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Prepared for: Trevor Davies, BC Ministry of Forests, Lands, and Natural Resource Operations

Executive Summary

The number of adult wild steelhead trout (*Oncorhynchus mykiss*) returning to the Keogh River between December 2015 and June 2016 was estimated by employing a resistivity fish counter and by mark-recapture methods. The resistivity counter-derived estimate is 79 wild steelhead, a marked decrease from previous years. Mark-recapture estimates were 133 wild spawners (95% CI 35-213) of which 83 were female (95% CI 25-163) although assumptions of a closed population were broken due to high flow events that enabled fish to pass over the floating fence. Substantial decreases in steelhead spawner abundance have also been observed in other systems this year suggesting poor ocean survival. Mean steelhead spawner abundance has increased annually since 2010 until this year. However new techniques were employed this year to increase accuracy of resistivity counter population estimates including graphical and video validation.

There were 2,009 steelhead smolts enumerated at the fence in 2016. This is in the 32\textsuperscript{nd} percentile of smolt abundances since 1977 and lower than both the overall mean smolt abundance (3,962) and the mean smolt abundance since 1990 (2,570). Smolts per wild female spawner estimates are 79.8 and 27.1 for the 2011 and 2012 brood years respectively (with 5-year smolts from 2012 brood yet to be sampled next year). The 2013 brood year has produced 24.3 smolts-per-female to date, with four-year-olds to be enumerated in 2017.

Marine survival in 2013 was 4.9%, a decrease from 6.0% in 2012. Recent marine survival (2009 to 2013: mean = 5.6%, range = 3.8 - 8.6%) remains higher than historical lows (1.8% in 2002 and 2.3% in 2005). However marine survival estimates remain low compared to the 1977-1990 mean (14.9%). Partial returns from 2014 (3.0%) are similar to the previous three years, and will be adjusted upwards as the majority of migrants from the 2014 cohort return as ocean-age-three and four steelhead in the 2017-2018 year.

Coho smolt (*O. kisutch*) abundance was 91,582 individuals. This is higher than the overall average of 67,449 smolts (1977-2014) and follows several years of high smolt production that appears to be unrelated to adult spawner escapements.

_Fisheries Project Reports frequently contain preliminary data, and conclusions based on these may be subject to change. Reports may be cited in publications, but their preliminary manuscript status should be noted._
Acknowledgements

Support for this work was provided by BC’s Habitat Conservation Trust Fund (Project 1-319) through funds provided to the BC Ministry of Forests, Lands and Natural Resource Operations. Fisheries and Oceans Canada (Pieter Van Will, Port Hardy) supported coded-wire-tagging of coho smolts. Jon Moore and Colin Bailey from Simon Fraser University assisted in summer fish tagging and winter sampling. We thank Lorraine Landry and the staff of the Northern Vancouver Island Salmon Enhancement Association in Port Hardy for equipment and logistical/staff support. We are especially grateful to the field crew of Lloyd Burroughs, Trevor Wesley, Cole Martin, Monica Redmond and Chris Pan. Marylise Lefevre and Cynthia Fell assisted with scale ageing.
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Introduction

This is a data report on the 42nd year of the operation of the adult steelhead (*Oncorhynchus mykiss*) and salmonid smolt enumeration facilities at the Keogh River located on northern Vancouver Island, BC. The primary focus of this study is to estimate and collect biological information of the 2015-2016 migration of wild adult winter-run steelhead trout to determine smolt-to-adult survival, monitor stock status, and enumerate and sample juvenile steelhead and coho salmon (*O. kisutch*). This data series has been an important regional index site that assists in the management and understanding of British Columbia's steelhead populations (Smith and Ward 2000; Johnston et al. 2002).

Freshwater productivity, marine survival, and the number of returning adults has declined for all monitored species on the Keogh since 1990. As an example, 2,939 adult steelhead returned to the Keogh in 1987, while fewer than 1% of that number returned in 1998. This decline is mirrored in other species, although the magnitude was not as drastic as with steelhead. Extensive habitat restoration was undertaken between 1998 and 2002 in an attempt to reverse these trends. In recent years, adult returns have increased although periods of lower abundance have occurred, coincident with decreases in marine survival. The monitoring program on the Keogh River provides a unique opportunity to understand long-term population dynamics for a variety of species by evaluating factors that affect discrete life history stages. These data have been collected since 1977 and have been used to understand the interactions between environmental variability, habitat use, marine survival, growth, and freshwater productivity. Population dynamics and behavioural interactions can also be inferred through examination of individual productivity and habitat use.

The Keogh site has provided many research opportunities beyond long-term population monitoring including:

- Monitoring the success of habitat manipulations and nutrient additions to improve watershed productivity (Ward et al. 2008). The Keogh and Waukwaas watersheds were chosen as a paired watershed study for BC’s Watershed Restoration Program (WRP) to assess the effects of restoration techniques on salmonid abundance, growth, and smolt yield (McCubbing and Ward 1997, 1998, 2000a, b & c, 2001, 2002; Ward et al. 2003, 2008). The Waukwaas River was chosen as an environmental reference watershed in this study, i.e., no rehabilitation to habitat but subjected to environmental perturbations (McCubbing 2003).

- Evaluating the benefits of hatchery supplementation to rebuild low-abundance steelhead populations. The Keogh site was the experimental river for conservation hatchery research and the steelhead Living Gene Bank (LGB) project (McCubbing 2005, 2006; Ward 2000b; Werlen 2003; Walters 2006).

- Evaluating the effects of mid-summer flow augmentation on smolt production through the spring storage and summer release of lake impoundment (Johnston et al. 2012, Habitat Conservation Trust Foundation (HCTF) project 1-509).

- Ocean growth study based on scale sample evaluations to evaluate the potential timing of marine mortality (Freidland et al 2014).

- Ongoing collaborative research with Jon Moore at Simon Fraser University on fish habitat use and salmon-derived nutrient subsides.
We report here on our findings on wild and hatchery adult steelhead returns, the annual enumeration and sampling of steelhead smolt migrants, juvenile coho salmon (*O. keta*), and other species for the winter-spring 2015-2016 season.

**Methods**

*Site Description*

The Keogh River is a third order (1:50,000) coastal stream that flows north-westward into Queen Charlotte Strait near Port Hardy on the north end of Vancouver Island. It is 31 km in length, drains an area of 129 km², and has a mean annual discharge of 5.6 m³·s⁻¹. The fish enumeration fence is located near the river mouth and is described in Mottram (1977), Ward and Slaney (1988), and Irvine and Ward (1989). The river supports runs of winter run steelhead trout, coho and pink salmon (*O. gorbuscha*), Dolly Varden char and minor runs of chum salmon and anadromous coastal cutthroat trout (*O. clarki*). The watershed resides within the coastal western hemlock biogeoclimatic zone that has been extensively logged over the last 40 years.

*Spring Fence Operations – Parr and Smolts*

Fence operations are similar to those described in Ward and McCubbing (1998) and in this series of annual reports. Smolt estimates in this report are raw data and should be considered minimum abundances.

All fish captured at the fence were identified to species and transferred to a 1500-litre tank supplied with fresh river water prior to processing. A sample of each species (i.e., between 15% and 20%) was collected daily by dip net to measure fork length to the nearest millimetre, with the exception of coho smolts. Coho smolts were sampled at a rate of 25 fish per day or the whole day’s catch, whichever was the least.

For the purposes of marking and abundance estimates, pre-smolt, smolt and adult classes are defined as:

- **Steelhead parr (SHP):** fork length < 130 mm unless clear evidence of smolting was observed
- **Steelhead smolts (SHS):** fork length ≥ 130 mm
- **Coho parr (COP):** fork length < 70 mm unless clear evidence of smolting was observed
- **Coho smolts (COS):** fork length ≥ 70 mm
- **Dolly Varden Smolts (DVS):** fork length < 200 mm
- **Dolly Varden Adults (DVA):** fork length ≥ 200 mm
- **Cutthroat parr (CTP):** fork length < 130 mm
- **Cutthroat smolts (CTS):** fork length ≥ 130 mm and <200 mm
- **Cutthroat adults (CTA):** fork length ≥ 200 mm

Refer to Clarke et al. (2015) for more information on smolt identification.

An Acculab v400 electronic scale was used to weight individual fish to the nearest 0.1 g once per week using the same fish from the fork length subsamples. Prior to weighing, fish were anaesthetized in a solution of clove oil (Hilltech Canada) and ethanol (1-unit clove oil to 10
units of 95% ethanol) which was added at a concentration of 1 ml anesthetic to 1 litre of river water. All mortalities were recorded and very rare (< 0.1 %).

Parr and smolt ages were determined from scale samples taken from above the lateral line and behind the dorsal fin in a stratified sampling regime based on fish size and migration timing (Ward et al. 1989). Fork lengths were measured on all aged fish. Ages were determined from two independent scale readings by persons without knowledge of fish length, size, or time of capture (Ward and Slaney 1988). Readers discussed each discrepancy and an age was recorded if all came to a consensus. Samples were omitted when consensus was not achieved.

Length-frequency distributions were generated to identify length/age distinctions of steelhead and coho. The Fulton condition factor (Ricker 1975) was calculated for fish when both length and weight were available. The average smolt length-at-age was calculated using the methods described in Ward and Slaney (1988). Smolt recruitment was the total number of smolts enumerated at the fence. Aged smolts were assigned to a brood year based on their age estimates from scale analyses. These proportions were then applied to total smolt recruitment to calculate the number of smolts per wild female spawner.

All steelhead and coho smolts captured at the fence were scanned for passive integrated transponder (PIT) tags prior to being released downstream of the fence with a hand held PIT reader (BIOMARK, FS20001S). We assume complete enumeration of smolts at the counting fence; however, smolt abundance estimates should be considered minimums.

**Adult Enumeration**

Adult steelhead immigrants were enumerated between November 16th, 2015 and April 7, 2016 using a Logie 2100C resistivity fish counter (McCubbing and Ward 2004) located approximately 300m upstream of the smolt fence. Fish passing over the counter electrodes are detected and produce size estimates based on their resistance signal. Fish were classified as adult steelhead trout if the peak signal size (PSS) exceeded 40. PSS corresponds to the peak of a sinusoidal curve that is created when a fish passes over the counter sensor. Previous validation indicated PSSs of 40 and above corresponded to fish > 550 mm fork length under a variety of river discharges (McCubbing et al. 2000). The total daily upstream count was calculated as the number of upstream counts minus the number of downstream counts over the monitoring period. Only upstream counts were used in the analysis after March 20th, which marked the onset of kelt outmigration. The daily net up counts were summed over the migration period to estimate the total number of upstream counts. Individual events were validated graphically to confirm up counts, down counts and events. Video validation further corrected data to account for events that were triggered by fish, debris, river otters or flow conditions. This final number was then adjusted to account for the proportion of hatchery fish (calculated as the proportion of all sampled adults that were hatchery origin throughout the 2015-2016 study period).

Adult coho immigrants were enumerated in the fall of 2015 with the resistivity counter using a counter accuracy of 80% (this was prior to video installation). Fish were classified as adult coho salmon if the PSS of a record exceeded 120, or if the record occurred after pink salmon finished migrating (October 15th). The total daily upstream count was calculated as the number of upstream counts minus the number of downstream counts for the period between September 1st and November 30th, 2015. The daily net up counts were summed over the migration period to estimate the total number of upstream counts.
The formula used to determine the escapement estimate for both species is:

$$
\hat{E} = \sum_{i=0}^{k} \left( \frac{U_t}{q_{up}} - \frac{D_t}{q_{down}} \right) + \sum_{i=k}^{\infty} \left( \frac{U_t}{q_{up}} \right)
$$

Where \( \hat{E} \) is the escapement estimate, \( U_t \) is the total number of upstream fish detections classified on each day \( t \), \( D_t \) is the corresponding number of daily downstream detections, \( q_{up} \) is the counter accuracy of upstream moving fish (80%) and \( q_{down} \) is the counter accuracy of downstream moving fish (80%), each assessed independently from video validation experiments (McCubbing et al. 1999). The value \( k \) is the day that kelts began migrating downstream and was approximated by visually examining the pattern of downstream detections of fish following the peak spawning period.

The resistivity counter provides a capture independent estimate of overall escapement, while a mark–recapture study provides sex-specific estimates of hatchery strays and wild fish. Upstream-migrating adult steelhead were captured by angling and in traps at the downstream fence smolt enumeration site. Each fish was assessed whether they were hatchery stray or of wild origin by the presence/absence of an adipose fin and gender and fork length were recorded. The general condition of each fish was recorded which included scars and wounds, date, capture location, and angling condition if applicable. Scale samples were collected from above the lateral line and mid-way between the dorsal and adipose fins. All adult fish were implanted with a PIT tag. Hatchery strays were also marked with a spaghetti tag and then released downstream. Kelts were captured post-spawning in a downstream trap at the fence site near the river mouth or by seine-netting the pool above the fence when fish were observed holding. Abundance estimates of male and female wild steelhead were calculated separately based on the relative number of recaptures in the kelt samples using the Chapman modification of the Peterson estimator (Ricker 1975) to account for possible differences in behaviour between sexes that might affect survivorship (Ward and Slaney 1988, 1990). The Chapman estimator has been shown to produce population estimates that are less biased than those derived from the Peterson estimator at low population sizes (Ricker, 1975). Small sample sizes may still produce biased population estimates, especially when the number of recaptures are low. Mark-recapture population estimates with 95% confidence intervals (95% CI) were calculated using the ‘mrClosed’ function in the FSA R package (Ogle, 2015 and R Core Team, 2014). Data distribution assumptions were selected automatically within the FSA package to calculate confidence intervals based on methods described in Seber (1982).

Estimates are not calculated for hatchery males due to the absence of recaptures, and only the actual number of initial captures are reported. Scales from adult upstream migrants and spawned kelts were analysed to determine age in the marine and freshwater life stages using the same methods described for smolts.

The criteria used to define annuli in scale aging were the cutting or crossing-over of circuli, the incompleteness of circuli, and the narrowing of distance between circuli. A single year of growth was equated to the formation of the last circulus of an annulus to the formation of the last circulus of the succeeding annulus (Narver and Withler 1971). Marine growth on steelhead scales was distinguished from freshwater growth by the increased spacing between circuli. All readable scales were examined to determine if spawning checks were present, which was defined as an area of moderate to heavy lateral and anterior reabsorption.
Age-classes of pre-spawn adults were assigned as freshwater age (1, 2, 3, etc.) and ocean-age (1, 2, 3, or 4) maiden or repeat spawners using the European nomenclature (e.g., 3.2 would be a fish that smolted at age three and spent two winters at sea; Ward and Slaney 1988). The percent composition of ocean-aged adults was then used to estimate the number of surviving adults from each smolt year-class (marine survival). Kelt scale samples have previously not been used in this assessment due to potential differences in post-spawning survival of two or three ocean-age fish and repeat spawners (Ward et al. 1989). However, due to low adult captures from angling and at floating fence, all adult scale ages are presented this year including kelts. Because fish may spend up to four years in the ocean prior to returning as spawners, estimates of marine survival presented here are considered minimum estimates until there is no potential for additional returns. For example, 2017 will be the final year of potential returns from the 2013 smolt cohort.

Water Management
Temperature and water stage were logged hourly by HOBO and Solinst Level (3100 Gold) data loggers located 500 m from river-ocean confluence at the fish counter site (Craig 2009). Stage levels were corrected for fluctuations in barometric pressure and discharge was calculated using the stage-discharge relationship used in previous years. A real time flow monitoring station (station 08HF014) was install in June 2016 with flow and temperature now recorded hourly by water survey Canada. These data are available online at https://wateroffice.ec.gc.ca.

Steelhead Monitoring
Results
The smolt fence was installed on April 5, 2016 and removed on June 16, 2016. High flow events and an early freshet delayed full sealing (with plastic) of the fence until April 11, 2016. Fish counts began on April 7th and ended on June 16th. Fish sampling started April 8th and ended on June 9th.

Steelhead Parr and Smolt Abundance and Migration Timing
Steelhead smolts were captured from April 7th to June 16th, 2015. A total of 852 smolts were captured at the peak migration between April 25th and May 5th. A total of 2,009 steelhead smolts (Figure 1) and 337 steelhead parr were captured in 2016 (Table 1).
Figure 1. Keogh River steelhead smolt abundance enumerated at the lower river fish fence from 1977 to 2016.

Table 1. Total fish enumerated at Keogh river smolt fence in 2016.

<table>
<thead>
<tr>
<th>Species</th>
<th>Total Live</th>
<th>Total Dead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastrange sculpin</td>
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<td>3</td>
</tr>
<tr>
<td>Prickly sculpin</td>
<td>482</td>
<td>31</td>
</tr>
<tr>
<td>Coho parr</td>
<td>438</td>
<td>0</td>
</tr>
<tr>
<td>Coho smolt</td>
<td>91582</td>
<td>420</td>
</tr>
<tr>
<td>Hatchery coho smolt</td>
<td>53</td>
<td>0</td>
</tr>
<tr>
<td>Cutthroat trout adult</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Cutthroat trout parr</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Cutthroat trout smolt</td>
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<td>0</td>
</tr>
<tr>
<td>Dolly Varden adult</td>
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</tr>
<tr>
<td>Dolly Varden parr</td>
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</tr>
<tr>
<td>Dolly Varden smolt</td>
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<td>0</td>
</tr>
<tr>
<td>Pacific lamprey</td>
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<td>2</td>
</tr>
<tr>
<td>Hatchery steelhead kelt</td>
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</tr>
<tr>
<td>Wild steelhead kelt</td>
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<td>Steelhead smolt</td>
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</table>
Steelhead Juvenile Size and Age

The length-frequency histogram for juvenile steelhead showed a bi-modal distribution (Figure 2) that corresponded to parr sizes (lower mode) and smolt sizes (upper mode). Totals for steelhead smolts are less than last year (2015: 2,981) but 2016 steelhead parr numbers are higher (2015: 337). Total abundances (smolts and parr combined) are 3,318 and 2,849 for 2015 and 2016 respectively. Overall, steelhead smolts are slightly larger than last year. Average fork length is 181.8mm (mean weight: 54.3g) compared to a 2015 average length of 178.8mm (mean weight: 48.8g; Table 2). Steelhead parr are substantially smaller this year with a mean length of 88.1mm (mean weight: 8.1g) compared to 107.7mm (mean weight: 12.0g) in 2015.

Figure 2. Fork length frequency distribution of steelhead juveniles sampled from the Keogh River in 2016.

Table 2. Mean fork length (mm) and weight (g) with 95% CI for a subsample of out-migrants from the Keogh River fence during spring of 2016. N = sample size.

<table>
<thead>
<tr>
<th>Species</th>
<th>Mean Length (mm)</th>
<th>Length Lower 95% CI</th>
<th>Length Upper 95% CI</th>
<th>N (Length)</th>
<th>Mean Weight (g)</th>
<th>Weight Lower 95% CI</th>
<th>Weight Upper 95% CI</th>
<th>N (Weight)</th>
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<tr>
<td>Coastrange sculpin</td>
<td>112</td>
<td>105.3</td>
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<td>Prickly sculpin</td>
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<td>110.7</td>
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<td>144</td>
<td>26.4</td>
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<td>36.4</td>
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<td>Coho parr</td>
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<td>10.9</td>
<td>13.1</td>
<td>197</td>
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<tr>
<td>Cutthroat trout adult</td>
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<td>217.7</td>
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<td>Steelhead smolt</td>
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<td>8.1</td>
<td>6.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>181.8</td>
<td>180.4</td>
<td>183.6</td>
<td>893</td>
<td>54.3</td>
<td>55.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean condition factor for steelhead smolts is 0.86 and lower than 2015 (1.01). Migration timing has multiple peaks this year (Figure 3) and a positive trend in size as the season progressed with the last 2 data points showing a notable drop in size (Figure 4). Mean condition factor showed an overall decrease throughout the season (Figure 5).

Figure 3. Live juvenile steelhead totals sampled at smolt fence in 2016.
Figure 4. Mean fork length (error bars = SD) of live juvenile steelhead sampled at smolt fence in 2016.

Figure 5. Mean Fulton condition factor (error bars = SD) of live steelhead smolts sampled in 2016.
The dominant steelhead age class in 2016 was three-year-old smolts followed by four and two-year-olds (Table 3). Of the 361 samples taken, 243 (67%) were suitable for ageing. The mean and dominant age of smolts in 2016 was older than in 2015 (2016: mean age = 3.25, dominant age = 3; 2015: mean age = 2.45, dominant age = 2). This is a change in recent trend towards younger smolts. The weighted mean age has decreased annually since 2010 from 3.19 years to 2.45 in 2015 but increased to 3.25 in 2016. The average length of two-year-old smolts in 2016 was 150 mm, smaller than the 2015 mean length of 157 mm (Table 4). Three-year-old smolts were also smaller (175 mm in 2016 vs. 203mm in 2015).

Table 3. Totals for aged steelhead smolts in 2016. Expanded estimate is based on total smolt abundance for the year.

<table>
<thead>
<tr>
<th>Smolt Age</th>
<th>Number Aged</th>
<th>Percent Total</th>
<th>Expanded Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0.004</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>49</td>
<td>0.202</td>
<td>406</td>
</tr>
<tr>
<td>3</td>
<td>95</td>
<td>0.391</td>
<td>786</td>
</tr>
<tr>
<td>4</td>
<td>85</td>
<td>0.35</td>
<td>703</td>
</tr>
<tr>
<td>5</td>
<td>13</td>
<td>0.053</td>
<td>106</td>
</tr>
<tr>
<td>Total</td>
<td>243</td>
<td>1</td>
<td>2009</td>
</tr>
</tbody>
</table>

Table 4. Mean fork length for aged steelhead smolts in 2016.

<table>
<thead>
<tr>
<th>Smolt Age (years)</th>
<th>Mean Length (mm)</th>
<th>Lower 95% CI</th>
<th>Upper 95% CI</th>
<th>Number Aged</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>144</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>150</td>
<td>147.3</td>
<td>152.7</td>
<td>49</td>
</tr>
<tr>
<td>3</td>
<td>175</td>
<td>171.5</td>
<td>178.5</td>
<td>95</td>
</tr>
<tr>
<td>4</td>
<td>208</td>
<td>203.4</td>
<td>212.6</td>
<td>85</td>
</tr>
<tr>
<td>5</td>
<td>268</td>
<td>250.2</td>
<td>285.8</td>
<td>13</td>
</tr>
</tbody>
</table>

**Steelhead Smolts Per Spawner**

An estimated 79.8 smolts per female spawner were produced from the estimated 31 wild female steelhead spawners in 2011, assuming only wild-origin spawners contributed to smolt production. Wild fish contributed 27.1 smolts per female spawner for the 2012 brood year, with five-year-old smolts to be enumerated in 2017 (Figure 6). Partial results for the 2013 brood year indicate a total of 24.3 smolts per female spawner, with four and five-year-old smolts to be enumerated in 2017 - 2018. The 2014 and 2015 brood years (two and one-year-old smolts respectively) have produced 4.4 and 0.1 smolts-per-female spawner to date.
Environmental Monitoring

Stage and temperature data were successfully uploaded at the resistivity counter and Wolf Creek locations in late July. Data after July 27th must still be uploaded. The Keogh Lake barologger was found to not be logging data and the lake stage logger was inaccessible. Future efforts should consider relocating the lake stage logger to a more accessible and safe location. The new water station installation at the counter site makes the stage and barologger at this location redundant going forward.

Winter temperatures were consistently low through the winter and spring monitoring period reaching a minimum of 2.8°C on January 11th (Figure 7). Peak discharge during winter monitoring of steelhead was 85 m³s⁻¹ on January 28th. Peak discharge during spring smolt migration was 23 m³s⁻¹ on April 6th (Figure 7). Peak discharges were substantially larger this year compared to the previous year (44 m³s⁻¹ on January 11th and 9 m³s⁻¹ on April 21, 2015). These very high discharge events spilled over the floating fence multiple times and over the smolt fence shortly after installation posing the possibility of adult steelhead bypass during both upstream and downstream migrations.
Figure 7. Discharge (blue line) and temperature (red line) at the Keogh River resistivity counter site through to July 27, 2016.

*Resistivity Counter Estimates*

Graphics validation produced a high degree of certainty for fish detections. If a fish detection was recorded as an event, it was re-assigned as an up or down fish event based on graphical characteristics. Correspondingly, up and down fish detections were re-assigned as events if they did not have the ‘sinusoidal’ wave produced when a fish swims over the counter electrodes (Figures 8 and 9).

Figure 8. Validated up fish detection on Keogh River resistivity counter.
Targeted video validation revealed that up and down fish events were also being triggered by river otters. Otters appear to trigger far more down events than up events likely due to differences in how they move up and down the counter. From validation we estimated that 25% of up events were triggered by otters and 71% of down events. These corrections were integrated into counter population estimates and are presented below.

The resistivity counter recorded a total of 129 upstream counts and 56 downstream counts (both corrected) between November 16th, 2015 and March 20th, 2016. After March 20th the counter recorded 12 up counts. This produces a net population estimate of 90 steelhead passing upstream of the counter. (Figure 10).
Figure 10. Panel A: Up counts (blue) and down counts (grey) logged on resistivity counter between November 16\textsuperscript{th}, 2015 to April 7\textsuperscript{th}, 2016. Vertical line represents the onset of kelt outmigration (March 20\textsuperscript{th}, 2016). Panel B: Electronic counts (cumulative corrected number) of adult wild steelhead migrants into the Keogh River 2015-2016.

Through the 2015-2016 season a total of 50 unique steelhead were caught by angling, the floating fence, and at the smolt fence. Of these, 44 were wild and 6 were hatchery producing a ratio of 88 percent wild adult steelhead. This percentage was applied to the counter estimate to produce an estimate of 79 wild and 11 hatchery adult steelhead during the 2015-2016 season (Table 5).

Table 5. Counter population estimates for adult steelhead at Keogh River 2015-2016.

<table>
<thead>
<tr>
<th>Adult Steelhead Type</th>
<th>Counter Population Estimate</th>
<th>Pop. Estimate with Otter Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wild</td>
<td>75</td>
<td>79</td>
</tr>
<tr>
<td>Hatchery</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Total</td>
<td>85</td>
<td>90</td>
</tr>
</tbody>
</table>
Mark-Recapture Estimates

The floating fence was installed on February 15, 2016 and removed on April 5, 2016. There was at least one very high flow event between March 4\textsuperscript{th} to 7\textsuperscript{th} that over-topped the floating fence and provided opportunity for fish to move upstream and downstream without detection.

A very small number of adult steelhead were marked this year (Table 6). This is thought to be a combined result of reduced marine survival, reductions in angling effort and high flow events that potentially allowed adults to pass upstream without detection due to the river over topping the fish fence. These over-topping events violate the assumption of a closed population, however, we believe the likely number of fish that passed in this method is small. In addition, the calculation of a population estimate for wild males and hatchery females in the absence of recaptured individuals is possible but should be interpreted with caution. A mark-recapture estimate was not possible for hatchery males as there were not any captures.

Table 6. Mark-Recapture estimates for adult steelhead at Keogh River 2015-2016. Wild population estimate for both sexes combined is additive of individual estimates for males and females.

<table>
<thead>
<tr>
<th>Origin</th>
<th>Sex</th>
<th>Marked</th>
<th>Captured</th>
<th>Recaptured</th>
<th>Estimate</th>
<th>Lower95CI</th>
<th>Upper95CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wild</td>
<td>Males</td>
<td>2</td>
<td>16</td>
<td>0</td>
<td>50</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Wild</td>
<td>Females</td>
<td>7</td>
<td>20</td>
<td>1</td>
<td>83</td>
<td>25</td>
<td>163</td>
</tr>
<tr>
<td>Wild</td>
<td>Both</td>
<td>9</td>
<td>36</td>
<td>1</td>
<td>133</td>
<td>35</td>
<td>213</td>
</tr>
<tr>
<td>Hatchery</td>
<td>Male</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Hatchery</td>
<td>Female</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>38</td>
<td>7</td>
<td>38</td>
</tr>
</tbody>
</table>

Mark recaptures produced a total population estimate of 133 wild adults for the 2015-2016 season. This represents a decrease in mark-recapture population size for the first time since 2010 (Figure 11).
Angling, Biological Data and Age Structure

A total of 80 hours was spent angling for adult steelhead between December 16, 2015 and March 17, 2016. This is substantially lower than previous years (384.5 hours of angling in 2015). A total of four adults were caught (3 wild; 1 hatchery) with no angling recaptures (Table 1). Total catch per unit effort (# fish per hour) was 0.05 (0.038 wild; 0.013 hatchery). A summary of all adult steelhead sampled through the 2015-2016 season is presented in Table 7.
Wild marked fish represented approximately ~7% of the mark recapture estimate of returning migrant adults. A total of 38 steelhead were captured post-spawning during spring fence operations. Of these, 36 (16 males and 20 females) were wild origin plus 2 hatchery females (no hatchery males). Wild fish represented ~95% of the kelts captured at the smolt fence in 2016.

The age composition of steelhead adults ranged from four to seven years in 2016. Scale regeneration limited the aging to 23 of the 34 wild steelhead scale samples (Table 8). Seven fish were repeat spawners and comprised ~21% of all adults sampled.

Through analysis of smolt abundances and the age structure of returning adults, we estimate that 192 individuals returned from the 2012 smolt cohort out of 3,193 smolts resulting in a mean marine survival point estimate of 6.0% for this cohort (Figure 12). The marine survival estimate for the 2013 smolt cohort is 4.9%, based on an estimate of 128 adults returning from 2,620 smolts. To date, a total of 72 fish have returned from the 2014 smolt cohort (2,382 smolts), for a current marine survival estimate of 3.0%, with adults spending three and four years in the ocean to return in 2016 and 2017 respectively.
Figure 12. Marine survival estimates for wild adult steelhead at the Keogh River 1977-2013.

Discussion

Steelhead Smolt and Parr Abundance and Migration Timing
Steelhead smolt abundance has generally increased since 2008, coincident with a decrease in average smolt age. However, this year there was a drop in abundance and increase in average age. Over the same time period, pink salmon escapement has been increasing. Recent suggestions of a link between steelhead abundance and the escapement of pink salmon in the previous year are confounded by this year’s results as younger smolts would be expected. Years with exceptional pink salmon returns are often followed by increased smolt abundances. The link between steelhead growth and pink salmon nutrient subsidies has been previously documented (Johnston et al. 1990, Wipfli et al. 2010), but little is known linking steelhead abundance to variation in pink salmon escapement.

Steelhead Juvenile Size and Age
The mean sizes of age-two and three smolts have declined over the last six years. The observed changes in smolt size-at-age lend support to the theory that pink salmon are important for steelhead growth (Cederholm et al. 1999). In addition, these changes in length-at-age lend support to the hypothesis put forward by Atlas et al. (2015) that steelhead habitat use has contracted to smaller, and higher quality, areas of available habitat. This results in significant density dependant effects, such as competition for food resources, despite small population sizes.

Steelhead Smolts Per Spawner
Smolts per spawner is expected to be higher at lower spawner abundances due to density-dependent effects on juvenile growth and mortality (Keeley, 2001, Ricker 1975). The abundance of smolts-per-female spawner (79.8 smolts) from 2011 reflects this density...
dependent productivity but is a decrease from the previous two years. Individual female steelhead productivity has been consistently high since 1996 (average 63.2 smolts-per-female), largely due to limited spawner abundance (average 52 females, 1996-2013). In contrast, the number of smolts produced per female averaged 19.5 (1977-1990) when the density of spawners was higher.

**Steelhead Adult Abundance and Marine Survival**

Adult steelhead abundance declined precipitously in 1990 and remains low. In 2016, a total of 79 wild adults were estimated by the resistivity counter, while the mark-recapture estimate was 133 wild spawners. The mark recapture estimate of 133 wild steelhead spawners (95% CI 35-213) represents 25% of the long-term average escapement (522 adults, 1976-2016) to the Keogh River, and ~11% of the average escapement prior to the shift in marine survival (1,168 adults, 1977-1990). The 2016 return is a change in a minor trend of increasing adult returns since 2010. Marine survival is 4.9% and represents a decrease to levels observed in 2008 and 2009 but remains higher than minimums observed between 2002 and 2007 (mean survival of 3.4%).

The density of returning steelhead is low compared to the density prior to 1990. In general, steelhead populations are highly productive at low spawner densities due to changes in the dynamics of competition among juveniles. Although the spawner density is low, density-dependent effects are potentially greater now than previously observed during years of higher spawner abundance (Atlas et al. 2015). Atlas et al. (2015) suggest that fish populations will spatially contract to occupy a fraction of the available habitat at low density. As a result, individual productivity is high, but density-dependent mortality is stronger than expected given the population size and quantity of available habitat.

The mark-recapture estimate of 133 wild steelhead has considerable uncertainty (95% CI 35-213). It is recommended to depend more on the resistivity counter estimates going forward. Confidence in mark-recapture estimates can be improved by increasing the numbers of marked and recaptured fish, although this may be difficult as wild fish tend to spread throughout the Keogh mainstem and may hold in areas that are difficult to access. Increasing angler effort early in the migration period and continuing to use the floating fence may help strengthen future mark-recapture estimates if required however recent upgrades to the resistivity counter further increase confidence in population estimates compared to mark-recapture methods. Capturing and aging more adult steelhead prior to kelting is also required to improve estimates of the proportions of fish returning from particular brood and smolt emigration years. However, the efficiency of the floating fence in trapping upstream migrating adults is highly dependent on flow conditions which have been more unpredictable in recent years. Ongoing efforts to PIT tag juvenile steelhead (since 2014) will provide an independent measure of marine survival through the use of full river PIT antenna arrays, beginning with returns of ocean-age-two fish in 2016.

**Hatchery Steelhead**

Hatchery fish return to the Keogh annually. Although these numbers can vary, total hatchery fish can be comparable to wild spawners in some years. The presence of hatchery fish presents several issues for the wild population. Semi-domesticated hatchery steelhead stocks are known to have reduced fitness compared to wild stocks (Williamson et al. 2010), and can reduce the fitness of the wild population via interbreeding (Chilcote et al. 2011, Christie et al. 2012), mate competition (Flemming and Gross, 1993), and potentially negative behavioural interactions (Jonsson, 1997, Kostow et al. 2003). Furthermore, rearing salmonids to the smolt
stage in hatcheries imposes artificial selection for traits that may be maladaptive in wild populations (Araki et al. 2007, Christie et al. 2012). In addition, hatchery steelhead complicate reliable estimates of wild population returns in the Keogh. Using PIT tag data, we have determined that hatchery steelhead can behave differently than wild fish, often failing to migrate past 1 km above the estuary and stage in lower river reaches for the duration of the migration period. These behaviours manifest as multiple detections on lower-river PIT arrays, and cycling over the resistivity counter. Should the hatchery fish spawn in the lower reaches, they would contribute to the negative density-dependent effects described by Atlas et al. (2015). The floating fence that was installed in 2012 to increase the number of wild adults sampled also functions to exclude hatchery fish from the river. Unfortunately, the floating fence is installed in February during lower flow periods, leaving the river open to hatchery migrants in December and January.

Coho Salmon Monitoring
Results
A total of 91,582 coho smolts and 438 coho parr were enumerated at the fence in 2016. Similar to steelhead, coho smolt totals are less than last year (2015: 111,718) but parr numbers are higher (2015: 170; Figure 13). Total abundances (smolts and parr combined) are 111,888 and 92,020 for 2015 and 2016 respectively. Overall, coho smolts are slightly smaller than last year. Average fork length is 102.3mm (mean weight: 11.8g) compared to a 2015 average length of 105.0mm (mean weight: 13.8g). The length frequency distribution of smolts and parr is bi-modal representing different smolt age cohorts and indicated smolts emigrated at one and two-years of age (Figure 14).

Figure 13. Coho smolt abundance at the Keogh River 1977-2016. Line indicates running three-year average.
Figure 14. Length (mm) frequency distribution of coho smolts captured at the Keogh River smolt fence in 2016.

Migration timing (for smolts and parr combined) indicates a single peak around May 4\textsuperscript{th} with a large spike in smolt numbers around April 25\textsuperscript{th} (Figure 15).

Figure 15. Daily totals and migration timing for coho smolts captured at the Keogh River smolt fence in 2016.
Daily mean size was variable but may correlate with peak timing; where larger fish out-migrate over the peak with smaller fish exiting during the onset and tail-end of the migration period (Figure 16). Mean condition factor is variable and shows a slight negative trend farther into the season (Figure 17). The mean Fulton condition factor is 1.02 representing an increase from 2015 (0.84).

Figure 16. Mean fork length (error bars = 1 SD) of live coho (smolts and parr combined) sampled during 2016 season.
Figure 17. Mean Fulton condition factor (error bars = 1 SD) of live coho smolts sampled during 2016 season.

Adult coho abundance and marine survival dropped precipitously in 2015. The adult population estimate for 2015 is 748 individuals and marine survival is 16%. This represents a concerning break from increasing trends since 2010-2011 and are all-time lows since 1998 (Figures 18 and 19).
Figure 18. Estimated adult coho abundance at the Keogh River 1998-2015.

Figure 19. Estimated coho marine survival at the Keogh River 1998-2015.
Discussion
Coho smolt abundance in 2016 was the sixth highest since the Keogh project began in 1976 and exceeds the post-restoration average abundance (73,571; 2000-2015). The number of adults that returned in 2015 was an all-time low. Possible explanations include In-river conditions were negatively influenced by extensive dry conditions two years prior that reduced habitat area and increased water temperature.

The 2014 brood year produced 67 smolts per spawner. This is an increase from the previous year (2013: 53 smolts per spawner). The 2014 smolts per spawner represents an increase closer to the 74 smolts per female observed for the 2011 brood year. The juvenile abundances from 2011-2013 and 2015-2016 were high, despite widely varied rearing conditions and spawner density. Coho abundance in 2014 was comparatively low (66,765). Fry produced in the 2010 brood year reared during a wet summer with increased river flows (Johnston et al. 2012), but this has not been the case recently with this summer also experiencing dryer conditions.

Coho smolts were smaller in 2016 when compared to smolts from recent years but the condition factor increased slightly from last year. It is possible that the smaller smolt size is a result of the strong density dependent effects of high juvenile abundance leading to slower growth rates in freshwater. In addition, dry summers reduce the amount, and quality, of available habitat through reduction in water levels and wetted area (McCullough, 1999).

Coho smolts out-migrating in 2014 experienced the lowest marine survival since 1998 and represents a marked drop from recent years (average: 3.7 % for adult return years 2006 to 2013) (McCubbing and Troffé 2006; McCubbing and Clarke 2014). This drop in marine survival was not observed in steelhead.
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