**Deep Drawdowns at Rimrock Lake are Associated with Decline in Bull Trout Redd Counts the Following Year**

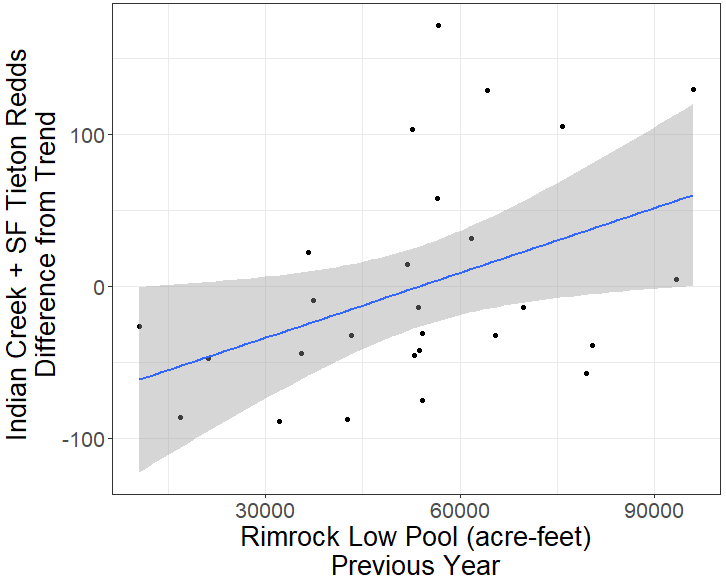
September 2024

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Executive Summary

Fish, including bull trout, are entrained from Rimrock Lake through the unscreened outletworks of Tieton Dam each year. Operations to support flip-flop irrigation deliveries in the late summer and early fall lead to deep drawdowns. The depth of drawdown is known to predict the rate of kokanee entrainment from Rimrock Lake. Drawdowns may also influence bull trout indirectly through impacts on prey base and habitat quality, and directly through entrainment. To better understand the potential effects of Rimrock drawdowns on bull trout we examined redd count data, reservoir storage, and snowpack from 1994 to 2023. After accounting for the overall trend towards decline, we found that there is a significant association between the depth of drawdown at Rimrock Lake (minimum annual pool elevation) and the number of bull trout redds observed the following year in the South Fork Tieton River and Indian Creek populations.

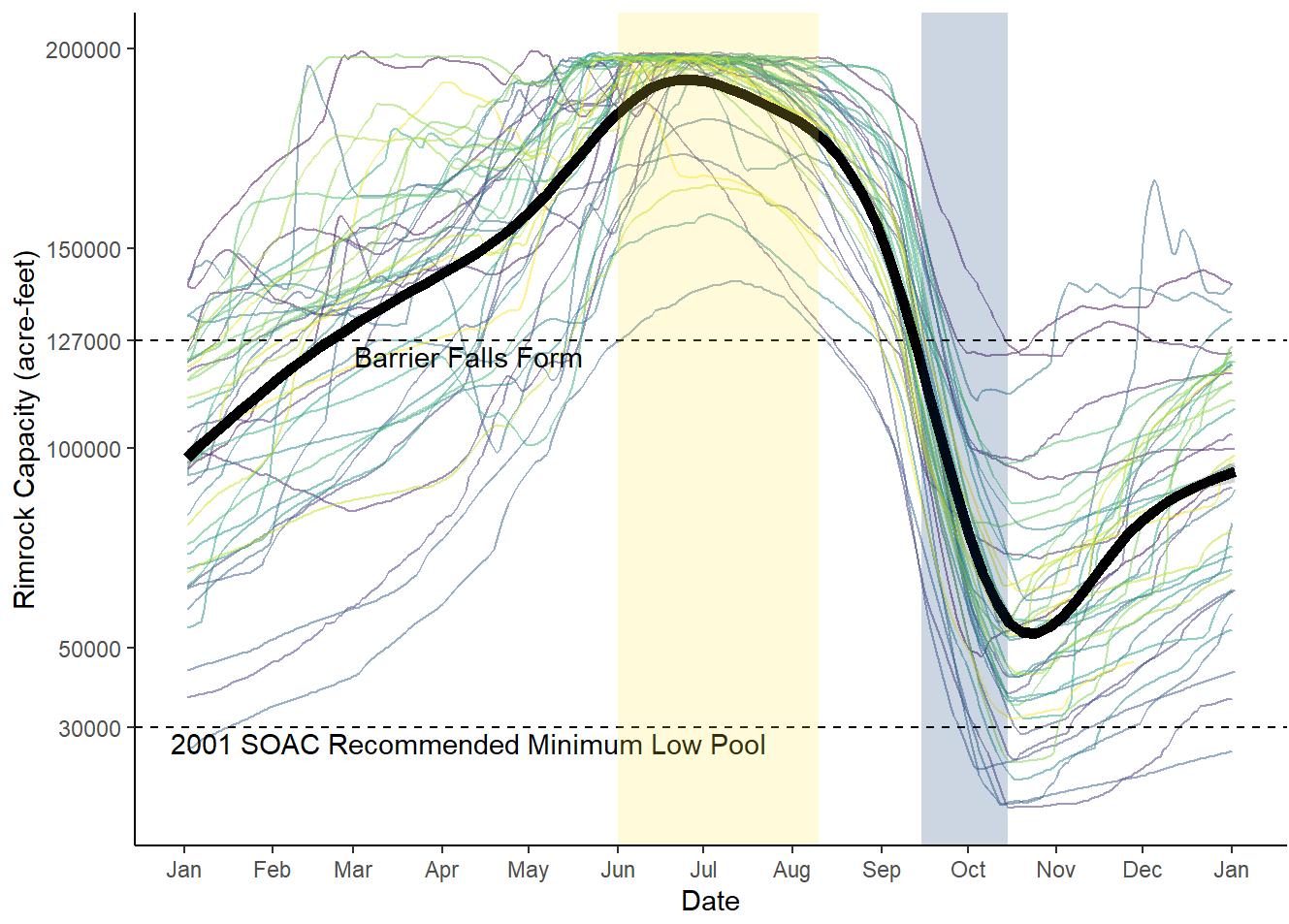


The final model predicts a loss of 34 redds in the year following a drawdown to 30,000 acre-feet. This predicted loss of redds is in addition to the overall trend towards decline. No similar association was between drawdown depth and redd counts two and three years later. In a model that included both snowpack and minimum annual pool elevation, we found that only minimum annual pool elevation improved the fit to the data.

Background

Construction of the Tieton Dam in 1925 impounded Rimrock Lake and isolated three local populations of bull trout above the dam: North Fork Tieton River, South Fork Tieton River, and Indian Creek. Clear Lake Dam further fragments habitat in the area by limiting migration along the North Fork Tieton River between Rimrock Lake and the upstream Clear Lake. No natural lake existed in the area and these local populations likely expressed a fluvial life history prior to construction of Tieton and Clear Lake dams. Currently, all three populations express an adfluvial life-history; using individual tributaries to spawn and returning to lake habitats to forage and overwinter.

The Rimrock populations share several threats related to the presence and operation of Tieton Dam. In addition to blocking upstream passage, Tieton Dam entrains fish through its unscreened outlet works. Rimrock Lake is rapidly drawn down in late summer and early fall to support “flip-flop” operations of the Yakima Project and meet irrigation demands (Fig. 1). The rate of entrainment for fish in reservoir habitats is determined by forebay habitat usage and the velocity at the intake (Coutant & Whitney, 2000; Harrison et al., 2019, 2020). Many adult Rimrock bull trout are expected to be in upstream spawning habitats during peak flip-flop water delivery (Fig. 1). However, adult Rimrock bull trout have been documented in the forebay during the period when peak flows occur (Mizell & Anderson, 2008, p. 42), and many subadult bull trout are expected to remain in Rimrock Lake throughout the year.



**Figure 1:** Volume of Rimrock Lake through the year demonstrating drawdown, and the overlap of flows with migration timing and formation of a passage barrier at the mouth of South Fork Tieton River. Colored lines are individual years from 1981- 2023, with more recent years in lighter (yellow) colors. Yellow period from June to mid-August approximates peak upstream spawning migration for South Fork Tieton River, blue period from mid-September to mid-October approximates peak downstream, post-spawn migration of adults (James, 2002). Heavy black line is loess-smooth of all years. Rimrock Volume Data from Bureau of Reclamation-Hydromet.

Studies conducted during typical drawdowns in 2002 and 2003 estimated 145 and 120 bull trout were potentially entrained from Rimrock Lake each year, respectively (Hiebert, 2004, p. 18; Hiebert et al., 2003, p. 12). These estimates may be spuriously large due to the possibility of non-entrained bull trout entering the study nets, and confidence interval of these estimates are also large (2002: 60 – 900). Twenty percent of the potentially entrained bull trout were adults, while the remaining entrained bull trout were subadults (Hiebert, 2004, p. Appendix B; Hiebert et al., 2003, p. Appendix B). Given population estimates in South Fork Tieton River and Indian Creek at the time (James, 2002, pp. 59, 64), this represent an entrainment rate of ~0.6 – 9.2% of the adult spawning population annually. Genetic stock identification of bull trout collected in stilling basin just below Tieton Dam found fish from each of the three Rimrock local populations (Small et al., 2009, p. 26).

Entrained bull trout likely suffer injury and mortality (Algera et al., 2020). While the rate of injury and mortality for adult bull trout entrained through Tieton Dam are not known, kokanee have been used as surrogates to estimate mortality for sub-adult bull trout. Mortality is estimated at 45% for sub-adults (Courter & Vaughan, 2011). Bull trout that survive entrainment are permanently displaced from the lake and unable to contribute to the productivity of their natal streams. Few entrained fish are expected to spawn elsewhere (Mizell & Anderson, 2015, p. 108).

Drawdowns of Rimrock Lake also pose a threat to bull trout through impacts on bull trout prey base. Unlike other reservoirs in the Yakima Project, Rimrock Lake was not a natural lake, and operations at Tieton Dam can draw Rimrock down to extremely low levels. Complete drawdowns of Rimrock Lake occurred four times, (1926, 1931, 1973, and 1979), and are associated with collapse of the Rimrock kokanee fishery the following year (Mongillo & Faulconer, 1980). The kokanee fishery did not recover from the 1973 drawdown for six years, despite stocking, and 95 – 99% of the population was lost to entrainment during the 1979 drawdown (Mongillo & Faulconer, 1980, pp. 31, 35). Analysis of kokanee catch records also indicate that deep drawdowns, defined as those below ~30,000 af, measurably reduce kokanee abundance and productivity (Mongillo & Faulconer, 1980, p. 31), prompting the Yakima Systems Operation Advisory Committee (SOAC) to recommend operating Rimrock Lake above this level in 2001. Rimrock has been drafted beneath 30,000 af eight times since 1981, but only once since the 2001 recommendation (Fig. 1).

While tagging (Mizell & Anderson, 2008, 2015), genetic stock identification (Small et al., 2009), netting (Hiebert, 2004, 2004), fishery records studies (Mongillo & Faulconer, 1980) indicate that entrainment poses a risk to Rimrock Lake bull trout populations, neither the extent of entrainment that occurs each year, nor the relationship between Tieton Dam operations and entrainment rate are well understood. Future monitoring efforts using PIT and acoustically tagged sockeye and bull trout are likely to provide answers to these questions. However, available redd count data may provide immediate insights. In this report, we examine if the bull trout redd counts in South Fork Tieton River and Indian Creek are associated with the extent of drawdown in previous years.

Methods

Detailed computational logs and all data from this report are available at a github repository, <https://github.com/david-dayan-usfws/Rimrock-Drawdown>. An R notebook containing narrative logs of all analyses with integrated code, results, and commentary is available at <https://rpubs.com/david_Dayan/rimrock_drawdown>

To explore the potential relationship between drawdown and entrainment risk in bull trout we considered redd count data, reservoir storage, and snowpack. Redd count data were collected from spawning ground surveys on South Fork Tieton River and Indian Creek from 1994 to 2023 (Divens, 2024). Redd counts from North Fork Tieton River (2007 – 2023) were not included to increase sample size. Raw redd counts were summed across the South Fork Tieton River and Indian Creek for each year. The data was filtered to exclude any year with an incomplete spawning survey in either population. Summed redd counts were then detrended using a linear regression against year. Residuals from this regression (*redd\_residuals)* were used as the dependent variable in all following models.

Hydological data was collected from Bureau of Reclamation Hydromet Service. We collected daily Reservoir Water Storage for Rimrock Lake (acre-feet) from January 1, 1981 to November 27, 2023. Environmental data was collected from the Natural Resources Conservation Service database. We collected April 1st Snow Water Equivalent at the White Pass E.S, WA SNOTEL site (SNOTEL 863) for all years from 1981 to present.

We fit a linear model of *redd\_residuals* using minimum annual reservoir water storage (acre-feet) in Rimrock Lake one, two, and three years prior (*rim\_1*, *rim\_2,* and *rim\_3*, respectively). We chose minimum annual reservoir water storage (*rim\_1*, *rim\_2,* and *rim\_*3) over other variables that capture the extent and duration of winter drawdown at Rimrock Lake to maintain precedent with previous analyses (Mongillo & Faulconer, 1980) and SOAC recommendations, and to better relate our results to operational decisions at Tieton Dam. The global model was validated using residual, QQ, and leverage plots in R. We then conducted backwards stepwise model selection based on likelihood ratio tests for each predictor, and a p-value cutoff of 0.05. Statistical significance of the association with the remaining predictors was conducted using a t-test, and a p-value cutoff of 0.05.

To parse the role of drawdown depth the previous year from potential environmental effects, we also fit a linear model on *redd\_residuals* using *rim\_1* and April 1st snow water equivalent at a nearby SNOTEL site (White Pass E.S.) the prior year (*swe*). After model validation, we calculated correlation between *rim\_1* and *swe,* and the variance inflation factor. We then conducted backwards stepwise model selection based on likelihood ratio tests for each predictor, and a p-value cutoff of 0.05.

Results and Discussion

*Redd Count Trends*

There was a trend towards decline in redd counts in South Fork Tieton River and Indian Creek from 1994 to 2023 (Fig. 2). This trend may reduce power or lead to spurious associations if the depth of past drawdowns is not evenly distributed over time. Therefore, we used residuals from the linear regression against year (*redd\_residuals*) as the dependent variable in all following models.

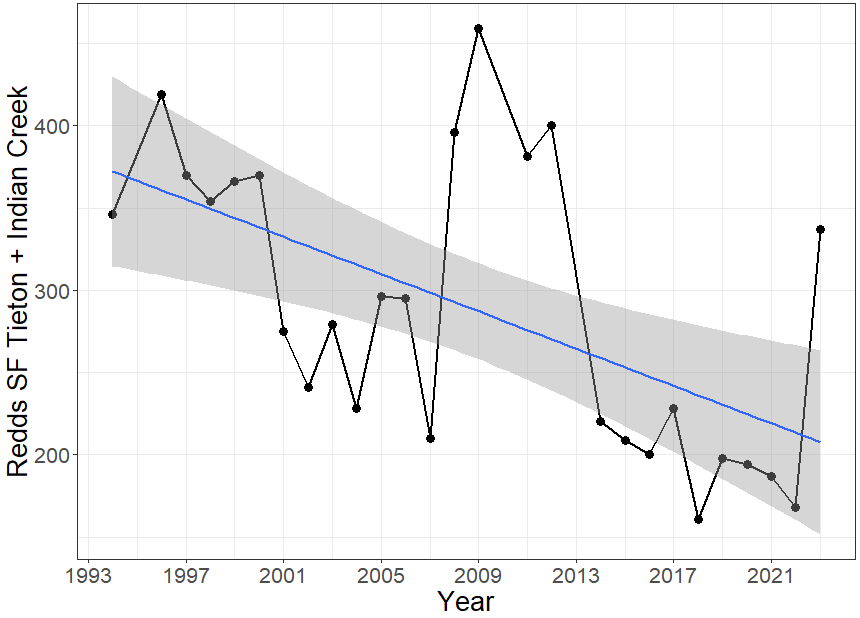


Fig. 2: Sum of redd counts in South Fork Tieton River and Indian Creek from 1994 to 2023. Line is a linear regression against year, and its 95% confidence interval. Incomplete survey years are excluded.

*Association of Redd Counts with Rimrock Drawdown in Previous Years*

After model selection, our final model includes only *rim\_1* as a predictor of *redd\_residuals* data. There is a significant correlation between detrended redd counts in South Fork Tieton River and Indian Creek (*redd\_residuals)* and the extent of drawdown at Rimrock Lake the previous year (*rim\_1*) (t-test, p-value = 0.0299, Fig. 3). This result suggests that deep drawdowns are associated with a loss of redds the following year, greater than the overall trend towards decline. The final model predicts a loss of 34 redds following a drawdown to 30,000 acre-feet. This predicted loss of redds is in addition to the overall trend towards decline.

We focused on the 30,000 acre feet cutoff based on the previous recommendation by the Yakima SOAC to maintain Rimrock Lake above this level. However, it is not clear if 30,000 acre-feet represents a sharp inflection point in the relationship between *rim\_1* and *redd\_residuals*. For example, in eight of the nine years when Rimrock Lake was drafted below 50,000 acre feet, fewer redds were observed the following year than predicted from the annual trend.

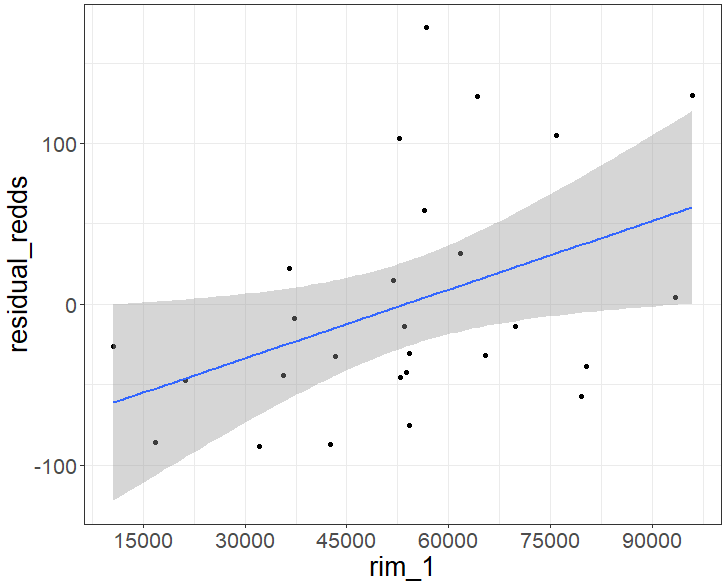


Fig. 3: Minimum annual water storage in Rimrock Lake one year prior (*rim\_1*) *vs.* *redd\_residuals*. Line is a linear model (p-value = 0.0299) and its 95% confidence interval. *Redd\_residuals* are residuals from a linear regression of redd counts *vs.* year from 1994 to 2023 in Indian Creek and South Fork Tieton River.

*Other Factors Potentially Driving Relationship*

A decline in bull trout redd counts following deep drawdowns may be due to entrainment, impacts to prey base, loss of connectivity between reservoir and stream habitats, changes in water quality, or some combination of these factors. We predicted that if impacts were mediated primarily through the bull trout prey base, we would only observe declines in redds multiple years later. However, we did not find that minimum annual reservoir water storage (acre-feet) in Rimrock Lake two and three years prior improved the fit to the data (p-values = 0.73 and 0.39, respectively, likelihood ratio test). This finding suggests that direct impacts to bull trout are primarily responsible for the association between drawdown depth and redd counts the following year.

Alternatively, this association may be driven by a correlation between environmental factors that simultaneously reduce redd counts and create the need for deeper drawdowns. In attempt to parse these causal pathways, we also fit a general model of redd count residuals using two explanatory variables: *rim\_1* and snow pack, estimated as snow water equivalent at White Pass on April 1st *(swe*). Not surprisingly, *rim\_1* and *swe* were correlated (r = 0.49). However, the variance inflation factor was low (VIF = 1.31), indicating indicating that despite correlation, there is sufficient information in the dataset to parse their individual effects on *redd\_residuals*. We found that the *rim\_1* (p-value = 0.021, likelihood ratio test) and not snow pack (p = 0.50, likelihood ratio test) improved the fit to the data.

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