early winter steelhead: 2 – 6% mature

  Craig, WDFW, unpublished

- Measureable proportion of males have initiated maturation and will spend less than 1 year in the ocean (1 – 12% or 13%)

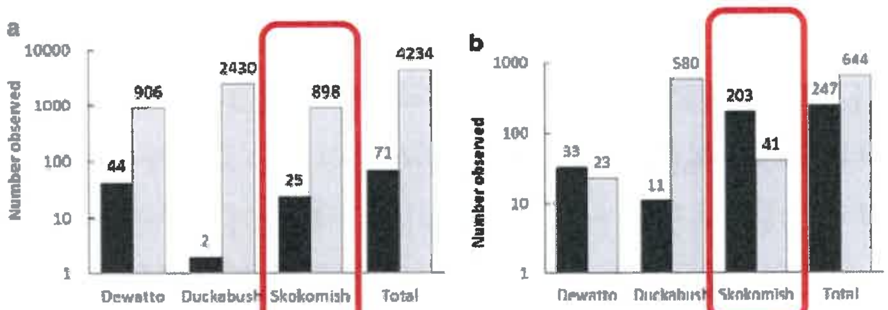
Larsen et al. 2017, Tatara et al. 2016



Larsen et al. 2017

Precocial maturity is often associated with a propensity to residualize

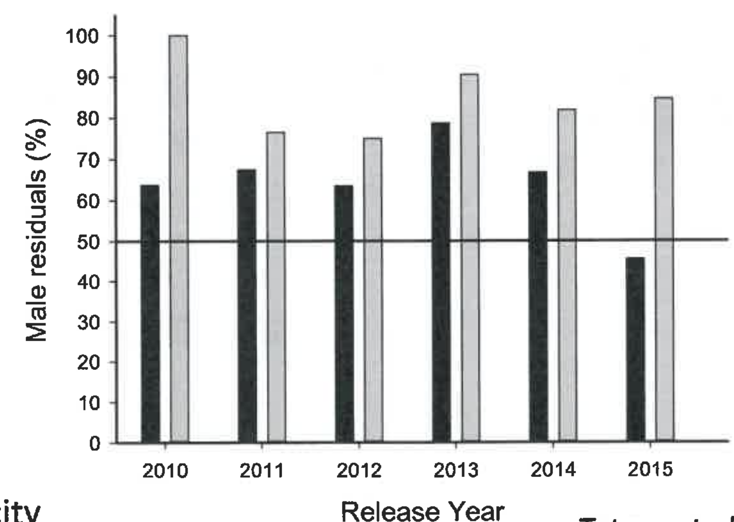
Higher residualism rate could be due to high precocity rate *Berejikian et al. 2012*



Berejikian et al. 2012

Fig. 4 The number of residual hatchery steelhead (*black bars*) and natural origin *Oncorhynchus mykiss* (*grey bars*) juveniles observed in the Dewatto, Duckabush and S.F. Skokomish Rivers during single pass snorkel surveys in 2009. Fish estimated to be between 100–200 mm are shown in panel a, and fish larger than 200 mm are shown in panel b. Note the log_{10} scale on the y axis: the total number of fish observed in each river shown above each bar

Residuals are male-biased *Sharpe et al. 2007, Berejikian et al. 2012, Tatara et al. 2016*



Tatara et al. 2016

Skokomish: 35% hatchery residuals, 20% pre-release precocity
Dewatto: 8% hatchery residuals, 7% precocity
Duckabush: <1% hatchery residuals, 2% precocity

Non-anadromous *O. mykiss* spawn with steelhead and produce anadromous offspring

- Complex mating behavior
- Difficult to directly observe spawning
- Parentage studies show non-anadromous contribution *Seamons et al. 2004, Christie et al. 2011*
  - Assignments missing a father = resident/non-anadromous father
  - Substantial contribution from residents
  - May vary depending on wild population demographics

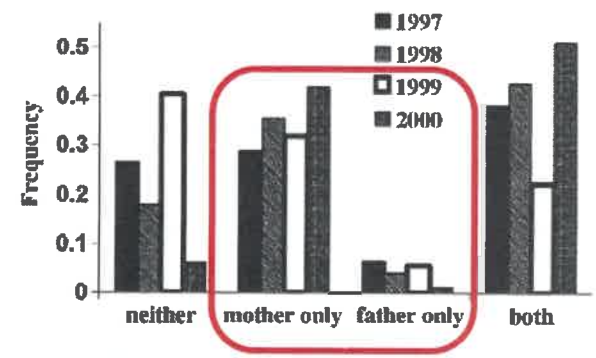


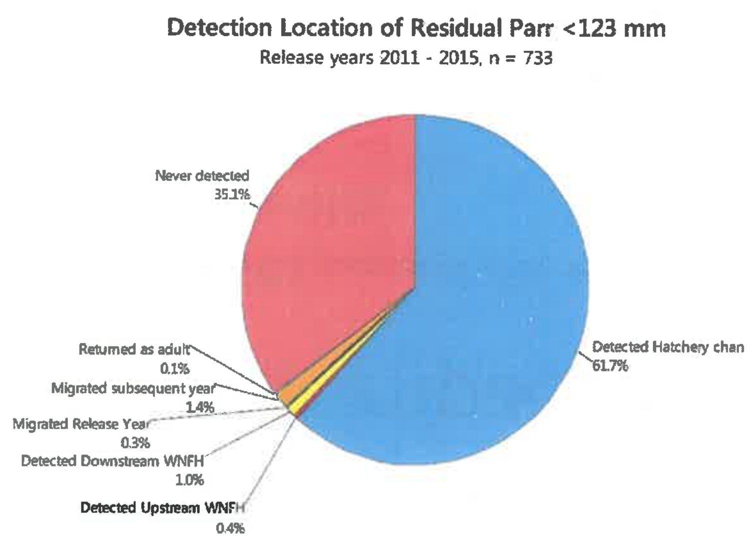
Figure 2. Frequency of the type of parental assignment – both parents, one parent (mother or father only) or neither parent – for all juvenile fish samples by BY (1997–2000). *Seamons et al. 2004*

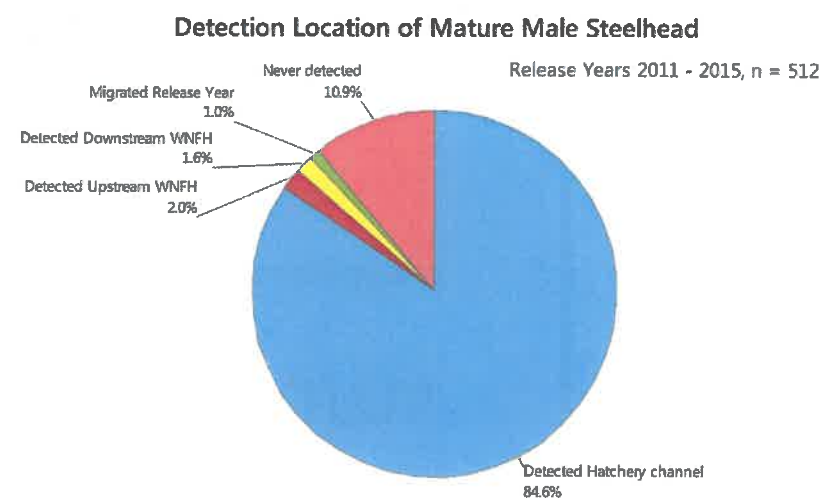
Hatchery-origin residuals successfully spawn with wild anadromous steelhead

- Few studies, especially with quantified reproductive contribution
- Parentage based: Hood River
  - 1% of all steelhead genes from residualized hatchery fish *Christie et al. 2011*
- Direct observation: Quiluete River
  - 1% of attempted matings with wild female steelhead involved hatchery residual *McMillan et al. 2007*
- Hatchery spawning channel reproductive success study: Methow River
  - 7% and 16% of offspring from precocious hatchery males *Tatara et al. 2016*

Impacts of residuals may be localized

- Residuals do not disperse far from release site soon after release
- Dispersal distance may increase with time, unknown





Tatara 2016, unpublished

Volitional releases can minimize residualism with minimal impact to adult returns

- Volitional releases *Snow et al. 2013, Tatara et al. 2016, Moran- WDFW, unpublished*
  - Migrate more quickly
  - Higher survival
  - Less residualism

- Non-migrants (forced out)
  - Majority of residuals (82% in Methow River) *Snow et al. 2013*

- Retention of non-migrant = minimal impact to adult returns *Snow et al. 2013*

Relatively low impacts expected from potential Skagit integrated program

- Wild parr/residuals may outnumber hatchery residuals
- Lower spawning success than anadromous males or wild resident males
- Localized spatial distribution

- Impacts will likely vary annually due to wild and hatchery population demographics, environmental conditions
- Volitional release can minimize residuals

Relatively low impacts expected from potential Skagit integrated program

200K release * 10% residualism = 20,000 residuals

75% male * 42% mature/maturing = 6,300 mature male residuals

100,000 – 250,000 wild steelhead smolts
* 8.1% residual-specific pHOS = 8,100 – 20,250 hatchery residuals

Recommendations for Skagit integrated program

1) Volitional release strategy
   - Retain all non-migrants

2) Monitor rates of precocial maturation
   - Pre-release, during release, post-release

3) Consider field surveys for residuals
   - Hook & line, electrofishing, PIT tag arrays

Follow-up Questions and Analyses
Potential Skagit River Integrated Hatchery Program
Draft February 21, 2018

PSSAG Questions from January 22 and February 1 Meetings

1) **What residual and stray rates have been observed in the Elwha River?**

The residual rate of hatchery-origin juvenile steelhead in the Elwha River is currently unknown (John Mahan, Lower Elwha Klallam Tribe, personal communication February 2018), although anecdotal reports suggest that there are a number of residuals present in the vicinity of the hatchery. The stray rate from the Elwha Hatchery of returning adults on to the natural spawning grounds has averaged approximately 91% from return years 2013 to 2016 (range 89% to 92%). It appears that a lack of attractant flow out of the hatchery creek, as well as channel instability and braiding in the Elwha River may be the primary reasons for the high stray rate. Fish are primarily reared on well water, and the hatchery creek does not discharge a significant amount of flow. Additionally, sedimentation after the dam removal has resulted in the isolation of the hatchery creek on a side channel of the river, further reducing the likelihood of fish returning to the hatchery.

2) **How would broodstock be collected across the entire run timing if broodstock are collected from above the Sauk River? Isn't it likely that fish are holding in that area prior to moving to spawning locations?**

It is likely that adult steelhead will be holding in the area above the Sauk River prior to spawning. Logistical and facility constraints would likely result in the collection of broodstock from the central 90% of the run with the tails (earliest and latest components of the run) potentially being less well-represented. Selecting bright fish throughout the run might help ensure that the fish collected for broodstock are more likely to be recent arrivals into the system. As historic run and spawn timing data are available, this could be used to help guide broodstock collection to ensure that we incorporate as much of the spectrum of the run as possible into the program. Although certain portions of the run will not be completely represented, not including the earliest and latest components would reduce the risk of unintentionally amplifying these portions of the run. This also could help to reduce potential fitness and demographic impacts on these smaller more sensitive portions of the population.

3) **What would be the likelihood and potential effects of amplifying certain spawn- or run-timing components of the Skagit steelhead population?**

Given the low projected pHOS (proportion hatchery origin spawners in natural spawning areas) from the Inseason Implementation Tool (ISIT) model and the robust natural population, hatchery fish are not anticipated to significantly amplify certain run or spawn timings. The greatest concern would be amplifying one of the tails of the run or shifting the entire run timing earlier or later, resulting in over representation of certain components of the population that may not be best suited to the environmental conditions. A broad and diverse run and spawn timing enables Skagit steelhead to withstand a greater degree of environmental variability than they would if they lacked this diversity. The likelihood that the population with be impacted by adverse or catastrophic environmental conditions increases significantly for a population with a narrow run and spawn timing, compared to a diverse population.

It is unlikely with the low projected pHOS from the purposed program that the program would result in a shift of the run timing for the Skagit population. The use of natural-origin steelhead as broodstock will help reduce the effects of selection that occurs in the hatchery, allowing the natural population to drive selection. Amplifying one of the tails of the run is a greater concern as a minor portion of the population could potentially become more dominant with an influx of similarly-timed hatchery fish on the spawning grounds. This could be most easily avoided by selecting broodstock from the peak of the run with limited inclusion from the early and late components.

4) What would be the likelihood and potential effects of localized areas of higher pHOS?

There is some likelihood that pHOS would be elevated near Marblemount Hatchery, as the returning adult steelhead are expected to home back to the facility. With the strong attractant flows coming from the facility, however, as well as a lack of barriers, the majority of fish would be expected to enter the facility. Approximately 70% of spring Chinook released from Marblemount Hatchery typically return to the facility after fisheries, with the remaining 30% to the natural spawning grounds; steelhead would be expected to home to the facility at a similar rate. Of the hatchery fish that do end up on the natural spawning grounds, it is likely that a significant proportion will spawn near or downstream of the hatchery, as has been observed at other facilities (e.g. the Lower Elwha Hatchery). Natural origin fish spawning in the immediate vicinity of the hatchery will likely have some loss of fitness. It is also likely that there will be some hatchery-by-hatchery spawning in this area, the offspring of which may be less fit than their counter parts with wild parents.

5) Provide analysis regarding the potential interbreeding of precocious males from the hatchery program with natural-origin spawners.

See attached document "A Brief Review of Residualization and Precocial Male Maturation in Hatchery Steelhead Programs".

6) How would a rebuilding trajectory be affected by the potential hatchery program and associated fisheries?

With the implementation of a hatchery program and the associated fisheries on the Skagit River, there would be some detrimental effects on the rebuilding trajectory of the natural population. However, habitat and marine survival are likely to have a greater impact.

The ISIT model represents the best available science for projecting potential impacts of a hatchery program, but there may be adverse effects from processes or natural events not incorporated in the model. If the natural population were to decrease below mid-2000 levels, it is possible that there could be an unforeseen decrease in fitness that modelling did not calculate from the integrated program. Additionally, the model does not take hatchery kelts or residuals into account, with could also inflate pHOS. Studies have observed a large decrease in fitness (up to 30%) of the progeny from hatchery-origin steelhead that return tp natural spawning areas, even in integrated hatchery programs. Some hatchery steelhead smolts will residualize; this is likely to reduce carrying capacity, therefore increasing competition, and pHOS. Thompson and Beauchamp (2016) showed that juvenile steelhead were limited by prey availability and quality in several Skagit tributaries; as such, density-dependent effects and competition with hatchery residuals could be a concern. Handling/collecting/holding brood will result in increased mortality of wild fish and have a negative impact. While this could be alleviated with live-spawning and reconditioning kelts, there will be some mortality associated with broodstock collection, which will take some natural spawners out of the system. As discussed above, there is a risk of amplifying a particular part of the run or reducing the span of the run through both fisheries and hatchery practices. This has the potential to reduce diversity within the population and thus reduce the population's ability to adapt to a changing environment or cope with adverse environmental conditions.

If the decision is made to proceed with the program, each of these topics would be discussed in the associated Hatchery Genetic Management Plan and assessed by NOAA Fisheries for consistency with requirements of the 4(d) rule regarding a co-manager resource management plan.

7) Is space available at the Marblemount Hatchery to increase production above 200,000?

The Marblemount Hatchery may have the capacity to operate a program of up to 250,000 steelhead.

8) What is the expected run-timing of the fish? Would they be accessible to the recreational fishery?

Information from tribal test fisheries, acoustic tagging, and spawning ground surveys suggests that wild steelhead return to the Skagit River primarily from mid-February through mid-April. The intent of the potential integrated hatchery program would be to maintain that run-timing by collecting broodstock from throughout the run. The Skagit River Steelhead Fishery Resource Management Plan (RMP) submitted to NOAA Fisheries allows for recreational fisheries to occur from February 1 through April 30. If approved, this would suggest that most of the returning adults from the hatchery program would be accessible to the recreational fishery if the return of wild steelhead was sufficiently large to allow fisheries throughout that time period.

9) The analysis assumed a 70% harvest rate on marked fish. Is that achievable?

If the decision is made to proceed with the program, monitoring and adaptive management will be essential to ensure that the hatchery program and fishery are operating in a manner consistent with expectations and requirements. The 70% harvest rate used in the model analysis is primarily based on estimates of previous harvest rates on hatchery-origin steelhead in the Skagit River. Harvest rates on hatchery-origin steelhead averaged 75% from the 1988-1989 through the 2012-2013 season.

10) **The preliminary draft model analyses incorrectly set a parameter value for fitness loss to 0.80 rather than 1.00. How would the model results be affected if the correct parameter value was used?**

Rerunning the simulations with the corrected parameter value resulted in very small changes in model predictions. Perhaps most importantly, the predicted fitness of the wild population remained greater than 99% for both the "good" and "poor" marine survival conditions. This indicates that there are very limited projected effects of the potential program to the productivity of the wild population.

Tasks to address if integrated hatchery program is included in any draft portfolios developed by advisors on February 22, 2018.

11) What would a recreational fishery season look like with and without the potential hatchery program? What would be the associated program costs and economic benefits?
12) What might the tribal fishery season look like with and without the hatchery program?
13) What is the accuracy of the preseason forecasts of abundance?

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A brief review of residualization and precocial male maturation in hatchery steelhead programs

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February 16, 2018

Some wild and hatchery-reared steelhead (*Oncorhynchus mykiss* sp.) do not migrate to saltwater, but instead residualize in freshwater

Steelhead that do not migrate to sea during the primary migration period are considered residuals, and may delay migration for a year or more, or remain in freshwater until reproductively mature, essentially becoming a resident rainbow trout (Hausch and Melnychuk 2012). Parentage studies have shown that these non-anadromous fish are part of the spawning population and regularly produce anadromous offspring (e.g., Seamons et al. 2004, Christie et al. 2011). Hatchery-origin residuals tend to be either smaller or larger than average and composed of small, immature parr or large, precocious fish (Sharpe et al. 2007, Hausch and Melnychuk 2012, Tatara et al. 2016).

Hatchery programs that use wild born fish as broodstock (integrated programs) produce more residuals than do programs that use hatchery-produced fish as broodstock (segregated programs)

A recent review of 16 independent studies estimated that 0 – 17 % (average = 5.6%) of steelhead released from hatcheries did not emigrate to sea during the primary migration period (Hausch and Melnychuk 2012). Published studies are more common in summer steelhead east of the Cascades (inland redband, *O. mykiss gairdneri*), and the majority of studies in the Hausch and Melnychuk (2012) review were from summer programs in the Columbia and Snake basins, which are mainly integrated programs. From the same review, integrated programs tended to produce more residuals than did segregated programs, for which evidence existed for both inland redband and coastal lineage (*O. mykiss irideus*) hatchery programs. Two recent studies on an integrated summer hatchery program in the Methow River estimated residual rates of 5% (1-year smolt program) and 9% (2-year smolt program) from five years of pre-release sampling (Tatara-NFMS, unpublished data), and 6%, 8%, and 23% from three years of post-release summer-time creek surveys (Snow et al. 2013). These residualism rates may be slight overestimates as there is evidence from both a coastal-lineage segregated program and an inland-lineage integrated program that some small proportion of hatchery residuals emigrate to sea after spending an additional year in freshwater after release from the hatchery (Dauer et al. 2009, C. Tatara- NMFS, unpublished data).

A measurable proportion of hatchery-reared steelhead males exhibit sexual maturity prior to release

Rates of precocial maturation measured by Tatara et al. (2016) over five years on an integrated summer steelhead hatchery program in the Methow River (inland redband lineage) ranged from 0 – 18 %, with an additional 1 – 13% in the early stages of maturation. In the Hood River, and in three systems in Hood Canal (all coastal lineage), rates of maturation were 1 - 2%, and 2%, 7%, and 20%, respectively, for integrated winter steelhead hatchery programs (Larsen et al. 2017, Berejikian et al. 2012). Preliminary analysis of WDFW's segregated early winter steelhead programs in the Snoqualmie, Stillaguamish and Dungeness rivers (coastal lineage) indicates 2 - 6% of males were mature prior to release (B. Craig- WDFW, unpublished data).

Precocial maturity is often associated with propensity to residualize rather than migrate

In a Kalama River steelhead study, two-thirds to three-quarters of creek-caught residual fish were male, and among male residuals, 42% were mature or showed signs of maturing (Sharpe et al. 2007). Hatchery residuals represented 0.4%, 8%, and 35%, respectively, of all observed steelhead during summer snorkel surveys in the Duckabush, Dewatto, and Skokomish rivers in Hood Canal (Berejikian et al. 2012). The high proportion of residuals in the Skokomish may have resulted from their large size and high precocity rate (20%) (Berejikian et al. 2012). Hatchery residuals detected in the Methow were male-biased and were composed of precocious males and undersized male parr (Tatara et al. 2016).

Hatchery-origin precocial males can and do successfully spawn with anadromous females, but very few studies have quantified their reproductive contribution, especially of spawning success in the wild

We found only two published studies that directly estimated the spawning contribution of hatchery-reared, precocial or residualized steelhead males in the wild. Using genetic methods, Christie et al. (2011) found that 1% of steelhead genes originated from residualized hatchery fish in a three generation pedigree of the Hood River, Oregon population. However, key demographic parameters (size of hatchery program, abundance time series of wild steelhead) were not provided in that paper. Based on direct observation in the Quileute River system, 2 of 200 (1%) attempted matings with anadromous females involved a hatchery residual, with N = 169 involving an anadromous male and N = 29 involving wild resident males (McMillan et al. 2007). Preliminary results from a spawning channel reproductive success study at the Winthrop National Fish Hatchery (Methow River, WA) observed that precocious hatchery parr participated in fewer spawning events than mature anadromous hatchery-origin males and produced 7% and 16% of all offspring per channel as determined by parentage assignment (Tatara et al. 2016).

The effects of residualism may vary spatially, with higher impacts localized around the hatchery release site

Tatara (NMFS, unpublished data) tracked the location of hatchery-origin residuals via summer-time electrofishing and angling, and found that 67% of immature parr residuals, and 85% of precocious male residuals remained within the hatchery release channel, suggesting that residuals do not disperse far from the release site soon after release. The distance a mature parr may travel to find mates during spawning season is unknown. However, we expect dispersal distance to increase with time since release, and that the distribution of hatchery-origin precocial parr is likely centered around the release site, especially if natural wild spawning normally occurs nearby.

Volitional release strategies can reduce residualism rates with minimal impact to adult returns

Studies comparing volitional and forced release strategies have found that volitionally-released steelhead migrate downstream more quickly, have greater survival, and residualize to a lesser degree than steelhead forcibly released at the end of the volitional outmigration period ("non-migrants")(Tatara et al. 2017, Snow et al. 2013, Moran- WDFW, unpublished data). Eighty-two percent of residuals detected during summer surveys in the Methow were from forced non-migrant releases (Snow et al. 2013). Smolt to adult survival to Wells dam averaged 1.54% for volitional releases compared to an average of 0.37% for forcibly released non-migrant fish (Snow et al. 2013) suggesting that retention of non-migrants would have minimal impacts on adult returns.

We expect relatively low impacts from residuals and precocious males from the potential Marblemount integrated winter steelhead hatchery program

At a proposed release of 200,000, we might conservatively expect 10% to residualize due to failure to smolt or precocious maturation (mid-range residualism rate from volitionally released fish in the Methow, Snow et al. 2013), yielding an estimated 20,000 residuals. If we assume 75% of those fish are males (mid to upper estimate of hatchery residuals in stream from Sharpe et al. 2007, Tatara et al. 2016), and roughly 42% of those males are mature (estimate of mature + maturing residuals, Sharpe et al. 2007) then 6,300 mature residual males could be produced. Based on snorkel surveys in three systems in the Hood Canal, hatchery residuals were estimated to account for only 8.1% of all observed residuals/residents, which effectively serves as "residual specific" estimate of pHOS for an integrated program. This number seems reasonable for the Skagit, given that we estimate an annual abundance of wild, migratory smolts at roughly 100,000 – 250,000 (C. Kinsel- WDFW, unpublished data). Hatchery-origin residuals or precocious parr would likely be at a numerical disadvantage to wild-born residuals, and at a competitive disadvantage to anadromous males in acquiring fertilization success.

Despite expectations of low risk, if initiated, we recommend the following for the potential Skagit integrated hatchery program

The following actions are intended to reduce the risk of hatchery origin residual males breeding with anadromous wild females, and to monitor potential impacts

1. Adopt the volitional release strategy in the current plan such that any smolts that do not leave the hatchery ponds after 2 – 4 weeks are planted in non-anadromous lakes rather than forcibly released into the Skagit River system
2. Monitor rates of sexual maturity in hatchery-reared smolts immediately before, during and after release from the hatchery

3. Consider field surveys for observation of hatchery residuals in the immediate vicinity of the hatchery, especially if rates of precocial maturation (#2 above) are higher than expected (> 10%)

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Northern Cascades Draft Delisting Scenarios

Date: Feb. 1, 2018

Subgroup:	Members	Staff
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4	Nick Chambers, Mark Spada, Conrad Gowell (Jim Scott)	Scott

Category		Number Required	
Name	Coding	Winter	Summer
Primary	3	5	2
Contributing	2		
Stabilizing	1		

		Group			
Population	Current	1	2	3	4
Drayton Harbors (W)	2	2	1	1	2
Nooksack (W)	2	3	3	3	3
S. FK. Nooksack (S)	2	3	3	3	3
Samish/Bellingham (W)	2	3	2	3	2
Skagit (S/W)	2	3	3	2	3
Nookachamps (W)	2	2	2	3	3
Baker (S/W)	2	1	2	1	2
Sauk (S/W)	1.5	3	3	3	3
Stillaguamish (W)	1	3	2	2	2
Deer (S)	2	3	3	3	3
Canyon (S)	2.5	2	3	2	3
Snohomish/Skykomish (W)	2	2	3	2	3
Pilchuck (W)	1	3	3	3	3
N. Fk. Skykomish (S)	2	1	2	3	3
Snoqualmie (W)	2	2	3	3	3
Tolt (S)	2	2	3	2	3
Geometric Mean	1.83	2.25	2.47	2.30	2.71

2017 STATE OF THE SOUND: VITAL SIGNS

WEBINAR

DATE:

Wednesday, Jan. 31, 2018
10 am to Noon

Ask questions! Get answers!

Topical experts will give you the most up-to-date information on the Puget Sound Vital Signs

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