

# Estimates of Wenatchee Steelhead Redds in 2019

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## Abstract

This report contains estimates of total steelhead redds in the Wenatchee, after accounting for observer bias. It also includes estimates of spawners, as well as prespawn mortality.

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# 1 Introduction

Redd counts are an established method to provide an index of adult spawners (Gallagher et al. 2007). In the Wenatchee subbasin, index reaches are surveyed weekly during the steelhead spawning season (Mar 11, 2019 - Jun 03, 2019) and non-index reaches are surveyed once during the peak spawning period. The goal of this work is to:

1. Predict observer net error, using the model described in Murdoch et al. (2018).
2. Use estimates of observer net error rates and the mean survey interval to estimate the number of redds in each index reach, using a Gaussian area under the curve (GAUC) technique described in Millar et al. (2012) and Murdoch et al. (2018).
3. Estimate the total number of redds in the non-index reaches by adjusting the observed counts with the estimated net error where possible.
4. Sum the total number of estimated redds for the entire Wenatchee subbasin.

# 2 Methods

## 2.1 Net Error Model

The net error ( $NE$ ) for a reach  $i$  is defined as

$$NE_i = \frac{F_i}{V_i}$$

where  $F_i$  is the number of redds the surveyor reported and  $V_i$  is the true number of redds in the reach. Therefore, if we have an estimate of net error ( $\hat{NE}_i$ ), we can calculate the true number of redds based on that estimate and the number of redds the surveyor reported:

$$V_i = \frac{F_i}{\hat{NE}_i} \quad (1)$$

The model for observer net error is fully described in Murdoch et al. (2018). It uses covariates of the log of observer experience, mean discharge, the observed redd density and mean thalweg CV as a proxy for channel complexity. After normalizing these covariates, the model coefficients are shown in Table 1. The response, net error, is scaled such that estimates of net error less than 1 suggest more errors of omission, while estimates greater than 1 suggest more errors of commission. An estimate of net error equal to one would indicate the observed count equals the true number of redds.

Table 1: Net error model covariates and coefficients.

Covariate	Estimate	Std. Error
(Intercept)	0.682	0.039
Obs. Redd Density	0.277	0.053
Mean Thalweg CV	-0.169	0.043
Mean Discharge	0.116	0.048
Log Surveyor Exp.	0.115	0.042

## 2.2 Data

Redd counts were conducted on a nearly weekly basis for index reaches, and once during the peak spawning period for non-index reaches. The covariates in the observer error model of Murdoch et al. (2018) were collected during each survey. They were compared with the covariates contained in the model data set, as well as the estimates of net error (Figure 1).

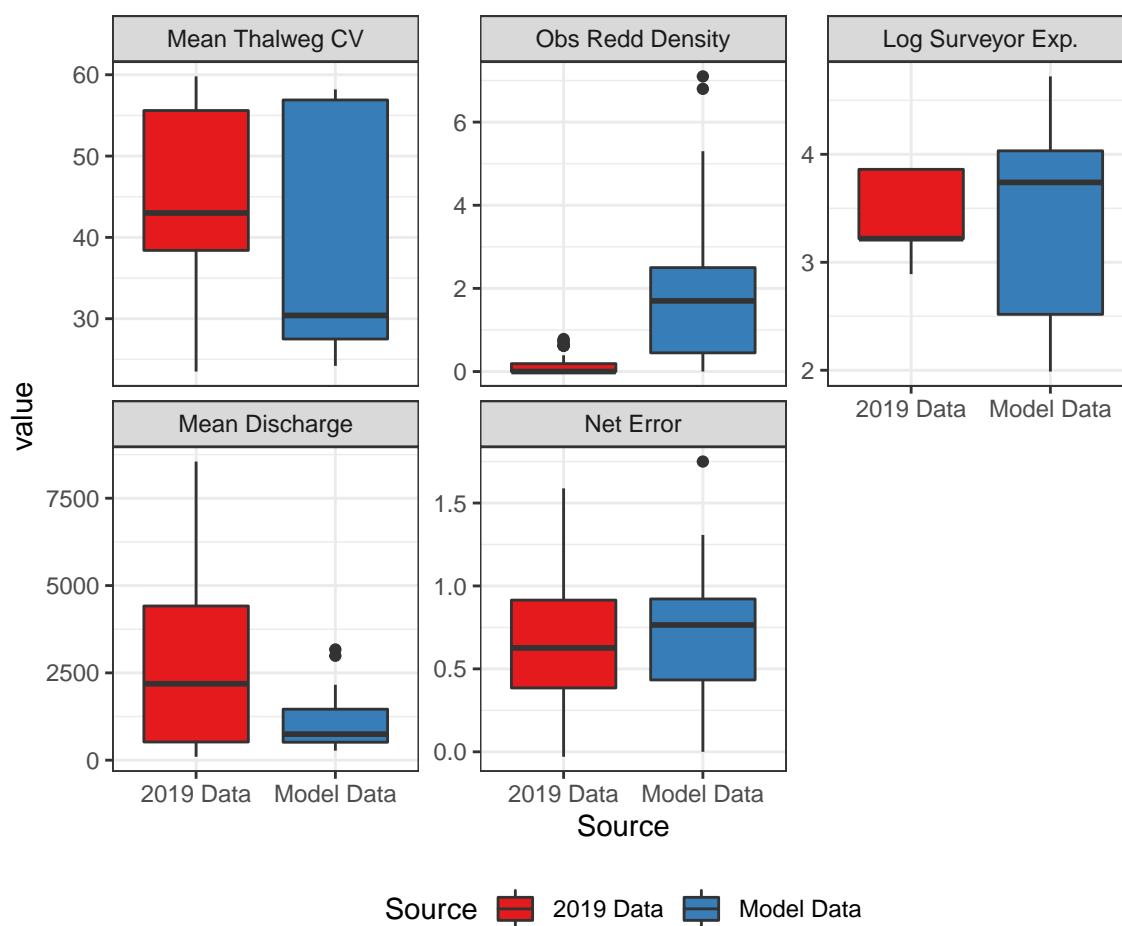


Figure 1: Net error covariate values from the original study the predicted reaches in this report.

Those covariates in the observer error model were collected during each survey in 2019, and predictions of net error were made for each survey. From these survey specific estimates of net error, a mean and standard error of net error was calculated for each reach. The standard deviation was calculated by taking the square root of the sum of the squared standard errors for all predictions within a reach.

## 2.3 Estimating Redds

Use of the GAUC methodology was limited to index reaches with a minimum of two redds and at least three weeks with at least one new redd found. For those reaches, we used the method described in Millar et al. (2012) and Murdoch et al. (2018). The GAUC model was developed with spawner counts in mind. As it is usually infeasible to mark every individual spawner, only total spawner counts can be used, and an estimate of average stream life must be utilized to translate total spawner days to total unique spawners. However, in adapting this for redd surveys, we note that individual redds can be marked, and therefore the GAUC model can be fit to new redds only. The equivalent of stream life thus the difference between survey numbers which can be fixed at 1.

For non-index reaches, which were surveyed only once during peak spawning, the estimate of total redds was calculated by dividing the observed redds by the estimate of net error associated with that survey (Eq. (1)). This assumes that no redds were washed out before the non-index survey, and that no new redds appeared after that survey. As the number of redds observed in the non-index reaches ranged from 0 to 2, any violation of this assumption should not affect the overall estimates very much. Any index reaches that did not meet the thresholds described above were treated as non-index reaches, and the total observed redds in those reaches were divided by the mean estimate of net error for each reach.

When summing reach-scale estimates to obtain estimates at the stream scale, an attempt was made to incorporate the fact that the reaches within a stream are not independent. Estimates of correlation between the reaches within a stream were made based on weekly observed redds. This method may not be perfect, since spawners could use certain reaches preferentially at different times in the season, but it may be the best we can do. Because correlations are often quite high between reaches, this is a better alternative than to naively assume the standard errors between reaches are independent of one another. These correlation estimates were combined with estimates of standard error at the reach scale to calculate a covariance matrix for the reaches within each stream, which was used when summing estimates of total redds to estimate the standard error at the stream scale. Failure to incorporate the correlations between reaches would result in an underestimate of standard error at the stream scales. Different streams (and therefore reaches in different streams) were assumed to be independent.

## 2.4 Estimating Spawners

Estimates of escapement to various tributaries in the Wenatchee were made using a branching patch-occupancy model (Waterhouse, L. et al., *in review*) based on PIT tag observations of fish tagged at Priest Rapids dam. All fish that escaped to the various tributaries were assumed to be spawners (i.e. prespawn mortality only occurs in the mainstem).

To convert estimates of redds in mainstem areas into estimates of natural and hatchery spawners, the estimates of redds were multiplied by a fish per redd (FpR) estimate and then by the proportion of hatchery or wild fish. The fish per redd estimate was based on PIT tags from the branching patch-occupancy model observed to move into the lower or upper Wenatchee (below or above Tumwater dam), but not into tributaries upstream of Tumwater. FpR was calculated as the ratio of male to female fish, plus 1. Reaches W1 - W7 are below Tumwater, while reaches W8 - W10 are above Tumwater. Similarly, the proportion of hatchery and natural origin fish was calculated from the same group of PIT tags for areas above and below Tumwater.

## 2.5 Prespawn Mortality

After translating estimates of redds to estimates of spawners by origin, we can then compare the spawner estimates to escapement estimates made using PIT tags, and estimate a prespawn mortality rate. Taking the total PIT-tag based escapement estimate, by origin, to the Wenatchee, we then subtract any fish removed at

Table 2: Known number of fish removed at dams or due to harvest, by origin.

Source	Hatchery	Natural
Dryden	37	31
Harvest	0	0
Tumwater	27	29

Tumwater or Dryden for brookstock or surplus, as well as any deaths due to harvest (Table 2), and then subtract the total estimate of spawners, including the tributaries, to provide an estimate of how many fish succumbed to prespawn mortality. Dividing that number by the total escapement estimate provides an estimate of the prespawn mortality rate, by origin across the entire Wenatchee population.

We can also compare estimates of escapement to the mainstem lower Wenatchee (after subtracting the the fish removed at Dryden) and to the upper mainstem above Tumwater (after subtracting the fish removed at Tumwater) to total estimates of spawners in mainstem areas below and above Tumwater dam. This allows us to estimate prespawn mortality in the mainstem above and below Tumwater, by origin. Using this approach, it is unclear which area deaths due to harvest should apply to, which is a moot point in years when there was no harvest.

If any group had a higher estimates of spawners compared to escapement, we fixed our prespawn mortality estimate at 0, reflecting a very low level of prespawn mortality. There is uncertainty in both the escapement and spawner estimates, which could explain why these types of scenarios could arise.

Table 3: Estimates of mean net error and redds for each reach.

River	Reach	Type	Net Error	Net Error CV	Observed Redds	Estimated Redds	Std. Err. Redds	Redds CV
Chiwawa	C1	Index	1	0	0	0	0	-
Nason	N1	Index	1	0	0	0	0	-
Peshastin	P1	Index	1	0	1	1	0	0
Wenatchee	W1	Non-Index	1.588	0.238	0	0	0	-
Wenatchee	W2	Index	0.88	0.285	0	0	0	-
Wenatchee	W3	Non-Index	1	0	0	0	0	-
Wenatchee	W4	Non-Index	1	0	0	0	0	-
Wenatchee	W5	Non-Index	1	0	0	0	0	-
Wenatchee	W6	Non-Index	1.047	0.217	0	0	0	-
Wenatchee	W6	Index	0.782	0.181	5	6	3	0.507
Wenatchee	W8	Non-Index	0.92	0.232	0	0	0	-
Wenatchee	W8	Index	0.644	0.207	1	2	0.3	0.161
Wenatchee	W9	Non-Index	0.689	0.263	1	1	0.4	0.382
Wenatchee	W9	Index	0.555	0.313	18	32	13.4	0.42
Wenatchee	W10	Non-Index	0.406	0.36	2	5	1.8	0.355
Wenatchee	W10	Index	0.356	0.411	25	70	32	0.457

Table 4: Estimate of redds for each stream

River	Location	Index	# Reaches	Observed Redds	Estimated Redds	Std. Err. Redds	Redds CV
Chiwawa	Tributaries	Y	1	0	0	0	-
Nason	Tributaries	Y	1	0	0	0	-
Peshastin	Tributaries	Y	1	1	1	0	0
Wenatchee	Above Tumwater	N	3	3	6	2.158	0.4
Wenatchee	Above Tumwater	Y	3	44	104	43.485	0.4
Wenatchee	Below Tumwater	N	5	0	0	0	-
Wenatchee	Below Tumwater	Y	2	5	6	3.039	0.5
<b>Total</b>	-	-	<b>16</b>	<b>53</b>	<b>117</b>	<b>43.644</b>	<b>0.4</b>

## 3 Results

### 3.1 Redd estimates

The estimated net error, observed redds and estimates of redds at the reach scale are shown in Table 3. Plots of the new redds and the GAUC fit to those data are shown in Figure 2. The results are summarized at the stream and population scale in Table 4.

### 3.2 Spawner Estimates

Parameter estimates for fish / redd and proportion hatchery based on PIT tag data are shown in Table 5.

Combining PIT tag-based estimates of spawners in the tributaries with adjusted redd-based estimates of spawners in the mainstem areas, Table 6 shows all of them, broken down by area and origin.

Table 5: Fish per redd and hatchery / natural origin proportion estimates.

Area	Fish / redd	FpR Std. Error	Prop. Hatchery	Prop Std. Error
Below TUM	1.591	0.151	0.600	0.083
Mainstem above TUM	1.625	0.259	0.308	0.128

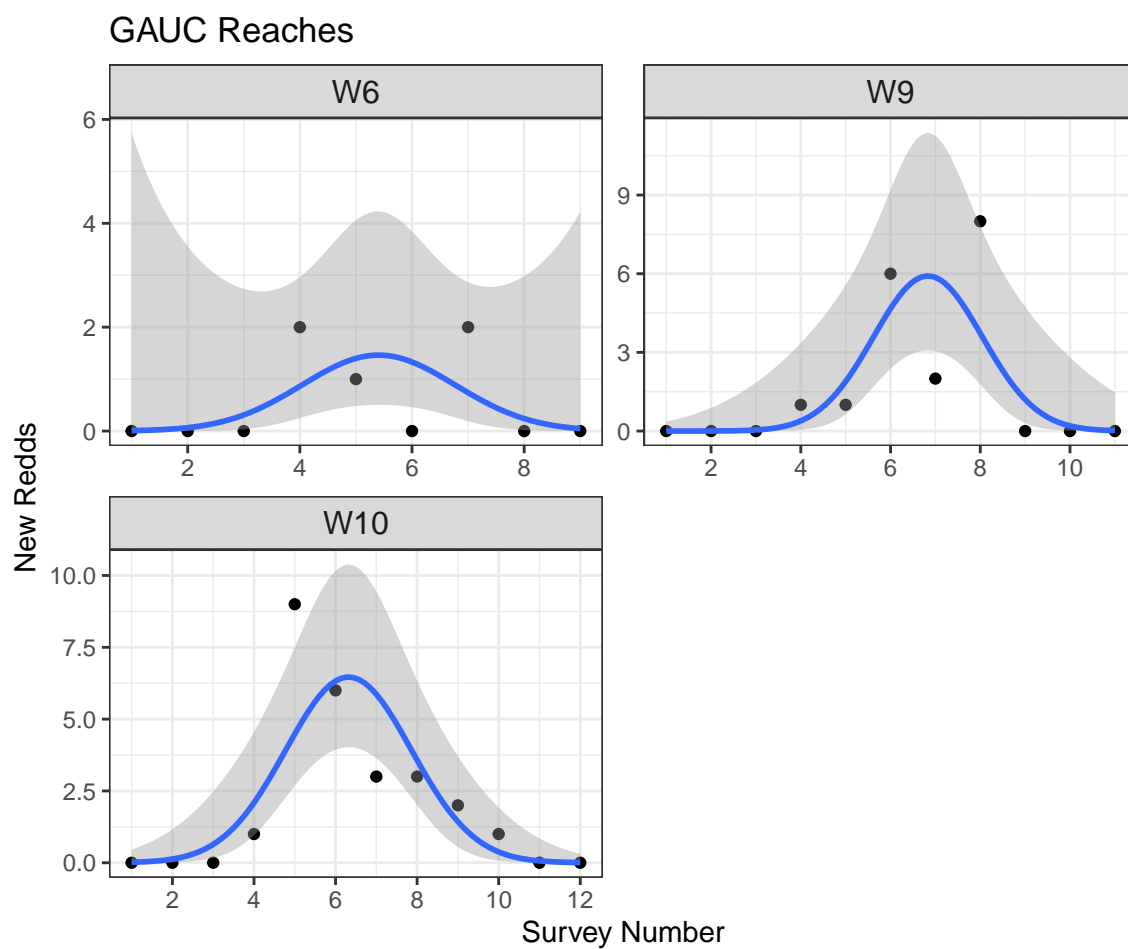


Figure 2: Plots of observed redd counts (black dots) through time for each qualifying index reach, and the fitted curve from the GAUC model (blue line) with associated uncertainty (gray).

Table 6: Estimates (CV) of spawners by area and origin.

Area	Type	Natural	Hatchery
W1	Non-Index	0 (-)	0 (-)
W2	Index	0 (-)	0 (-)
W3	Non-Index	0 (-)	0 (-)
W4	Non-Index	0 (-)	0 (-)
W5	Non-Index	0 (-)	0 (-)
W6	Index	4 (0.56)	6 (0.53)
W6	Non-Index	0 (-)	0 (-)
W8	Index	2 (0.29)	1 (0.47)
W8	Non-Index	0 (-)	0 (-)
W9	Index	36 (0.49)	16 (0.61)
W9	Non-Index	1 (0.45)	1 (0.59)
W10	Index	79 (0.52)	35 (0.64)
W10	Non-Index	6 (0.43)	3 (0.57)
Icicle	Trib	11 (0.69)	23 (0.45)
Peshastin	Trib	50 (0.31)	7 (0.88)
Mission	Trib	12 (0.62)	7 (0.81)
Chumstick	Trib	8 (0.86)	8 (1.02)
Chiwaukum	Trib	0 (-)	0 (-)
Chiwawa	Trib	22 (0.44)	49 (0.31)
Nason	Trib	15 (0.52)	15 (0.51)
Little Wenatchee	Trib	0 (-)	0 (-)
White River	Trib	0 (-)	0 (-)
<b>Total</b>	<b>-</b>	<b>246 (0.48)</b>	<b>171 (0.53)</b>



Table 7: Wenatchee prespawn mortality estimates. Includes estimates (standard error) of escapement, spawners, prespawn mortality, and standard error of this rate, separated by origin.

Origin	Escapement	Spawners	Prespawn Mortality	SE
Natural	133 (29)	245 (50)	0	0.557
Hatchery	145 (30)	171 (34)	0	0.340

Table 8: Wenatchee prespawn mortality estimates. Includes estimates (standard error) of escapement, spawners, prespawn mortality, and the standard error of this rate, separated by origin and mainstem areas above and below Tumwater dam.

Origin	Area	Escapement	Spawners	Prespawn Mortality	SE
Natural	Above Tumwater	15 (14)	124 (44)	0.000	8.063
Hatchery	Above Tumwater	0 (11)	55 (24)	0.000	196.733
Natural	Below Tumwater	0 (11)	4 (2)	0.000	0.492
Hatchery	Below Tumwater	25 (16)	6 (3)	0.775	0.189

### 3.3 Prespawn Mortality

The estimates of overall prespawn mortality within the Wenatchee population, by origin, are shown in Table 7. The estimates when split into the mainstream areas above and below Tumwater dam, are displayed in Table 8.

## 4 Discussion

Most of the covariates collected in 2019 were within the range of those in the model data set from Murdoch et al. (2018), leading to estimates of net error in a very similar range to the model dataset (Figure 1). However, most reaches did not meet the minimum thresholds of number of observed redds or number of weeks with at least one new redd observed, so we used the GAUC method in only three reaches.

The estimates of high prespawn mortality in the lower mainstem of the Wenatchee for hatchery fish could be accurate, but it should be noted that many of the redd surveys failed to observe a single redd in many of the reaches (Table 3). Without any observed redds, any estimate of net error is moot, as the adjusted redd estimate will still be zero. So if all the redds were missed in some of those reaches, the estimate of total spawners in the lower mainstem should be higher, leading to a lower estimate of prespawn mortality. It is unclear whether that actually occurred, or if there were actually no redds this year in those reaches.

Most of the estimates of prespawn mortality were zero this year, due to higher estimates of spawners compared to escapement, at least after removals had been accounted for. In some cases, there were overlapping confidence intervals between spawners and escapement, so not too much should be made of that fact, and we interpret that as at least very low levels of prespawn mortality, perhaps even none. However, the natural-origin estimates of spawners, either in the Wenatchee as a whole (Table 7) or split between above and below Tumwater (Table 8), were much higher than estimates of natural-origin escapement. It is unclear exactly why that is, but we do note that the net error in reach W10 above Tumwater is quite low, and a number of redds were spotted there, leading to high levels of estimated redds and therefore spawners.

## 5 Acknowledgements

The data for this report was collected by Washington Department of Fish and Wildlife. Development of the observer error model was done in collaboration with Andrew Murdoch, WDFW.

## 6 References

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