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Technical Report Overview

Report: 2020 Calcite Effects to Spawning Habitat Suitability of Westslope Cutthroat Trout

Overview: This report provides results from further investigations into the relationship between calcite and fish incubation conditions. The 2020 study focused on calcite conditions and Westslope Cutthroat Trout habitat in locations distributed throughout the Elk Valley Watershed.

This report was prepared for Teck by Ecofish Research Ltd.

For More Information
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Teck Coal Ltd

2020 Calcite Effects to Spawning Habitat Suitability of Westslope Cutthroat Trout

Prepared for:

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EXECUTIVE SUMMARY

Teck Coal Limited (Teck) operates five steelmaking coal mines in the Elk River watershed in south-eastern British Columbia. Calcite formation has been observed in the tributaries both upstream and downstream of Teck mining activities, at some locations in the Fording River and, to a lesser extent, in the Elk River and in reference streams unaffected by mining. There are concerns that high levels of calcite may have an effect on Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*) and other biota.

In the Elk Valley Water Quality Plan (EVWQP), Teck committed to continuing a program of monitoring and management for calcite with the objective of understanding potential effects and managing mine-related calcite formation. In November of 2014, the BC Ministry of Environment and Climate Change Strategy (ENV) approved the EVWQP and issued Permit 107517, which included requirements related to calcite management and monitoring, monitoring of potential effects to aquatic ecosystems and implementation of a Water Quality Adaptive Management Plan (AMP). The AMP supports continuous improvement in understanding water quality and ecological conditions including an evaluation of the effect of calcite on aquatic ecosystem condition, focusing on periphyton, benthic invertebrates, and fish. This study helps address Management Question 4 from the AMP, which states: "*Is calcite being managed effectively to meet site performance objectives and to protect the aquatic ecosystem*?". The study specifically supports the reduction in Key Uncertainty 4.1 "*Are the calcite site performance objectives (SPOs) protective of fish and aquatic life?*" The SPOs for calcite under Permit 107517 include a short term SPO that comes into effect in 2024 of calcite concretion (CI_{conc}) < 0.5 and a long term SPO which comes into effect in 2029 of Calcite Index (CI_{total}) < 0.5. The initial CI_{conc} and the CI_{total} SPOs in Permit 107517 were developed using professional judgment of what was considered to be protective for aquatic ecosystem condition based on the information available at the time.

The purpose of this study is to assess potential effects of calcite on Westslope Cutthroat Trout (WCT) spawning suitability. The basic premise is that calcite accumulation on a streambed may influence the suitability of WCT spawning habitat, and thereby the carrying capacity of fish habitat. The study design in 2020 built on the outcomes of previous studies in the upper Fording River watershed, including the first two years of this study effects of calcite to spawning habitat suitability carried out in 2018 and 2019 (Hocking *et al.* 2019; 2020), as well as studies implemented in 2016 and 2017 that measured hyporheic flow and dissolved oxygen over a range of sites with varying levels of calcite (Wright *et al.* 2017; 2018). Studies in 2016 and 2017 did not find a strong effect of calcite on incubation conditions, and rather suggested that the more important effect of calcite to fish is likely to be related to spawning substrate suitability.

The sampling design was expanded in 2020 to include 19 tributary streams across the Elk River valley, which included intensive sampling of all mesohabitat units within ~ 1 km reaches in each stream that were accessible to WCT spawners (e.g., each riffle, pool, glide mesohabitat). The objective of the

current study was to develop a suitability curve between stream bed calcite and spawning habitat suitability for WCT including a statistical model to test the following research hypothesis:

$H_0$2 (null): Observed calcite conditions on stream substrates have no effect on suitability of WCT spawning habitat.

H_A2 (alternate): Observed calcite conditions on stream substrates have an effect on suitability of WCT spawning habitat.

This study measured the presence and abundance of WCT redds, calcite, and other fish habitat data (e.g., substrate composition, water quality, mesohabitat type and structure) at the mesohabitat scale. Results were used to model relationships between calcite and spawning use to ultimately develop a spawning habitat suitability curve with calcite, taking into consideration other components of fish habitat (i.e., covariates). Accounting for fish habitat variables in addition to calcite provided greater confidence in the assessment of calcite effects than a simpler model and provided a broader understanding of spawning habitat suitability across a range of fish habitat conditions in the Elk Valley. The program was applied to WCT because they are the most abundant fish species in most mine-affected stream habitats in the Elk Valley with higher levels of calcite, and because of their small body size relative to Bull Trout (*Salvelinus confluentus*) would make them potentially more sensitive than Bull Trout to the calcification of spawning habitat.

Fieldwork was conducted between May and September 2020 in all five streams sampled in both 2018 and 2019 (Lower Greenhills, LCO Dry, Clode, Fish Pond and Henretta Creeks) from the upper Fording River watershed as well as 11 of the 12 additional streams sampled in 2019 from throughout the Elk Valley. These streams included streams with moderate to high levels of calcite (Upper Greenhills, Corbin, Thompson, Michel, EVO Dry, and Harmer creeks) or as reference streams with generally lower calcite (Alexander, Grace, McCool, Lizard creeks and upper Grave creeks). New streams in 2020 included a reach in segment S8 from the Upper Fording River mainstem (mine-affected) and reaches in Line Creek (mine-affected) and South Line Creek (reference stream).

Redd surveys

A minimum of two WCT redd surveys were conducted on each stream between May 28 and July 19, 2020. A total of 88 WCT redds were observed in 16 of the 19 streams surveyed in 2020; no redds were observed in Alexander, Henretta and South Line creeks. The largest number of redds in 2020 was observed in Lizard Creek (31 redds, 35.2 % of all redds), Fish Pond Creek (12 redds, 13.6 % of all redds), and LCO Dry Creek (8 redds, 9.1 % of all redds). Most mesohabitats surveyed in 2020 did not have redd presence (n = 701, 93.2 % of observations). Two response variables were calculated from the redd survey data: the number of redds per mesohabitat unit, and the presence (1) or absence (0) of redds within a mesohabitat unit.

Average WCT redd counts by mesohabitat unit across all streams surveyed were generally lower in 2020 than in 2019, possibly due to higher flows and lower temperatures during the redd surveys in many streams, and broad-based declines in WCT that have been observed throughout the Elk Valley.

Calcite Index

Calcite levels on the streambed were quantified using the CI. Calcite surveys were conducted using Teck's CI measurement protocol to provide a CI (CI = CI_{Total}), calcite presence (CI_{Pres}) and calcite concretion (CI_{Conc}) score for each mesohabitat unit within sampled reaches. The design and sample size of the calcite data collection for this project was modified from Teck's current CI protocol. All mesohabitat units within ~1 km reaches in 19 streams were sampled, yielding a total of 752 mesohabitat units sampled in 2020. Consistent with methodology for 2019, 30 pebbles were sampled per mesohabitat unit. The total number of pebbles sampled per stream averaged 1,312 ± 459 (±SD) for a total of 22,496 pebbles sampled in 2020, 3% less than the 23,222 pebbles sampled in 2019 and 163% more than the 8,548 pebbles sampled in 2018.

CI varied spatially within and among streams of the study area across the total of 1,581 mesohabitat units (901 independent units) sampled over 2018 to 2020 in 20 tributary streams of the Elk River watershed. The range of CI observed has increased across the three-year program and now includes mesohabitats across the full range of CI (CI range of 0 to 3). The majority of the mesohabitats sampled occur at low levels of CI (CI < 1) at calcite concretion scores of 0 to 0.01. Highly concreted mesohabitats are fairly well represented with 200 mesohabitat units sampled with concretion scores between 1 and 2 (i.e., CI between roughly 2 and 3). However, only 137 mesohabitat units have been sampled across all three years that have low to moderate concretion between 0.01 and 1, which roughly overlaps with moderate CI scores of 1 to 2.

The highest calcite presence, calcite concretion, and CI were observed in Upper Greenhills, EVO Dry Creek, and Corbin Creek in 2020. Moderate to low levels of concretion (mean concretion of ≤0.6) was observed in Clode Creek (0.59), Lower Greenhills Creek (0.32), McCool Creek (0.02), Harmer Creek (0.01) and Grace Creek (0.01). Trace levels of concretion were observed in LCO Dry Creek, Lizard Creek, Michel Creek, Fording River S8, and Fish Pond Creek with average concretion values lower than 0.01. Zero concretion was observed in Upper Grave Creek, Henretta Creek, Alexander Creek, Thompson Creek, Line Creek, and South Line Creek.

Moderate calcite presence (mean presence >0.5) was observed in three streams where zero or trace levels of calcite concretion was recorded. These streams included Thompson Creek (mean CI_{pres}=0.74), Fish Pond Creek (CI_{pres}=0.66), and Line Creek (CI_{pres}=0.60). In 2019, two reference streams, Lizard and McCool Creeks, where no mining developments exist upstream, showed moderate to high calcite presence values (means of CI_{pre}=0.58 and CI_{pres}=0.83, respectively). However, in 2020, the CI_{pres} mean values observed for these two creeks was 0.31 for Lizard Creek and 0.20 for McCool Creek, suggesting a decrease in calcite presence levels in 2020 compared to 2019.

Fish Habitat

A Level 1 Fish Habitat Assessment Procedure (FHAP) was used to quantify fish habitat in all study streams. Fish habitat data included streamflow, velocity, depth, bankfull and wetted width, substrate, cover, functional large woody debris (LWD) tally, spawning gravel quantity, mesohabitat area, temperature during spawning, and water quality. Mesohabitat unit types were classified as pools, glides, runs, riffles, cascades, chutes, and falls according to definitions in Johnston and Slaney (1996).

Calcite is one of many influences on fish and fish habitat, and these other influences (e.g., substrate type, cover, gradient, water quality) need to be considered as potential covariates. Initial data exploration of explanatory variables used to predict redd presence and counts was carried out following the protocol of Zuur *et al.* (2010). Data exploration revealed collinearity among fish habitat variables. The final set of explanatory variables included CI, calcite presence, calcite concretion, mean velocity, proportion spawning gravel area, bankfull depth, functional LWD, water temperature, conductivity, and pH. In addition, mesohabitat unit area was included as a predictor to account for sampling effort. All of these fish habitat variables are hypothesized to affect spawning suitability.

Modelling of Redd Presence and Redd Counts

In 2020, the effects of calcite on redd presence and counts were tested and validated using several statistical modelling approaches that vary from simpler to more complex. This was completed to increase the confidence in the results observed and to account for the hierarchical structure of the dataset, the importance of fish-habitat covariates, the high numbers of mesohabitats with zero redds, potential interactions and non-linear relationships among the predictor variables, and the binomial and count-based distributions of the response variables. All analyses were conducted using the R Statistical Language (R Core Team 2018) and included the following:

- Univariate analyses to test the individual effects of CI, calcite concretion, and calcite presence on the likelihood of redd presence and redd counts.
- Generalized linear mixed effects (GLMM) model selection analyses to test the combined effects of calcite and fish-habitat variables on WCT redd presence and counts, including analyses across all streams, mine-influenced streams, and reference streams.
- Generalized additive mixed effects (GAMM) model selection analysis to account for potential non-linear relationships between calcite, fish-habitat variables, and WCT redd presence and counts.
- Model selection analysis on the 95th quantile of redd counts to assess effects of calcite and fish-habitat variables on high counts of redds.
- Boosted regression tree (BRT) analysis to test of the effects of calcite and fish-habitat variables on redd presence and counts within streams while accounting for potential interactions.

WCT spawning suitability response curves with calcite concretion were generated and compared across five of the different modelling approaches. The BRT analysis focused on predictions of effects of habitat variables within streams. Further work in 2021 and 2022 with 2021 data will remove stream from the model to test the ability of an expanded set of habitat variables to predict redds within and among streams.

Results

Based on mixed-model analysis performed herein, calcite concretion was one of the most important variables to describe variance in redd presence, mean redd count, and the 95th quantile of redd counts. Calcite concretion outcompeted CI in explaining redd presence and redd counts across all-streams and mine-influenced streams. The influence of calcite concretion on redd presence and counts was negative and the five spawning habitat suitability curves for WCT decreased exponentially with increasing levels of calcite concretion. An approximately 50% decline in WCT spawning suitability was observed at a calcite concretion score of 0.5, which is less steep than the result observed in 2019. BRT similarly found declines in suitability with increases in calcite concretion beyond values of 0.5, but the extent and shape of the decline differed. The extent of was not as large with an estimated 10% decline in presence and 38% decline in counts beyond this range. Further, most of the decline was after 0.5 – 0.7 concretion values and appeared as more of a threshold response rather than an exponential decline. In low-to-medium concretion streams the relative influence of calcite concretion was also much lower than other covariates, which differed from the mixed model approaches.

A new and important result for this year was an observed positive relationship between calcite presence and both redd presence and redd counts. The univariate analysis describes a non-linear relationship between calcite presence and WCT redds, with a peak in redd presence and counts at a calcite presence score of 0.70 to 0.75, which is often around the value where concretion begins to occur. The GLMM, GAMM, and BRT models that analyzed both calcite presence and concretion in the same models found a positive relationship with calcite presence and a negative relationship with calcite concretion. The mechanism underlying the positive relationship with calcite presence is somewhat unclear but potentially represents a benthic productivity gradient driven by inputs of nutrients and higher stream temperatures. There is no current hypothesis that would explain why increases in calcite presence would directly increase spawning suitability. However, calcite presence is likely to be correlated with another variable such as increased nutrients and higher water temperatures, which increase the productivity of the system and overall fish biomass. For example, one of the best predictors of redd presence and counts in reference streams was stream conductivity, which is positively correlated to calcite presence and has been found to be an indicator of nutrient inputs to streams and increased fish production. Further work is required to better understand the linkage between increased calcite presence and WCT production, but current data suggest that increases in calcite presence may be an indicator of higher WCT production up to the point that calcite concretion begins to occur.

Some habitat variables were found to positively influence WCT spawning. Habitat availability, both mesohabitat area and the proportion of spawning gravel area had a strong positive influence on the likelihood of redd presence and redd counts (including the 95th quantile) across all methods. Water temperature during spawning was also found to positively influence the mean and the 95th quantile of redd counts. The non-linear GAMM models also indicated a non-linear relationship with temperature during spawning with a peak in redd counts at 11-12 ºC. Another important variable observed to have a strong non-linear association with both redd presence and redd counts was water velocity. Peak redd presence and counts occurred in water velocities of ~0.25 to 0.6 m/s, which aligns with the observation of redds being more common in glides, runs, and riffles, less common in pools, and rarely found in chutes and cascades. The BRT analysis also suggested a non-linear relationship with bankfull width and redds were more common for units with values between 4 and 12 m. Response curves were generated for these variables with the presence and counts of redds, which could be applied to WCT spawning habitat remediation in the Elk Valley.

Overall, the results suggest that the null hypothesis $H_0 2$ should be rejected in favour of the alternate hypothesis $H_A 2$. The convergence of the effect of calcite concretion across models and when models were discretized into all-streams and mine-influenced streams analyses, provided a substantial weight of evidence for an effect of calcite concretion on redd presence and counts. However, it is important to note that the confidence interval surrounding the predicted effect size is high, which leads to uncertainty in the mean predicted slope of the draft spawning suitability curves, and some uncertainty in the effects prediction at low to moderate values of calcite concretion. In addition, the BRT analysis found that calcite concretion was not always a strong predictor for redd presence and counts within streams and that the effect of concretion is most pronounced above a calcite concretion score of 0.5. So, while we are confident that the slope between redd presence and redd counts with calcite concretion is negative, we are not yet confident in the magnitude of effect at specific calcite concretion values to help determine whether the SPOs are protective of fish and aquatic life.

Conclusion

A range of linear and non-linear statistical approaches were applied to a three-year dataset to test if calcite conditions influence spawning habitat suitability for WCT in tributaries streams of the Elk River, B.C. Relationships between calcite and WCT redd presence and redd counts were used to develop a draft WCT spawning suitability response curve for calcite that may be applied to calcite management in the Elk Valley.

Overall, based on the streams sampled across all years, redd presence and counts are negatively influenced by calcite concretion; few redds were observed in Erickson Creek, EVO Dry Creek, Corbin Creek, Upper Greenhills Creek, Lower Greenhills Creek, and Clode Creek where high levels of concretion were observed. In contrast, a broad range of redd counts (low to high) were observed in both mine-affected and reference streams with moderate to high calcite presence ($CI_{Pres} > 0.5$) but limited to no concretion. In all models, calcite concretion and calcite presence outcompeted CI in explaining redd presence and counts, with a negative relationship observed with calcite concretion and a positive relationship observed with calcite presence. This result suggests that calcite presence and concretion differ in their functional relationship with the probability of presence and count of WCT redds. CI is a composite of calcite presence and calcite concretion, and these two components of the calcite index could thus be used differently for calcite management in the Elk Valley. Further work is required to better understand the linkage between increased calcite presence and WCT production, but current data suggest that increases in calcite presence may be an indicator of higher stream productivity and higher WCT production up to the point that calcite concretion begins to occur.

While the results presented here indicate a response relationship that is similar but less steep with reduced confidence intervals than those presented in 2018 and 2019 (Hocking *et al*. 2019; 2020), there remains uncertainty in the spawning suitability curves based on the broad confidence intervals. The BRT analysis found less of a steep relationship between calcite and redds and found other predictors to be more influential in streams with low-to-moderate levels of calcite. The different results between the GLMMs and GAMMs and the BRT approach is possibly driven by the structure of the BRT models, which allows for the influence of concretion, and other variables to vary by stream. A substantial amount of the variation in redd presence and counts is observed among streams and further analyses aimed at explaining these larger-scale differences could lead to greater overall insight into the influence of variables across streams. Additional field work and analysis would be required to reduce uncertainties in the results presented and to improve the predictive ability of the spawning suitability response curves, particularly at low to moderate levels of concretion. At this time, the 2021 work is advancing, which will focus on expanding surveys in areas with low to moderate calcite concretion. Additional analyses in 2021 and 2022 will also focus on confirming the drivers of redd presence and abundance across streams and WCT populations.

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1. INTRODUCTION

Teck Coal Limited (Teck) operates five steelmaking coal mines in the Elk River watershed in south-eastern British Columbia. Calcite formation has been observed in the tributaries downstream of Teck mining activities, at some locations in the Fording River and, to a lesser extent, in the Elk River and in reference streams unaffected by mining. Calcite is created by the reaction between dissolved calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions under conditions that occur naturally but can be enhanced when water passes through waste rock from mining. A number of seasonal factors can contribute to the precipitation or dissolution of calcite, including physical forces (e.g., scouring of the substrate during high flow periods) and water chemistry (water temperature, pH, composition of dissolved ions and minerals); therefore, timing and location of calcite formation can be challenging to predict (Minnow Environmental 2016a,b; Hocking *et al.* 2021).

In the Elk River watershed, there are wide ranges in the spatial extent and degree of calcite cover. Calcite cover ranges from areas with minimal calcite formation to areas in certain streams where calcite precipitation can completely cover portions of the stream bed, making the gravels largely immovable (Smithson *et al.* 2019). There are concerns that high levels of calcite may have effects on Westslope Cutthroat Trout (WCT) (*Oncorhynchus clarkii lewisi*) and other biota.

In the Elk Valley Water Quality Plan (EVWQP), Teck committed to continuing a program of monitoring and management for calcite. The objective of the program is to understand and manage mine-related calcite formation so that streambed substrates in the Elk and Fording rivers and their tributaries can support abundant and diverse communities of aquatic plants, benthic invertebrates, and fish comparable to those in reference areas (Teck 2014). Teck's requirements for monitoring biological effects as part of its Regional Aquatic Effects Monitoring Program (RAEMP) include:

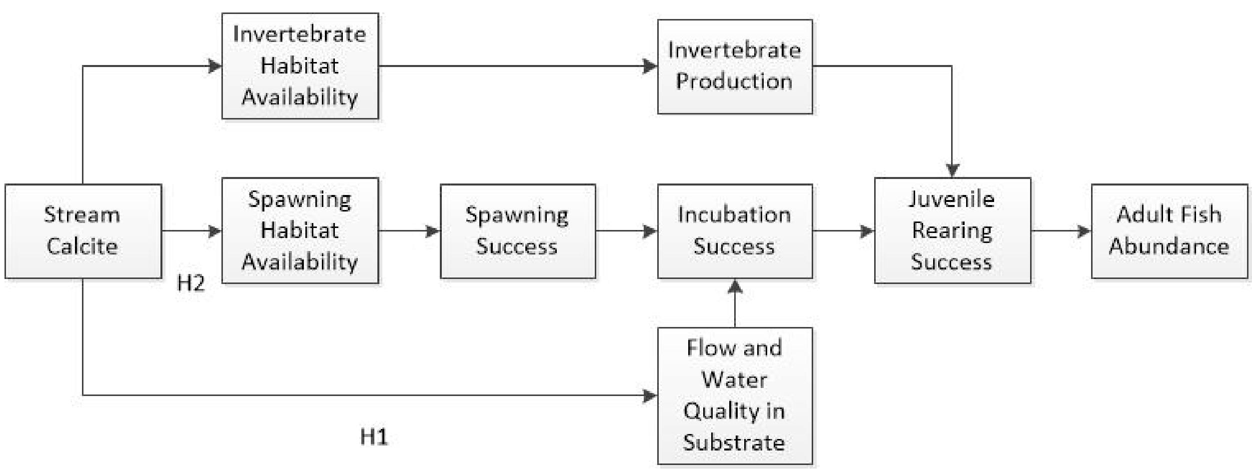
> "*Teck shall complete the assessment to determine the potential relationships between calcite and benthic invertebrate community structure, periphyton productivity and fish spawning and incubation success. Teck shall work in collaboration with the Ministry and Ktunaxa Nation representatives ideally in a monitoring committee forum to prepare study designs for work proposed in 2015 and 2016.*"

This study addresses the "fish spawning and incubation success" aspects of the RAEMP requirements described above by furthering assessment of potential calcite effects on spawning and incubation habitat. The study design builds on the outcomes of the calcite effects study in 2018 and 2019 (Hocking *et al.* 2019; 2020), and of previous studies in the Elk Valley, including studies implemented in 2016 and 2017 that measured hyporheic flow and dissolved oxygen over a range of sites in the upper Fording watershed with varying levels of calcite (Wright *et al.* 2017; 2018) and ongoing biological programs being undertaken by Teck. The basic premise of the study is that calcite accumulation on a streambed may influence the suitability of WCT spawning habitat and incubation habitat, and thereby the carrying capacity of fish habitat. The effects of calcite on spawning and incubation habitat are hypothesized links in effect pathways linking calcite to fish production (Figure 1).

The objective of this study is to further test the link between streambed calcite and spawning habitat availability for WCT (i.e., impact hypothesis H2 in Figure 1) and represents Year 3 of the program focused on potential effects of calcite to WCT spawning suitability. Note that studies in 2016 and 2017 focused on impact hypothesis H1 related to the effects of calcite on incubation conditions including flow and water quality in the substrate (Wright *et al.* 2017; 2018).

This study also helps address Management Question 4 from the Water Quality Adaptive Management Plan (Teck 2018), which states: "*Is calcite being managed effectively to meet site performance objectives and to protect the aquatic ecosystem*?". The study specifically supports the reduction in Key Uncertainty 4.1 "*Are the calcite site performance objectives (SPOs) protective of fish and aquatic life?*". The SPOs for calcite under Permit 107517 include a short term SPO that comes into effect in 2024 of calcite concretion (CI_{conc}) < 0.5 and a long term SPO that comes into effect in 2029 of Calcite Index (CI_{total}) < 0.5. The initial CI_{conc} and the CI_{total} SPOs in Permit 107517 were developed using professional judgment of what was considered to be protective for aquatic ecosystem condition based on the information available at the time.

Figure 1. Effect pathway diagram linking calcite on the streambed to fish production.



1.1. <u>Study Questions and Hypotheses</u>

The calcite effects on fish habitat study aims to address the following three study questions:

1. To what extent does calcite influence incubation conditions within the shallow hyporheic zone?
2. What is the response relationship between calcite and spawning habitat suitability in Elk Valley tributaries affected by Teck operations?
3. What is the status of spawning habitat as affected by calcite in Elk Valley tributaries?

In addressing the questions, the calcite effects on fish habitat study is designed to test the following two research hypotheses, which include null and alternate hypotheses:

$H_0$1 (null): Observed calcite conditions on stream substrates have no effect on hyporheic flow and dissolved oxygen.

H_A1 (alternate): Observed calcite conditions on stream substrates have a negative effect on hyporheic flow and dissolved oxygen.

$H_0$2 (null): Observed calcite conditions on stream substrates have no effect on suitability of WCT spawning habitat.

H_A2 (alternate): Observed calcite conditions on stream substrates have a negative effect on suitability of WCT spawning habitat.

Habitat use by WCT is well known in the Elk River and the upper Fording River, and their respective tributaries, which aided development of the study design and selection of study sites (Russell and Oliver 1996; Windward Environmental *et al.* 2014; Cope *et al.* 2016; Minnow Environmental 2016b; Lamson 2018; Hocking *et al.* 2019; Robinson, pers. comm. 2019). Research hypotheses were tested by empirically assessing incubation conditions and spawner use in tributaries to Elk and Fording Rivers. As discussed at the EMC#12 meeting[1], some aspects of the study questions may have to be addressed over multiple years, as conditions allow for adequate sampling. Study question #1 and hypothesis H1 were addressed in earlier research reports (Wright *et al.* 2017; 2018). The present study focuses on study question #2 and hypothesis H2; and builds upon findings and recommendations from the Year 1 and Year 2 spawning suitability reports (Hocking *et al.* 2019; 2020).

Several key recommendations from the Year 1 spawning suitability report (Hocking *et al.* 2019) were implemented in the 2019 study. This includes expansion of field effort to include twelve more streams, specifically targeting streams with moderate to high levels of calcite. Including additional streams for 2019 with higher calcite was also confirmed as a priority during the January 9, 2019 EMC meeting[2]. Second, the addition of reference streams was identified as a key priority to understand the natural range of spawning in the absence of mining and to better interpret spawning suitability relationships with other measured fish habitat variables.

The Year 2 study concluded that redd presence and counts are negatively influenced by calcite concretion (Hocking *et al.* 2020). In all models from Year 2, calcite concretion outcompeted CI in explaining redd presence or counts, which led to the conclusion that concretion is a better measure of spawning suitability than CI. However, the study recommended that additional field work and analysis were required to reduce uncertainties in the results presented and to improve the predictive ability of the spawning suitability response curves, particularly at low to moderate levels of calcite concretion.

[1] EMC#12 meeting, 26 April 2017, Cranbrook, BC.

[2] EMC meeting, 9 January 2019, Cranbrook, BC.

Therefore, three new streams were added to support the 2020 field study for a total of 19 streams sampled in 2020, and 20 across all years.

2. METHODS

2.1. Study Area

The study was conducted in tributaries of the Elk and Fording rivers, located in the East Kootenay region of south-eastern British Columbia. The Fording River is itself a tributary to the Elk River. Study sites were selected to represent tributary spawning habitats used by WCT. The focus continues to be on tributary rather than mainstem habitats, however, mainstem habitats of the upper Fording River were included in the study in 2020.

Data collection in 2020 was carried out in all five streams sampled in both 2018 and 2019 (Lower Greenhills, LCO Dry, Clode, Fish Pond, and Henretta Creeks) from the upper Fording River watershed as well as 11 of the 12 additional streams sampled in 2019 from throughout the Elk Valley. These streams included streams with moderate to high levels of calcite (Upper Greenhills, Corbin, Thompson, Michel, EVO Dry, and Harmer creeks) or as reference streams with generally lower CI (Alexander, Grace, McCool, Lizard creeks and upper Grave creeks) (Map 1, Map 2). New streams in 2020 included a reach in segment S8 from the Upper Fording River mainstem (mine-affected) and reaches in Line Creek (mine-affected), and South Line Creek (reference stream) (Map 1, Map 2). The Upper Fording River S8 and Line Creek reaches were added because they are additional stream areas used by WCT to spawn (e.g., Windward Environmental *et al.* 2014; Cope *et al.* 2016) and were thought to have low levels of calcite concretion as observed in the Regional Calcite Monitoring Program (McCabe and Robinson 2020). Waypoints and study reach lengths for each stream are shown in Appendix A.

Calcite prevention activities have begun on Lower Greenhills Creek in reach GREE1 (Smithson *et al.* 2019; Teck 2019). Habitat improvements (e.g., pool and spawning habitat creation) are also being completed on Fish Pond and Henretta creeks to improve conditions for WCT (Teck 2016).

The specific watercourses selected have habitats used by WCT for spawning, have a range of calcite scores (i.e., 0 to 3 CI, see definition of CI in Section 2.3.2), and are expected to be representative of streams and WCT spawning conditions throughout the Elk Valley. WCT spawning has been confirmed in various tributaries of the upper Fording watershed (Beswick 2007; Cope *et al.* 2016; Minnow Environmental 2016a; Buchanan *et al.* 2016; Faulkner *et al.* 2018; Hocking *et al.* 2019; 2020). Spawning habitat and redd information for streams in the larger region was acquired from technical reports (Russell and Oliver 1996; Windward Environmental *et al.* 2014; Cope *et al.* 2016; Minnow Environmental 2016b; Lamson 2018) and was also provided by Lotic Environmental (Robinson, pers. comm. 2019). Table 1 summarizes existing fish habitat, calcite, and fish presence/spawning data available for each of these streams prior to 2020 sampling. Spawning was previously confirmed (i.e., redds and/or fry present) in all study streams, except for Corbin Creek.

Table 1. Summary of fish, calcite and habitat information available for study streams prior to 2020 sampling.

Project[1]	Stream Name	Stream Type (Mine Influenced or Reference)	Existing FHAP[2]	Mean CI Score[3]			Existing Redd Surveys[4]	Fish or Redds Observed[5]
				CI_{pres}	CI_{conc}	CI (CI_{pres} + CI_{conc})		
CMO	Corbin Creek	Mine Influenced	2019	0.90	1.15	2.05	Yes	Yes
	Michel Creek	Mine Influenced	2019	0.68	0.00	0.68	Yes	Yes
EVO	Dry Creek (EVO)	Mine Influenced	2019	1.00	0.95	1.95	Yes	Yes
	Upper Grave Creek	Reference	2019	0.05	0.00	0.05	Yes	Yes
	Harmer Creek	Mine Influenced	2019	0.88	0.01	0.89	Yes	Yes
FRO	Clode Creek	Mine Influenced	2018	0.82	0.24	1.06	Yes	Yes
	Fish Pond Creek	Mine Influenced	2018	0.29	0.00	0.29	Yes	Yes
	Henretta Creek	Mine Influenced	2018	0.08	0.00	0.08	Yes	Yes
	Fording River	Mine Influenced	No	-	-	0.20 - 1.09	Yes	Yes
GHO	Lower Greenhills Creek	Mine Influenced	2018	0.47	0.14	0.62	Yes	Yes
	Upper Greenhills Creek	Mine Influenced	2019	0.93	0.85	1.77	Yes	Yes
	Thompson Creek	Mine Influenced	2019	0.70	0.00	0.70	Yes	Yes
LCO	Dry Creek (LCO)	Mine Influenced	2016	0.52	0.00	0.52	Yes	Yes
	Line Creek	Mine Influenced	No	-	-	0.46 - 0.93	Unk.	Unk.
	South Line Creek	Reference	No	-	-	0.08	Unk.	Unk.
SRO	Alexander Creek	Reference	2019	0.12	0.00	0.12	Yes	Yes
	Grace Creek	Reference	2019	0.14	0.00	0.14	Yes	Yes
	Lizard Creek	Reference	2019	0.58	0.00	0.58	Yes	Yes
	McCool Creek	Reference	2019	0.83	0.00	0.83	Yes	Yes

[1] CMO (Coal Mountain Operations, EVO (Elkview Operations), FRO (Fording River Operations), GHO (Greenhills Operations), LCO (Line Creek Operations), SRO (Sparwood Regional Operations).

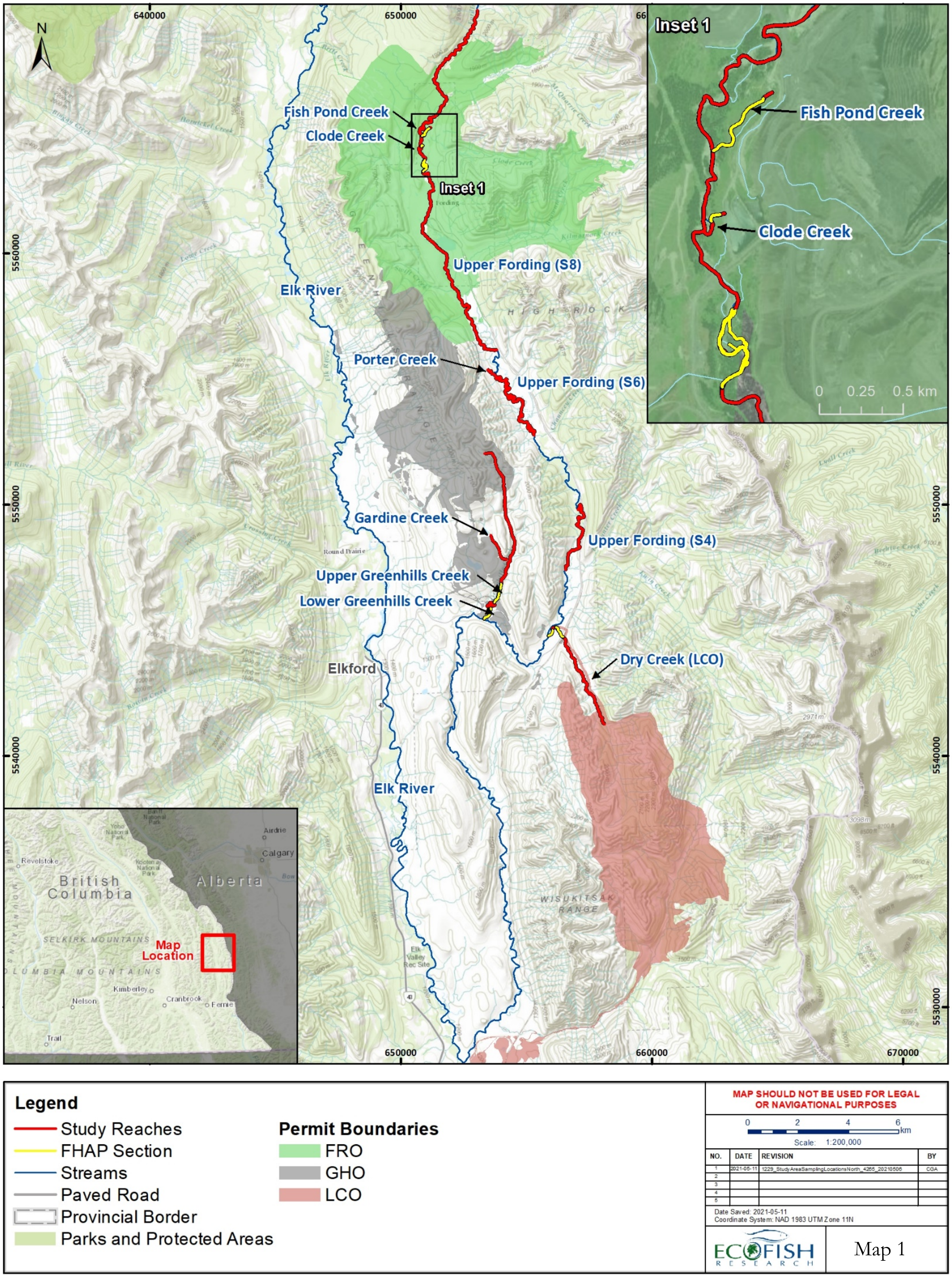
[2] FHAP = Fish Habitat Assessment Procedure

[3] Calcite values reported in Hocking *et al.* 2020. Values for Fording River, Line Creek and South Line Creek collected from Smithson *et al*. 2019. CI_{pres} denotes calcite presence score, CI_{conc} denotes calcite concretion score, CI denotes calcite index.

[4] Includes surveys completed by Ecofish and/or Lotic (Robinson, pers. comm. 2019).

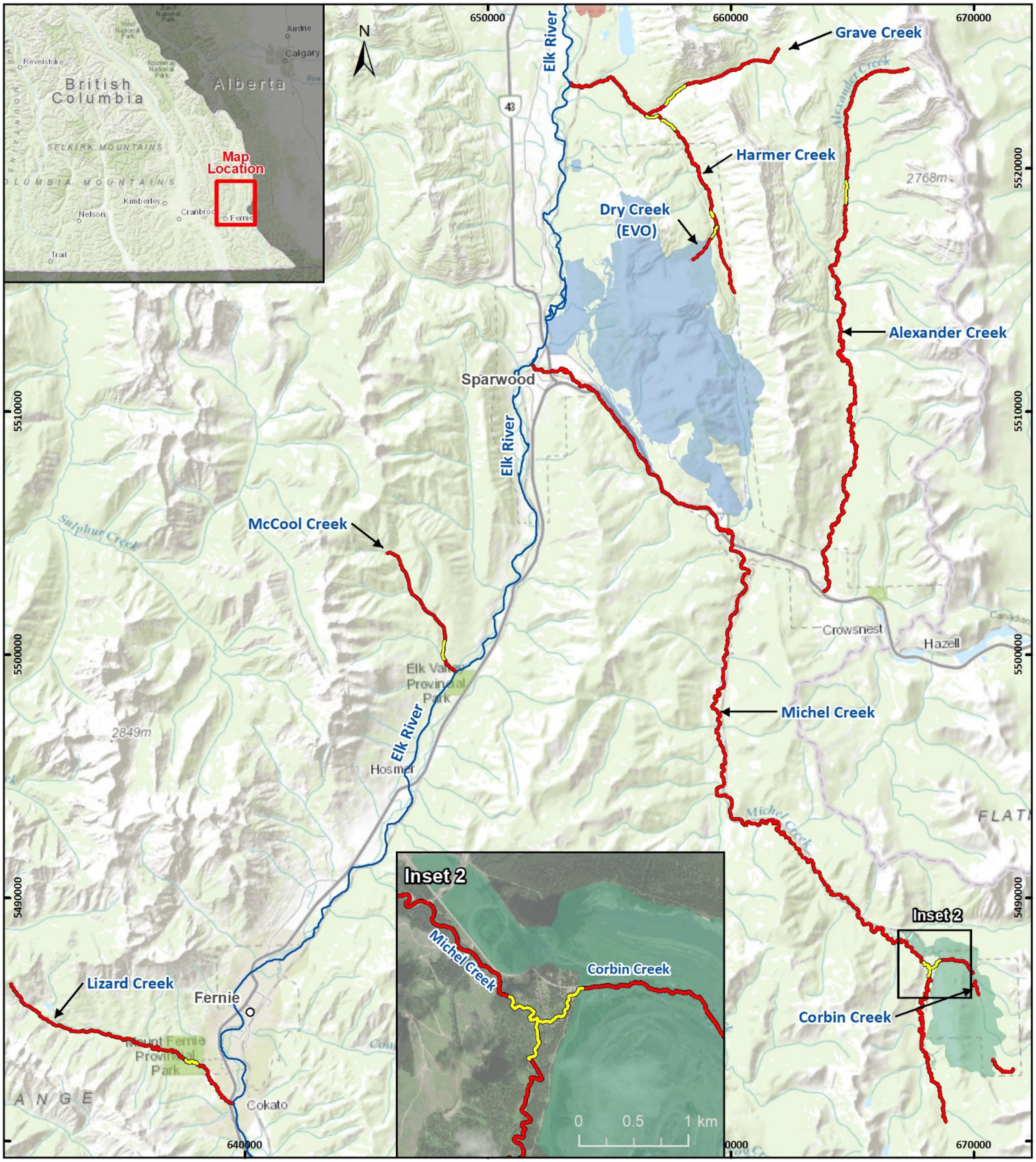
[5] Includes Ecofish, Lotic and Westslope Fisheries surveys and other sources.

Study Area and Sampling Locations North



Path: M:\Projects-Active\1229_EVWQP\MXD\Overview\1229_StudyAreaSamplingLocationsNorth_4265_20210506.mxd

Study Area and Sampling Locations South



Legend

- Community
- Study Streams
- FHAP Section
- Streams
- Paved Road
- Provincial Border
- Parks and Protected Areas

Permit Boundaries

- CMO
- EVO
- LCO

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 2 4 6 km

Scale: 1:225,000

NO.	DATE	REVISION	BY
1	2021-04-20	1229_StudyAreaSamplingLocationsSouth_4224_20210420	CGA
2			
3			
4			
5			

Date Saved: 2021-04-20
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

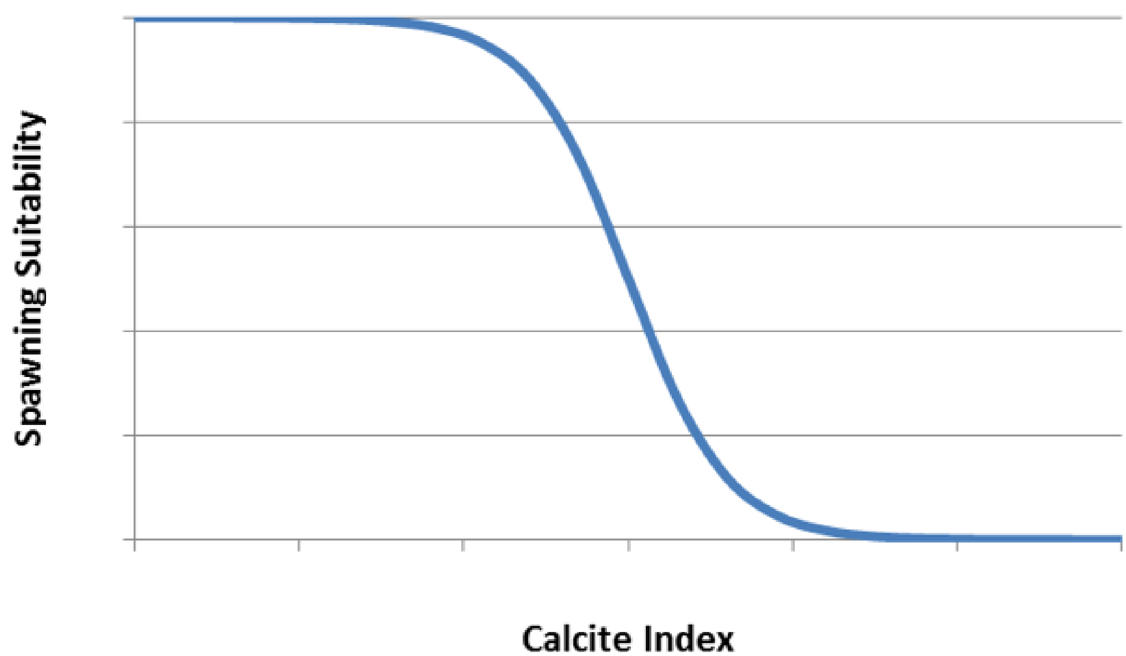
Map 2

Path: M:\Projects-Active\1229_EVWQP\MXD\Overview\1229_StudyAreaSamplingLocationsSouth_4224_20210420.mxd

2.2. Experimental Design

The relationship between calcite and WCT spawning habitat will be referred to here as a response curve (conceptual curve shown in Figure 2), to quantitatively describe the influence of calcite (i.e., one aspect of habitat) on WCT spawning habitat suitability. A response curve can be used in combination with habitat surveys to describe the status of spawning habitat in an area. The two main response variables used to develop the spawning suitability curve were redd presence and redd abundance, measured as counts (# of redds) or density (redds/m^2) in the study tributaries.

Figure 2. Conceptual response curve for calcite as it relates to spawning habitat suitability for Westslope Cutthroat Trout.



There are two fundamental challenges to developing a response curve for calcite, which need to be considered when implementing the WCT spawning suitability study. First, calcite is one of many influences on fish and fish habitat, and these other influences (e.g., substrate type, cover, gradient, water quality) need to be considered as potential covariates. Likewise, it is necessary to assess where fish are spawning as well as where they are not spawning. The approach to this study component can therefore be described as a mensurative experiment because the intent is to undertake measurements across a range of conditions occurring in the watershed, rather than directly manipulating conditions (variables) of interest (Hurlbert 1984). The approach thus attempts to develop a habitat suitability model for WCT that includes the key variable of interest, calcite, but also other potential fish habitat drivers. Other fish habitat predictors assessed in this study include water velocity, temperature, and some measures of water quality during spawning, spawning gravel availability, and stream morphology such as depth, width, and habitat area. A limitation is that likely not all possible drivers of WCT spawning have been able to be measured and included in the presented analyses, such as growing season degree days, which is an important driver of WCT population productivity (Heinle *et al.* 2021).

Second, to build a spawning suitability response curve, the overall experimental design requires that redd data, calcite data and fish habitat data be collected at the same spatial scale. The most appropriate scale for measuring spawning habitat selection by WCT is at the mesohabitat scale (i.e., individual pools, riffles or runs in a given stream reach) (Johnson and Slaney 1996). In the 2018 study, redd sites and a roughly equivalent number of null sites, which are defined as sites without redds, were sampled on each stream, with redd, calcite and fish habitat data collected at the mesohabitat scale in all tributaries (Hocking *et al.* 2019). In 2019 and in 2020, sampling for redds, calcite and fish habitat information was again carried out at the mesohabitat scale. However, rather than selecting a comparable number of null sites to spawning sites, all mesohabitat units were sampled in a roughly 1 km reach per stream (mean = 964 m, range = 172 to 1,758 m). This removed potential bias in null site selection. For each stream, sample reaches were identified using historical redd and/or fry presence data and input from local experts (e.g., Robinson, pers. comm. 2019).

The two main response variables used were redd presence/absence (0, 1) and redd abundance, measured as counts (# redds) or density (redds/m^2) in each mesohabitat unit. Data collected in 2020 was integrated with data collected in 2018 and 2019 (Hocking *et al.* 2020).

2.3. Field Data Collection

Sampling in 2020 included a combination of redd surveys, calcite data collection, spawning gravel assessments, a fish habitat assessment procedure (FHAP), and in situ water quality and velocity sampling in nineteen waterbodies within the Elk Valley and was carried out based on the sampling schedule in Table 2. Assessment of water quality included basic parameters such as conductivity, pH, DO, and temperature during spawning but did not include water quality contaminants such as Selenium.

All 2020 field sampling was performed between May 28 and September 23. This generally included two redd surveys per stream from May to July, initial stream habitat (FHAP) for new sites (Upper Fording River (S8), Line Creek, and South Line Creeks), water quality and water velocity data collection in May, June and July during WCT spawning, and calcite data collection in August and September. The specific dates of field sampling by stream are shown in Appendix A.

Westslope Cutthroat Trout redd data, calcite data and most of the stream habitat data were collected at the mesohabitat scale at each stream (i.e., in individual pool, riffle, run habitat units). Fish habitat and water quality data collected are described in sections 2.3.3 and 2.3.4. Dissolved oxygen (DO) and oxidation reduction potential (ORP) were the only two variables collected solely at the reach scale due to the long field measurement times of the YSI Pro Plus. The average ± SD reach length sampled per stream was 865 ± 303 m, while the average ± SD mesohabitat unit length was 39.6 ± 14.8 m. A total of 752 mesohabitat units were sampled across the 19 streams in 2020 (39.6 ± 15.2 units per stream).

Maps highlighting mesohabitat units and redd locations within each stream are presented in Appendix B. Summaries of habitat, water quality, water velocity, calcite, and WCT redd data are shown in Appendix C for each stream and broken down by habitat type within streams.

Table 2. Summary of field data collection completed for the 2020 calcite study during each sampling trip by stream.

Field Trip	Survey	CMO		EVO			FRO				GHO			LCO			SRO			
		Corbin Creek	Michel Creek	Dry Creek (EVO)	Grave Creek	Harmer Creek	Clode Creek	Fish Pond Creek	Fording River	Henretta Creek	Lower Greenhills Creek	Thompson Creek	Upper Greenhills Creek	Dry Creek (LCO)	Line Creek	South Line Creek	Alexander Creek	Grace Creek	Lizard Creek	Mccool Creek
Trip 1: late May to early July	Delineate mesohabitats (start FHAP)					✓			✓						✓	✓		✓		
	Redd Survey #1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Redd Survey #2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Water Quality and Velocity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Trip 2: Early to mid August	Complete FHAP					✓									✓	✓		✓		
	Spawning Gravel					✓									✓	✓		✓		
	Calcite Index	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Trip 3: Late August and September	Complete FHAP					✓			✓											
	Spawning Gravel					✓			✓											
	Calcite Index				✓	✓	✓	✓		✓										
	Water Quality and Velocity					✓														

Redd surveys include surveys completed by Westslope Fisheries (Dry (EVO and LCO), Grave, Harmer, Clode, Fish Pond, Lower Greenhills creeks and Fording River)
Sampling completed on Harmer Creek in September to expand study area.

2.3.1. Redd Surveys

A minimum of two WCT redd surveys were conducted on each stream between May 28 and July 19 (Appendix A). Redd surveys were completed over a large geographic area and the timing of spawning varied among streams. Spawn surveys were generally completed earlier in warmer lower elevation streams (e.g., Lizard, McCool, and Thompson creeks) and later in cooler higher elevation streams (e.g., Upper Fording River and tributaries). Prior to undertaking the redd surveys, available information on weather, flows, turbidity, and WCT spawn timing were reviewed to maximize the likelihood of observing redds. Field reconnaissance trips were also undertaken in late May and early June to confirm whether spawning had commenced and that conditions were suitable to initiate surveys across all streams. Redd survey dates were adjusted based on observed fish/redds and stream conditions, particularly high flows, which can inhibit observations of redds.

The redd surveys were conducted as bank walk counts during which two surveyors walked slowly and methodically along opposite banks in an upstream direction to maintain water visibility and minimize flushing fish prior to observation. Efforts were made to flush holding fish out from under cover such as undercut banks, large woody debris, and heavily aerated riffles/chutes. Observed fish were counted and assigned to one of four size bins: 0-70 mm (fry), 71-150 mm (1+ and 2+ parr), 151-200 mm (sub-adults or small adults), and ≥201 mm (adults). All fish counted during these surveys ≥150 mm in fork length were conservatively considered to be potential spawners based on observations of fish on or near redds during the surveys. During each survey, the presence of redds, habitat unit type, and water quality data (i.e., water temperature and visibility) were recorded. Additional water quality and velocity data were collected during redd surveys as described in Section 2.3.4. Redds were identified as recent, clean excavations in gravel substrates. All redds were recorded by fish biologists with extensive redd survey experience. Test redds, identified as partial or incomplete excavations, were recorded on datasheets but excluded from analyses. Water clarity was assessed using a measuring stick in each mesohabitat unit. GPS coordinates were recorded for each redd, and the site was flagged for subsequent habitat surveys (see sections below on methods for calcite (2.3.2) and habitat (2.3.3) surveys). Two response variables were calculated from the redd survey data: the count of redds per mesohabitat unit, and the presence (1) or absence (0) of redds within a mesohabitat unit.

Redd survey observation and sample dates are presented in Appendix A. Maps of each stream showing the mesohabitat units and redd observations are presented in Appendix B.

2.3.2. Calcite Index

Calcite surveys were conducted using Teck's calcite index measurement protocol (Robinson and MacDonald 2014, Minnow Environmental 2016, Robinson *et al.* 2016, McCabe and Robinson 2020) to provide a CI score for each mesohabitat unit within sampling reaches. The surveys were carried out from July 30 to September 15 in all study streams (Appendix A).

While the methods of calcite data collection were generally the same, the design and sample size of the calcite data collection for this project differs slightly from Teck's current CI measurement protocol. The current Regional Calcite Monitoring Program measures CI in reaches of 100 m in length, which includes observations of CI on 100 pebbles per stream site with 1-6 sites per reach (McCabe and Robinson 2020). In comparison, the ~1 km reaches per stream sampled in this study had up to 164 mesohabitat units to be sampled. Representative calcite data were desired for each mesohabitat unit to provide an indication of the within-stream variability in calcite conditions. Because the number of units sampled is equal to the sample size of the study, the level of inference that can be drawn increases directly with number of mesohabitats sampled. Therefore, due to trade-offs between effort and time for sampling, the number of pebbles sampled per mesohabitat unit was reduced from 100 to 30. This step was taken for the 2019 data collection (Hocking *et al.* 2020) and maintained for the 2020 study. Previous work by Robinson *et al.* (2016) showed that a reduction in pebble count to as low as 25 pebbles had a minimal effect on the mean CI result observed. Despite this reduction in effort per mesohabitat unit, the total number of pebbles sampled per stream averaged 1,312 ± 459 (±SD) for a total of 22,496 pebbles sampled in 2020, 3% less than the 23,222 pebbles sampled in 2019 and 163% more than the 8,548 pebbles sampled in 2018. Sampling effort in 2020 resulted in 752 mesohabitat units sampled versus 766 and 62 mesohabitat units sampled in 2019 and 2018, respectively.

At each mesohabitat unit, the observer moved systematically over the unit, stopping every, one, two, or three steps to randomly select a pebble ≥ 2 mm in diameter (i.e., gravel or larger) along a stream section of variable length (20 to 100 m). If the substrate selected was < 2 mm in diameter, this was noted and another pebble was chosen to ensure a total count of 30 pebbles per mesohabitat unit.

Thirty pebbles were sampled for each CI measurement and the following information was recorded for each pebble:

- The concretion score (CI_{Conc}): if the pebble was removed with negligible resistance (not concreted to an adjacent pebble, score = 0), notable resistance but removable (partially concreted, score = 1), or immovable (fully concreted, score = 2);
- Absence or presence of calcite (score = 0 or 1 respectively) (CI_{Pres}); and
- The b-axis length of the pebble, to the nearest mm. Pebbles less than 2 mm (b-axis) were recorded as fines for the purpose of CI calculations.

Substrate was classified using the Wentworth Scale (Table 3). Additional substrate classification was recorded for fines and sand (<2 mm). The mesohabitat unit type (riffle, run, cascade, pool, glide) was also recorded and mapped (Appendix B).

The results for each mesohabitat unit were expressed as a CI_{Total} score using the following equation:

$$CI_{Total} = CI_{Pres} + CI_{Conc}$$

where,

$CI_{Total} = Calcite\ Index$

$CI_{Pres} = Calcite\ Presence\ Score\ (Binary)\ = \frac{\text{Number of pebbles with calcite}}{\text{Number of pebbles counted}}$

$$CI_{Conc} = Calcite\ Concretion\ Score\ = \frac{\text{Sum of pebble concretion scores}}{\text{Number of pebbles counted}}$$

Note, for the remainder of the document, CI_{Total} is generally referred to as CI.

Ecofish, Lotic Environmental (Lotic), Minnow Environmental (Minnow), and Teck staff attended a calcite training program led by Mike Robinson of Lotic to improve the standardization of the calcite data collected across Teck programs (Hocking *et al.* 2021). Through the inter-program training, a potential modification was identified to increase the resolution of the calcite presence score and in doing so: 1) reduce within-reach variability, 2) improve power of detecting change in CI over time, and 3) reduce inter-crew variability. In addition to recording calcite presence as a binary measure (0 = no calcite, 1 = calcite), a new method was trialled to include an estimate of the amount of calcite that is present on each pebble (calcite coverage as a proportion 0 to 1 for each pebble). Calcite presence coverage ($CI_{Coverage}$) was thus collected in addition to the standard binary measure of calcite presence per pebble during the 2020 field season. The results per mesohabitat unit are calculated as:

$$CI_{Coverage} = Calcite\ Presence\ Score\ (Coverage)\ = \frac{\text{Average proportion of calcite coverage per pebble}}{\text{Number of pebbles counted}}$$

Data analyses described in Section 2.5 below were conducted on the calcite presence binary measure. However, initial analyses comparing CI_{Pres} to $CI_{Coverage}$ was completed as described in Appendix D.

Table 3. Substrate classification scheme.

Substrate Type	Substrate Category	Size Range (mm)
Fines and Sand	Clay	<0.0039
	Silt	0.0039-0.0625
	Sand	0.0625-2
Gravel	Small Gravels	2-16
	Large Gravels	16-64
Cobble	Small Cobble	64-128
	Large Cobble	128-256
Boulders	-	256-4,000
Bedrock	-	>4,000

2.3.3. Fish Habitat

A Level 1 FHAP, as described by Johnston and Slaney (1996), was used to quantify fish habitat in all study streams to be used as predictors of WCT redd presence and redd abundance. FHAP was collected for LCO Dry Creek in 2016 (Buchanan *et al.* 2016), Lower Greenhills Creek and Henretta Creek in 2017 (Wright *et al.* 2018), and Fish Pond Creek and Clode Creek in 2018 (Hocking *et al.* 2019) (Table 2). On Corbin Creek, FHAP was collected in May 2019 as part of the ongoing Corbin Creek EFN study (Teck 2018). FHAP data collection was collected in 2019 at Upper Greenhills, Thompson, Michel, Grave, Harmer, Erickson, EVO Dry, Alexander, Grace, Lizard and McCool creeks. In 2020, FHAP was collected on the new streams sampled in 2020, including Upper Fording River mainstem (S8), Line Creek and South Line Creek between June and August (Appendix A). Additional FHAP was also collected on Grace and Harmer Creeks to expand the existing study areas.

Mesohabitat unit types were classified as pools, glides, runs, riffles, cascades, chutes, and falls according to definitions in Johnston and Slaney (1996). Glide and run mesohabitat units typically share similar physical parameters (i.e., gradient, substrate, bankslope, depth profile) but are differentiated by flow profile. For example, run mesohabitat units have a defined thalweg, whereas glide mesohabitat units have uniform flow and lack a defined thalweg.

Table 4 lists the physical parameters surveyed at each mesohabitat unit along with the units of measurement and the equipment used. Parameters were measured rather than estimated wherever possible. Estimates were made for dominant and subdominant bed materials, and percent cover. Substrate was classified according to a modified Wentworth scale as shown in Table 3. The dominant and subdominant substrate type within each habitat unit was estimated based on coverage area. Photographs of each mesohabitat unit were taken.

Mesohabitat units were additionally classified by location within the stream as primary, secondary, and tertiary. Primary mesohabitat units occupy more than 50% of the wetted width of the main channel. Secondary units occupy secondary channels, and tertiary units are embedded within primary units but meet the minimum size criteria (Table 5).

A key habitat variable hypothesized to affect WCT spawning is spawning substrate availability. A spawning gravel assessment was completed to provide specific spawning substrate information following methods described by Johnston and Slaney (1996). Within each mesohabitat unit, functional (below water surface) and non-functional (above water surface) gravel patch area was measured for spawning fish using a gravel size range of 10 to 75 mm thought to represent the preferred substrate size range for spawning WCT (Cope *et al.* 2016). Available spawning habitat was further determined by summing the functional gravel area for all patches in each mesohabitat unit. Spawning gravel assessments were completed on new streams sampled in 2020, including Upper Fording River mainstem (S8), Line Creek, and South Line Creek (Appendix A). Spawning gravel data was also collected on expanded reaches of Grace and Harmer creeks. Spawning substrate area per mesohabitat unit was used as an additional fish habitat explanatory variable in data analyses described in Section 2.5.

Mesohabitat units identified within each stream are mapped in Appendix B, and a summary of habitat data collected at mesohabitat units during the calcite assessment is presented for each stream, and broken down by mesohabitat type, in Appendix C.

Table 4. Physical parameters, units of measure and equipment used during the FHAP.

Parameter	Unit	Measured or Estimated	Equipment Used
Bankfull Width	m	Measured	Metre Tape or Rangefinder
Bed Material Type	n/a	Visual Estimate	Visual
Cover Proportion	n/a	Visual Estimate	Visual
Cover Type	n/a	Visual Estimate	Visual
Gradient	%	Measured	Clinometer
Habitat Unit Length	m	Measured	Metre Tape or Rangefinder
Maximum Pool Depth	m	Measured	Metre Stick
Wetted Depth	m	Measured	Metre Stick
Wetted Width	m	Measured	Metre Tape or Rangefinder

Table 5. Minimum size criteria for tertiary mesohabitat unit types.

Bankfull Channel Width (m)	Minimum Area (m^2)	Minimum Residual Depth (m)
0 - 2.5	1.0	0.20
2.5 - 5	2.0	0.40
5 - 10	4.0	0.50
10 - 15	6.0	0.60
15 - 20	8.0	0.70
> 20	10.0	0.80

2.3.4. Water Quality and Velocity

In addition to calcite and measures of geomorphic habitat from the FHAP, other physical habitat parameters such as water quality and water velocity were also collected at mesohabitat scale. Because flows and temperature vary on shorter time scales than habitat or calcite, extra efforts were made to collect water quality and velocity data as close in time as possible to redd surveys. Field-based water quality and velocity measurements were performed between June 11 and July 10 to reflect conditions during the period of WCT spawning. Water quality and velocity data were collected in the immediate vicinity of redds when present, and in a representative location in mesohabitats where no redds were observed. A summary of stream level physical habitat data collected during the water quality and velocity surveys is presented in Appendix C.

At each mesohabitat unit, water temperature, pH, and electrical conductivity were measured with a handheld Hanna HI98129 Combo pH/Conductivity/TDS Tester. In addition, reach scale measures of water quality were taken at approximately 250 m intervals along assessed reaches. Reach scale water quality data was collected in triplicate using a calibrated YSI Pro Plus, and parameters included in analysis were DO, ORP, water temperature, pH, and electrical conductivity. Water quality meters were maintained and calibrated, and water quality sampling procedures followed the guidelines of the British Columbia Field Sampling Manual, Part E Water and Wastewater Sampling (Clark 2013). Water quality summary statistics (stream average and standard deviation) were calculated for DO (mg/L), water temperature (°C), pH, and specific conductivity (µS/cm), and broken down by habitat type within each study stream (Appendix C).

Velocity was measured in all mesohabitats at three stations (approximately one quarter, half, and three quarters of stream width) along a transect perpendicular to the primary flow using a calibrated Swoffer velocity meter (Model 2100) and a 140 cm top-set rod with an 8.5 cm diameter propeller. For each sampling site, an estimate of mean velocity was calculated from the measures recorded along the transect.

The upper section of Harmer Creek consisting of 14 mesohabitat units was not sampled for water quality during spawning and was sampled instead on September 22 to obtain mesohabitat scale information. Several redds were observed by Scott Cope in 2020 in this upper Harmer reach and it was desired to obtain mesohabitat scale data for this additional reach. This occurred for short sections of Grave and Harmer creeks in the 2019 study and a calibration procedure was applied to correct the water quality and velocity data to be representative of the spawning window (Hocking *et al.* 2020). This calibration of the 14 mesohabitat units sampled in September in 2020 was not completed this year (in error). We assume that this has had a negligible effect on the model results and the conclusions related to calcite concretion given that these mesohabitat units have low levels of calcite and counts of WCT redds. The calibration of these water quality and velocity data will be completed for the 2021 study and integrated into the development of the 2021 spawning suitability analyses.

2.4. Data QA/QC

All field data were entered into Ecofish's data management platform, EcoDAT. This data management platform has built-in rigorous QA/QC protocols. Hardcopy data from field forms were transcribed into EcoDAT and entries were visually compared by a second person to check for data entry errors. All data analysis was completed by a qualified data analyst and raw data, coding and exports were reviewed by a senior data analyst prior to reporting.

2.5. Data Analysis

2.5.1. Data Exploration and Variable Selection

The effects of calcite on WCT spawning suitability were assessed using two primary response variables, including the presence/absence of redds and the count of redds observed per mesohabitat unit within streams. Calcite data was tested as the primary explanatory variable of interest. Additional fish habitat variables were also included as explanatory variables to account for the range of conditions present in WCT spawning habitat. Data from 2018 (Hocking *et al.* 2019), from 2019 (Hocking *et al.* 2020), and from 2020 (this study) were included in the analysis.

The data collection methods differed between the pilot year in 2018 and years afterwards, which resulted in some analysis modifications. In 2018, an equal number of sites where redds present and absent were sampled. This may cause an overestimation of the probability of redds being present to 50% within the study area. To avoid this bias, data collected in 2019 and 2020 included all mesohabitat units in each reach per stream. Therefore, data analyses for redd presence but not redd counts excluded the data collected in 2018. An additional *a posteriori* analysis of redd presence showed that including 2018 data resulted in only small deviations from the results presented below for redd presence while included solely the 2019 and 2020 data. Prior to modelling, data exploration included generation of summary statistics for the redd survey, calcite, FHAP and water quality and velocity data. Proportion of spawning gravel was calculated by dividing the total area of WCT spawning gravel by the mesohabitat unit area (calculated as unit length × bankfull width).

Initial data exploration included generation of plots showing the distribution of redd presence and redd counts by tributary and mesohabitat type. CI scores were also plotted by tributary and mesohabitat type.

As a key step of data exploration of explanatory variables, collinearity was analysed between the values of CI, and its components (i.e., calcite presence score and calcite concretion score). High correlation was found between CI and calcite presence ($r = 0.842$) and between CI and calcite concretion ($r = 0.908$), and modest correlation was found between calcite presence and calcite concretion ($r = 0.540$; Figure 3). Low levels of calcite concretion (< 0.5) were observed in some instances below a calcite presence score of ~0.5, while moderate levels of calcite concretion (between 0.5 and 1) were observed to begin to occur above a calcite presence score of ~0.70. High levels of calcite concretion (>1) were more common above a calcite presence score of 0.9. However, high calcite presence levels (> 0.90) with zero concretion were also observed. Further inter-program analyses of the relationships between calcite presence and concretion are shown in Hocking *et al.* (2021).

The remaining data exploration of explanatory variables was carried out following Zuur *et al.* (2010) protocol. The explanatory variables initially hypothesized to affect WCT spawning included CI and its components calcite presence and concretion, mesohabitat type, streamflow, mean water velocity, mean substrate size, functional large woody debris (LWD), bankfull depth, bankfull width, spawning gravel area, water temperature during spawning, DO, conductivity, ORP, and pH (Table 6). Explanatory variables were standardized to have a mean of zero and a standard deviation of one prior to being included in the analyses. Data exploration revealed some collinearity among explanatory variables (Figure 4). For instance, conductivity was highly correlated with calcite concretion, bankfull width was correlated with bankfull depth, and mesohabitat type was correlated to water velocity and bankfull depth. Therefore, several variables were excluded from consideration due to collinearity. Additionally, DO and ORP were excluded from the final set of explanatory variables due to not being recorded at the mesohabitat unit scale. Data exploration also revealed these three variables, fish habitat area, bankfull depth, and proportion of spawning gravel, were skewed, and a log transformation was applied to those variables prior to modelling. The final set of explanatory variables included CI, calcite presence, calcite concretion, mean velocity, proportion spawning gravel, bankfull depth, functional

LWD, water temperature, conductivity, and pH (Table 6). In addition, mesohabitat unit area was included as a predictor to account for sampling effort.

Figure 3. Correlations between CI, calcite presence and calcite concretion across 20 streams in the Elk Valley in 2018, 2019 and 2020.

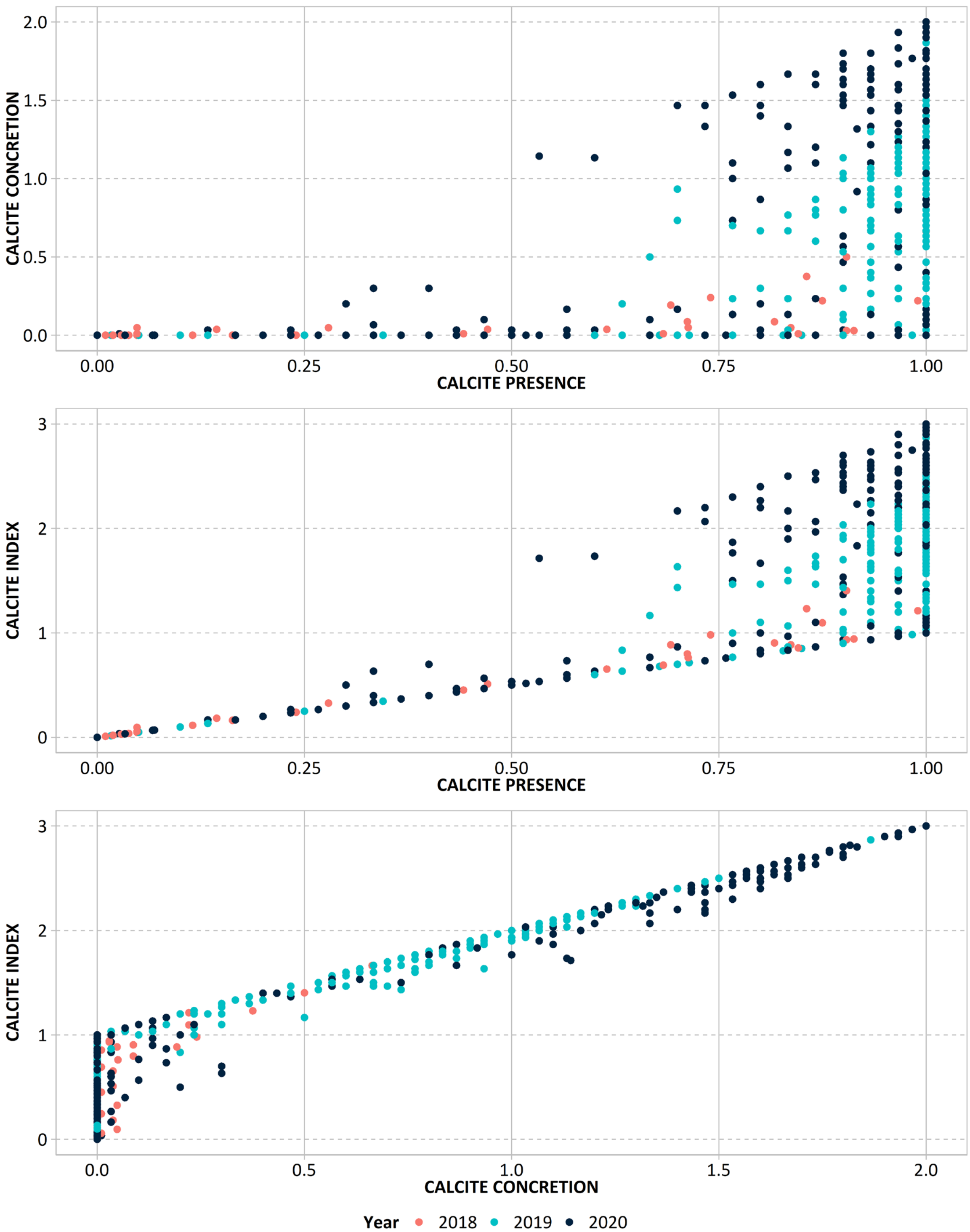


Figure 4. Correlation matrix of explanatory variables. Main diagonal: density plots. Lower triangle: scatterplots. Upper triangle: correlation coefficients and their level of significance depicted by "*", where "*" represents a level of significance of *p-value* = 0.05, "**" for a *p-value* = 0.01, and "***" for a *p-value* = 0.001.

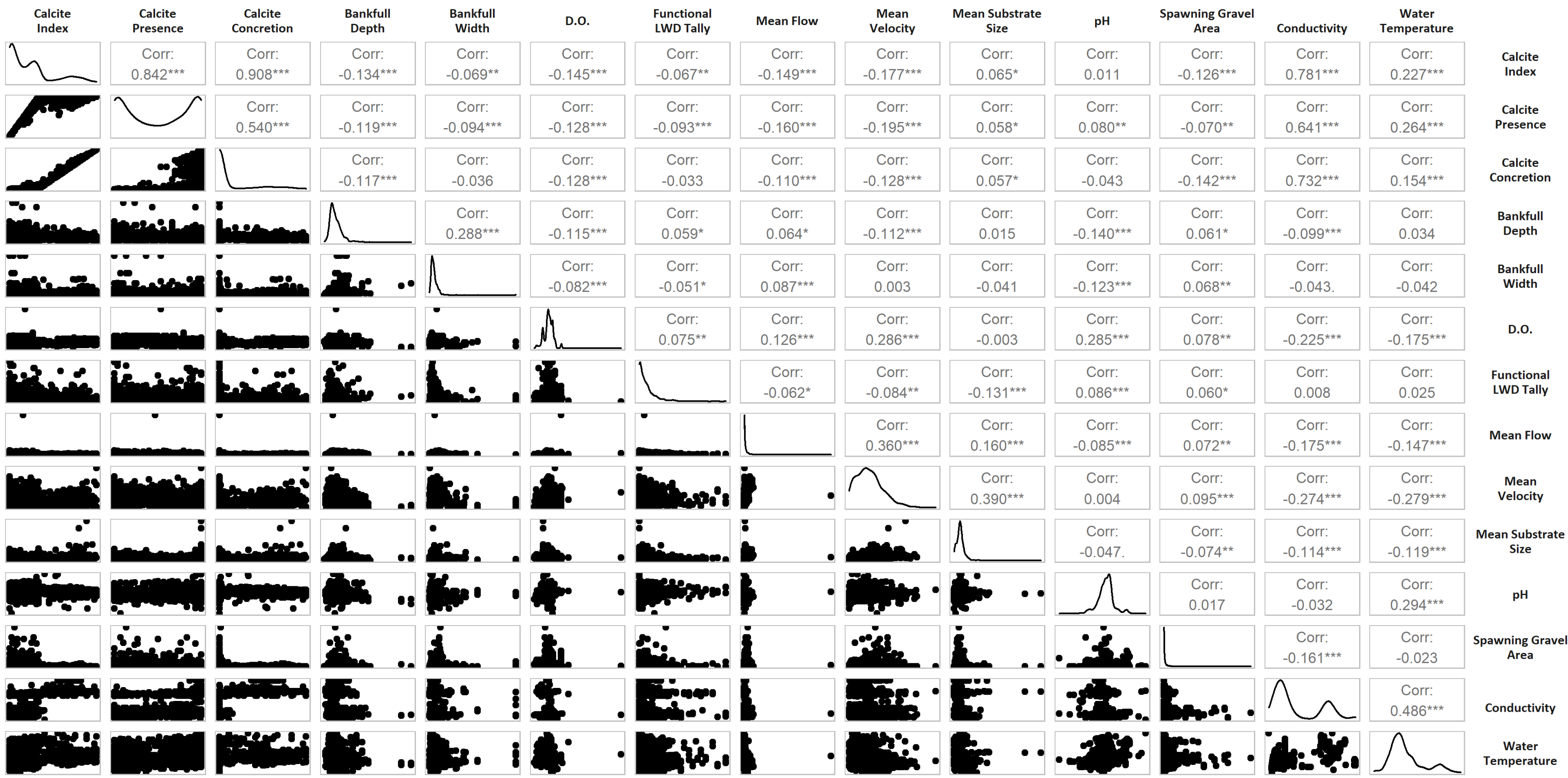


Table 6. Summary and description of variables selected for modelling and included in the final model set.

Variable Type	Variable	Description
Response	Redd Counts	Sum of the observed number of new redds observed during surveys within each mesohabitat unit.
	Redd Presence/Absence	Binary variable indicating presence (1) or absence (0) of redds within a mesohabitat unit.
Random Effects	Year	Categorical variable indicating year of sampling.
	Tributary Stream	Categorical variable indicating waterbody where sampling occurred.
Fixed Effects	Calcite Index (CI)	Sum of calcite presence and calcite concretion scores.
	Calcite Concretion (CI_{Conc})	Score (0, 1, 2) assigned to individual pebbles indicating degree of concretion.
	Calcite Presence (Binary) (CI_{Pres})	Score (0 or 1) assigned to individual pebbles indicating presence of absence of calcite.
	Calcite Presence (Coverage) ($CI_{Coverage}$)[1,3]	Score between 0 and 1 indicating the proportion coverage of calcite per pebble.
	Bankfull Depth	Water depth (m) within mesohabitat unit at bankfull flow conditions.
	Mean Velocity	Mean stream velocity (m/s) of mesohabitat unit.
	Proportion of Spawning Gravel	Proportion of mesohabitat unit area with gravel suitable for spawning. Calculated as the total area of functioning spawning gravel divided by the mesohabitat unit area.
	Water Temperature	Water temperature (°C) within mesohabitat unit, collected during WCT spawning.
	Mesohabitat Area	Total area (m^2) of mesohabitat unit, calculated as mean bankfull width × mean bankfull width.
	Specific Conductivity	Mean *in situ* measure of specific conductivity (µS/cm) collected within each mesohabitat unit.
	pH	Mean *in situ* measure of pH, collected within each mesohabitat unit.
	Mesohabitat Type[2]	Categorical variable indicating mesohabitat unit type (Pool, Glide, Run, Riffle, Cascade).
	Streamflow[2]	Volume of water (m^3/s) moving through the mesohabitat unit.
	Bankfull Width[2]	Width (m) of wetted channel at bankfull flow conditions.
	Mean Substrate Size[2]	Mean size of pebbles (mm) within each mesohabitat unit, collected during calcite index measurements.
	Oxidation Reduction Potential (ORP)[2]	Mean *in situ* measure of oxidation reduction potential (mV), collected within each stream but not each mesohabitat unit.
	Dissolved Oxygen[2]	Mean *in situ* measure of dissolved oxygen (mg/L and % saturation), collected within each stream but not each mesohabitat unit.

[1]Calcite Presence (Coverage) was only collected in 2020.

[2]These predictor variables were excluded from modelling due to collinearity or because they were not collected at mesohabitat scale.

[3]Calcite Presence (Coverage) was excluded from modelling due to not being represented prior to 2020.

2.5.2. Redd Presence Model Selection Analysis

Relationships between redd presence and explanatory variables were investigated using three complementary approaches: 1) a series of univariate analyses, where the effects of calcite metrics and conductivity on redd presence were assessed individually, 2) a model selection analysis, where the effects of calcite metrics and other explanatory variables were contrasted across mine-influenced streams, reference streams and all streams using model selection procedures on a series of generalized logistic mixed effect models (GLMM), and 3) a model selection analysis on a series of generalized additive mixed models (GAMM) to investigate the effects of calcite metrics and other explanatory variables while accounting for potential non-linear relationships. These steps were implemented using the "lme4", "mgcv", and "MuMIn" packages in the R Statistical Language (Bates *et al.* 2015; Wood 2017; R Core Team 2018; Barton 2018). Only 2019 and 2020 data were included in the redd presence analysis.

The effects of calcite on the presence of redds were investigated first using a series of univariate regressions. The objective of this preliminary approach was to assess the distribution of probability of redds occurring in mesohabitats that differ in CI, calcite presence, calcite concretion, and conductivity. Data exploration suggested that the relationship between the redd presence and calcite presence, calcite index, and conductivity variables were not linear, and so we fitted generalized additive models (GAM) to these relationships. One exception to this was calcite concretion, since data exploration showed that relationship was better explained using a logistic regression model. For the univariate model with concretion, redd presence variable followed a binomial distribution with a logit-link function.

Second, we used a model selection approach to assess the relative importance of all predictor variables, including CI, calcite presence, concretion, and fish habitat variables in explaining redd presence. A GLMM was fitted using a binomial distribution with a logit-link function (in other words a logistic regression with random effects) to estimate the effect and relative importance of each predictor variable (Hosmer and Lemeshow 2000; Zuur *et al.* 2009; Grueber *et al.* 2011). This involved fitting an initial 'global model' using the full final set of explanatory variables (see Section 2.5.1). To account for any environmental stochasticity when modelling redd presence, we introduced two random effects in the 'global model', year of sampling, and the sampled stream to account for synchronous temporal and spatial variation, respectively. Once the initial 'global model' was determined, the model selection procedure involved an all-model-combinations model selection approach where candidate models containing all possible combinations of each predictor variable (without including interactions) were competed against one another to find the top models that best describe redd presence.

Each candidate model was competed using Akaike Information Criterion corrected for small sample sizes (AICc), which balances model simplicity with variance explained. A subset of the candidate models was then retained based on the difference between each model's AICc value and the AICc of the best model (the ΔAICc). Models with a Δ value smaller than 2 have substantial empirical support (Burnham and Anderson 2002), and models with Δ values in the 2–7 range have some support (Burnham *et al.* 2011). Only models with a ΔAICc of less than 4 were retained, a cut-off threshold used to prevent the inclusion of overly complex models (Grueber *et al.* 2011). The retained models within ΔAICc <4 were then model-averaged to obtain a final, weighted model. Model-averaged products for each response variable include the set of top models that explain redd presence, and the parameter estimates, confidence and relative variable importance associated with each predictor variable. Model selection and model averaging was implemented using the "MuMIn" package (Barton 2018) in the R Statistical language.

Due to high collinearity between CI and the other calcite metrics (concretion and presence) as well as conductivity, the model selection approach described above constrained each model to include either CI, conductivity, or calcite presence and/or concretion. In other words, CI was not permitted in the same model as conductivity, calcite presence or concretion because they are highly correlated and explain similar variance in the distribution of redd presence. Conductivity was also not allowed in the same model as any of the calcite variables. Only calcite presence and concretion were allowed to occur in any one model. This set up a direct competition between CI, calcite presence, concretion, and conductivity in what best predicted redd presence. Conductivity was included as a variable in the model selection under the hypothesis that it represents a stream productivity gradient from low to moderate values, and then is representative of mine disturbance at high values. Conductivity also strongly predicts both calcite presence and concretion (Hocking *et al.* 2021), which also justifies why it cannot be included in the same model as the calcite variables.

To determine whether the results were influenced by certain groups of streams, the model selection analysis was applied across combinations of mine-influenced streams only, reference streams only, and across all streams. The objective of this approach was to contrast the effects of calcite in different sets of streams and determine the influence of the reference streams in the observed response. Due to model fitting challenges, such as singularity and non-convergence, the stream random effect was not included in the reference stream only analysis.

The third modelling approach assessed the effects of calcite and the other fish-habitat predictor variables using a generalized additive mixed effects model (GAMM). These types of statistical models infer potential non-linear relationships between variables while accounting for multiple sources of variability (i.e., random effects). Like the GLMM approach, a "global model" was fitted that included the final set of explanatory variables, and two random effects, year of sampling and the sampled stream to account for synchronous temporal and spatial variation, respectively. All possible model combinations composed by each predictor variable (without including interactions) were then fitted and competed against one another to find the top model that best described redd presence. The same restriction was imposed here, that all candidate models could have either one calcite variable, conductivity, both concretion and calcite presence, or none at all. All possible candidate models were built, and these were ranked based on AICc.

To further investigate the role of spawning conditions on the relationship between calcite and redd presence, we predicted redd presence probability using the top ranked GAMM model following a CI_{Conc} gradient between 0 and 2 and three stream spawning condition scenarios defined as:

- <u>Average stream conditions</u>: redd presence probability is predicted as a function of CI_{Conc}, while all other fish habitat predictor variables were kept at their average values across the studied streams.

- <u>Optimal stream conditions</u>: redd presence probability is predicted as a function of CI_{Conc}, while calcite presence is held at 0.75, mesohabitat area held at 710 m², proportion of spawning gravel at 0.2, pH at 9, mean water velocity at 0.4 m/s, and mean water temperature of 12.5 °C. The predictors and their respective values were chosen to maximize the probability of redd presence and are based on results obtained in Sections 3.3.3 and 3.4.3.

- <u>Sub-optimal stream conditions</u>: redd presence probability is predicted as a function of CI_{Conc} gradient, while calcite presence is held at 0.1, mesohabitat area held at 100 m², proportion of spawning gravel at 0.05, pH at 7, mean water velocity at 1 m/s, and mean water temperature of 5°C. The predictors and their respective values were chosen to minimize the probability of redd presence and are based on results obtained in Sections 3.3.3 and 3.4.3.

The comparison between the predictions obtained from these three steam condition scenarios allows a comparison of the effects of calcite on the probability of redd presence under contrasting spawning conditions. The average stream conditions depict the average stream, while optimal stream depicts an abstract stream that presents the ideal conditions for WCT spawning. In contrast, sub-optimal stream represents an abstract stream that is the least suitable for WCT spawning. Note that these scenarios do not represent any specific studied streams.

The redd presence models were validated using a combination of methods that are described and presented in Appendix E. These include model cross-validation, assessment of area-under-the-curve, and a variance partitioning analysis, which assesses the amount of variation explained by the models including among the fixed and random effects.

2.5.3. Redd Count Model Selection Analysis

To test the effect of calcite on the counts of redds, we applied four complementary approaches: 1) a series of univariate analyses, where the effects of calcite and conductivity on redd counts were assessed individually, 2) a GLMM model selection analysis, where the effects of calcite metrics and other explanatory variables were contrasted across mine-influenced streams, reference streams and all streams (McCullagh and Nelder 1989, Bolker *et al.* 2008), 3) a model selection analysis on a series of GAMMs to investigate the effects of calcite metrics and other explanatory variables while accounting for potential non-linear relationships, and 4) a model selection analysis on a series of 95th quantile regression models to investigate the effects of calcite metrics and other explanatories at the outer bounds of the WCT redd count data. All redd count analyses included data from 2018 to 2020.

The methods for the first three modeling approaches of univariate models, GLMMs, and GAMMs were similar to that described above in Section 2.5.2. with a few differences. In the univariate models, data exploration suggested that redd counts should be modelled with either a Poisson distribution with a log link function (for CI, calcite presence, and conductivity) or using a negative binomial distribution with a log link function (for concretion). The multivariate GLMMs applied a negative-binomial error distribution, which allows for a quadratic relationship between the mean and the variance term in the model and helps address the the large number of zeros present in the data. Year and stream were included as random effects in the models to account for repeated observations (Zuur *et al.* 2009) and models were again contrasted between mine-influenced streams, reference streams, and across all streams. GLMMs were estimated using packages "lme4" and "Mass" in the R Statistical Language (Bates *et al.* 2015, Brooks *et al.* 2017).

Similar to Section 2.5.2, GAMMs were also applied to the redd count data to account for non-linear relationships. To further investigate the role of spawning conditions on the relationship between calcite and redd counts, we predicted redd presence probability using the top ranked GAMM model following a CI_{Conc} gradient between 0 and 2 and three stream spawning condition scenarios defined as:

- Average stream conditions: redd count is predicted as a function of CI_{Conc}, while all other fish habitat predictor variables were kept at their average values across the studied streams.
- Optimal stream conditions: redd count is predicted as a function of CI_{Conc}, while calcite presence is held at 0.75, mesohabitat area held at 710 m², proportion of spawning gravel at 0.2, pH at 9, mean water velocity at 0.4 m/s, and mean water temperature of 12.5 °C. The predictors and their respective values were chosen to maximize redd counts and are based on results obtained in Sections 3.3.3 and 3.4.3.
- Sub-optimal stream conditions: redd count is predicted as a function of CI_{Conc} gradient, while calcite presence is held at 0.1, mesohabitat area held at 100 m², proportion of spawning gravel at 0.05, pH at 7, mean water velocity at 1 m/s, and mean water temperature of 5°C. The predictors and their respective values were chosen to minimize redd counts and are based on results obtained in Sections 3.3.3 and 3.4.3.

The comparison between the predictions obtained from these three steam condition scenarios allows a comparison of the effects of calcite on the count of WCT redds under contrasting spawning conditions. The average stream conditions depict the average stream, while optimal stream depicts an abstract stream that presents the ideal conditions for WCT spawning. In contrast, sub-optimal stream represents an abstract stream that is the least suitable for WCT spawning. Note that these scenarios do not represent any specific studied streams.

The fourth method applied to the redd count data was a 95th quantile model, which is similar to what was applied in earlier years (Hocking *et al.* 2019; 2020). Quantile regression is an analytical method well-suited to examining limiting factors for species abundance and distribution (Cade and Noon 2003). A species' abundance may be limited by many ecological factors and will be constrained to lower abundance than expected in a potentially suitable habitat if other factors are more limiting (Cade *et al.* 1999, Cade and Noon 2003, Cade *et al.* 2005). This means that species abundance data often appear wedge-shaped when plotted against any single habitat variable. Quantile regression is used to understand potential relationships at the outer bounds of the data and can be useful when there are many habitat factors that limit fish populations. For example, the 90th quantile is a robust model to describe the upper bounds of wedge-shaped relationships (Scharf *et al.* 1998, Koenker and Machado 1999; Armstrong *et al.* 2010, Hocking *et al.* 2013). The relationship between the 95th quantile of the number of redds and relevant explanatory variables described in Section 2.5.1 was modelled as a quantile regression model using the "quantreg" package (Koenker 2018) in the R Statistical Language (R Core Team 2018). Redd counts were modelled by applying a ln(x + 0.01) transformation to prevent the model from predicting negative redd counts. All possible candidate models (no interactions) were built and the top model was selected based on AICc (Burnham and Anderson 2002) and the derived measure evidence ratio (Anderson 2008).

The redd count models were validated using a combination of methods that are described and presented in Appendix E. These include model cross-validation, assessment of mean absolute error, and a variance partitioning analysis, which assesses the amount of variation explained by the models including among the fixed and random effects.

2.5.4. Boosted Regression Trees Analysis

The relationship between habitat predictors and spawning habitat can be complex. Generalized additive models pointed to clear non-linear relationships for some variables and there is the potential for selection patterns to vary among streams (Hall and Wissmar 2004). Thus, to support the GLMM analysis spawning habitat suitability was further quantified using boosted regression tree analysis. Boosted regression trees (BRT) do not assume any underlying relationship between response and predictors (i.e., can accommodate non-linearity). Further, developed trees have a hierarchical structure and the response to one predictor depends on the splits from other predictors higher in the tree; thus interactions between variables (i.e., the importance of one variable can depend on the value of another) and between stream and habitat variables (i.e., allow individual relationships between response and predictor to change within streams) are incorporated into the underlying model. Through these properties BRT analysis often leads to highly predictive models. The primary objective of the BRT analysis is to support the generalized mixed model analysis and investigate the importance of calcite and other covariates within streams on redd presence and counts. As a secondary objective, the BRT analysis allows for the importance of predictors for be quantified for each habitat unit and thus can be used to estimate the potential success of calcite remediation and target regions where remediation targeted at improving WCT spawning habitat would be most successful.

Similar to the GLMMs, the BRT analysis was conducted at the within-stream scale with data collected for individual mesohabitat units (i.e., individual pools, riffles, run habitat units) within a stream. The BRT analysis does not assume any underlying relationship between response and predictors. Instead it relies on first developing a series of simple decision trees, which use repeated binary splits of predictor variables to divide the dataset into groups with the objective of partitioning the response variable (e.g., probability of redd presence; redd counts) into homogenous groups to compare with predictor variables (Breiman *et al.* 1984; De'Ath and Fabricius 2000). The developed trees have a hierarchical structure and the response to one predictor depends on the splits from other predictors higher in the tree; thus, interactions are incorporated into the underlying model. To avoid overfitting the BRT models were parameterized through a cross validation approach that attempted to maximize the ability to predict to withheld data while minimizing the number of predictors to improve in interpretation.

We quantified the overall influence and effect of each of the calcite and fish habitat predictor variables using a breakdown analysis with the *flashlight* package in R (R Core Team 2018). This analysis quantifies the variable importance (i.e., how much influence each variable has on the presence or count prediction for that habitat unit) for each individual data point (i.e., mesohabitat unit) using approximate Shapley Additive Explanations (SHAPs; Lundberg *et al.* 2017; Gosiewska and Biecek 2019). The importance of each variable was measured by quantifying each variable's contribution to the change from the average prediction in each stream to the prediction at the individual mesohabitat. For example, if the average stream level prediction is a mean count of 1.5 and the prediction at an individual habitat unit is a count of 1, we quantified the contribution of each variable as the difference between the average stream prediction and the prediction at the habitat unit (i.e., how much does each variable contribute to the difference of 0.5). The overall influence of a parameter within a stream was quantified by averaging the absolute value of this difference and averaging across all variables within a stream. The overall effect of variables was quantified by examining the relationship between predictor values and the direction (positive or negative) and extant of the change in prediction for mesohabitat units within streams or groups of streams using a local polynomial regression (LOESS). LOESS models are a non-parametric approach that fits locally weighted regressions to estimate a smooth curve through the relationship between two variables.

Further details on the BRT approach and methods are described in Appendix F.

3. RESULTS

In total, 752 mesohabitats units were sampled in 2020. This sampling effort is similar to 2019 (n = 766), and higher than the number of mesohabitat units sampled in 2018 (n = 62). The most intensively sampled streams were Grace Creek (n = 61 mesohabitat units) and Upper Grave Creek (n = 61 mesohabitat units). Mesohabitats surveyed in 2020 included riffles (n = 231), runs (n = 167), cascades (n = 149), glides (n = 105), pools (n = 83), falls (n = 10), and chutes (n = 3). Three additional stream reaches were sampled in 2020, including Fording River S8 (n = 25 mesohabitats), Line Creek (n = 21 mesohabitats), and South Line Creek (n = 11 mesohabitats). Erickson Creek was not surveyed in 2020.

Redd survey data, calcite data, and data analysis results are presented in the sections below. More detailed summaries of all data collected are presented in Appendix B and C. Analysis of calcite coverage are shown in Appendix D, and model validation is shown in Appendix E. Detailed results of the BRT analysis are also shown in Appendix F.

3.1. Redd Surveys

WCT redd data are summarized by stream and mesohabitat type to provide an indication of the distribution and abundance of WCT redds in 2020 as compared to previous years of sampling.

WCT redds were observed in 16 of the 19 streams surveyed in 2020; no redds were observed in Alexander, Henretta and South Line creeks (Table 7; Figure 5). Most mesohabitats surveyed in 2020 did not have redd presence (n = 701, 93.2 % of observations). The total number of redds observed in 2020 was 88 and represented a 71% decrease in the number of redds compared to 2019 (311 redds) and 14.2% increase compared to 2018 (77 redds). The highest number of redds observed per mesohabitat unit was 7 redds, which was observed at two streams, Lizard Creek and Fish Pond Creek. Representative photos of redd sites in study streams are shown in Figure 6 to Figure 9.

The number of redds varied spatially; the largest number of redds in 2020 was observed in Lizard Creek (31 redds, 35.2 % of all redds), Fish Pond Creek (12 redds, 13.6 % of all redds), and LCO Dry Creek (8 redds, 9.1 % of all redds). High redd counts also occurred in LCO Dry Creek during 2018 and 2019 surveys. Low numbers of redds were consistently recorded in Henretta Creek (0, 1, 0 redds in 2018, 2019 and 2020, respectively; Figure 5).

Average WCT redd counts by mesohabitat unit across all streams surveyed were generally lower in 2020 than in 2019, possibly due to higher flows and lower temperatures during the redd surveys in many streams (Table 7; Table 8; Figure 10; Figure 11). Redd counts were lower in 2020 compared to 2019 in 10 streams, including Alexander Creek, LCO Dry Creek, Harmer Creek, Henretta Creek, Lizard Creek, McCool Creek, Michel Creek, Thompson Creek, Upper Grave Creek, and Upper Greenhills Creek. Redd counts were higher in 2020 compared to 2019 in Clode Creek, Corbin, Fish Pond Creek, and Lower Greenhills Creek. Total WCT redd counts in 2020 were lower than previous years, possibly attributable to high flows in the region during the spawning period, which limits observers' ability to count redds. Figure 11 shows periods of high flows in the Fording River near the Elk River confluence, in May, June and July, 2020. Flows were recorded above the 90th percentile of twenty-year median flows during early parts of the expected spawning window (WSC 2021a, 2021b). Periods of higher precipitation also resulted in high flows later during this period, including in later June and July when much of the redd surveys took place. Flows in 2020 were generally higher than flows observed in 2018 or 2019 during the WCT spawning period (Figure 11). In addition, the stream temperatures for many streams during the spawning period in June and early July was also cooler in 2020 than in 2019 (Table 8). Cooler spawning temperatures may limit or delay spawning activity.

Similar to 2019, redd counts were higher in mesohabitats with moderate velocity, including in runs, riffles and glides, and were less abundant in pools and cascades (Figure 12). Redds were not observed in chutes or falls.

Maps of the individual redd locations by stream are shown in Appendix B.

Table 7. Distribution of number of redds per stream and year.

Stream	Observed Redds[1] 2018	2019	2020
Alexander Creek	-	3	0
Grace Creek	-	0	4
Upper Grave Creek	-	5	2
Lizard Creek	-	196	31
McCool Creek	-	21	3
South Line Creek	-	-	0
Clode Creek	6	0	3
Corbin Creek	-	0	3
Dry Creek (EVO)	-	0	2
Dry Creek (LCO)	23	15	8
Erickson Creek	-	0	-
Fish Pond Creek	38	9	12
Fording River	-	-	6
Harmer Creek	-	15	7
Henretta Creek	0	1	0
Line Creek	-	-	1
Lower Greenhills Creek	10	1	2
Michel Creek	-	41	2
Thompson Creek	-	2	1
Upper Greenhills Creek	-	2	1
TOTAL	77	311	88

[1] Total number of Redds within all meso habitat units per Stream

Figure 5. **Distribution of Westslope Cutthroat Trout redd presence (orange) and absence (green) by stream and mesohabitat type in tributaries of the Elk River, B.C., in 2020.**

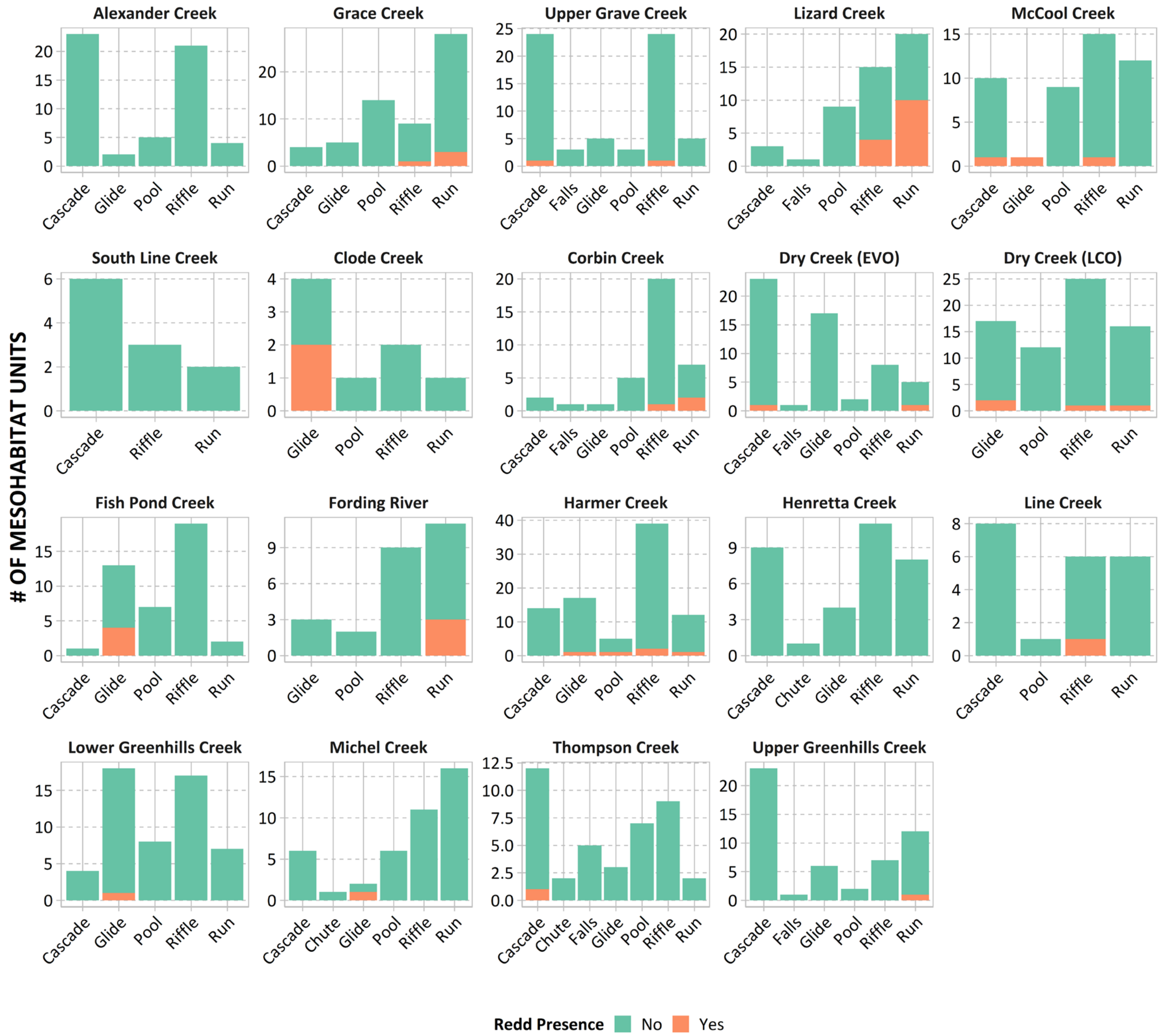


Figure 6. Westslope Cutthroat Trout (upper right circle) observed on redd (lower left circle) in Fish Pond Creek, FHAP unit 6 (Appendix B), on June 24, 2020.

Figure 7. Westslope Cutthroat Trout redds observed (circle) in LCO Dry Creek, FHAP unit 17 (Appendix B), on July 6, 2020.

Figure 8. Westslope Cutthroat Trout redd observed (circle) at Lizard Creek, FHAP unit 23 (Appendix B), on June 28, 2020.

Figure 9. Westslope Cutthroat Trout redd observed (circle) at Dry Creek (EVO), FHAP unit 13 (Appendix B), on June 22, 2020.

Figure 10. **Average Westslope Cutthroat Trout redd counts (± 1 SD) for each mesohabitat unit by stream in tributaries of the Elk River, B.C. from 2018, 2019, and 2020. CMO: Coal Mountain Operations, EVO: Elkview Operations, FRO: Fording River Operations, GHO: Greenhills Operations, LCO: Line Creek Operations.**

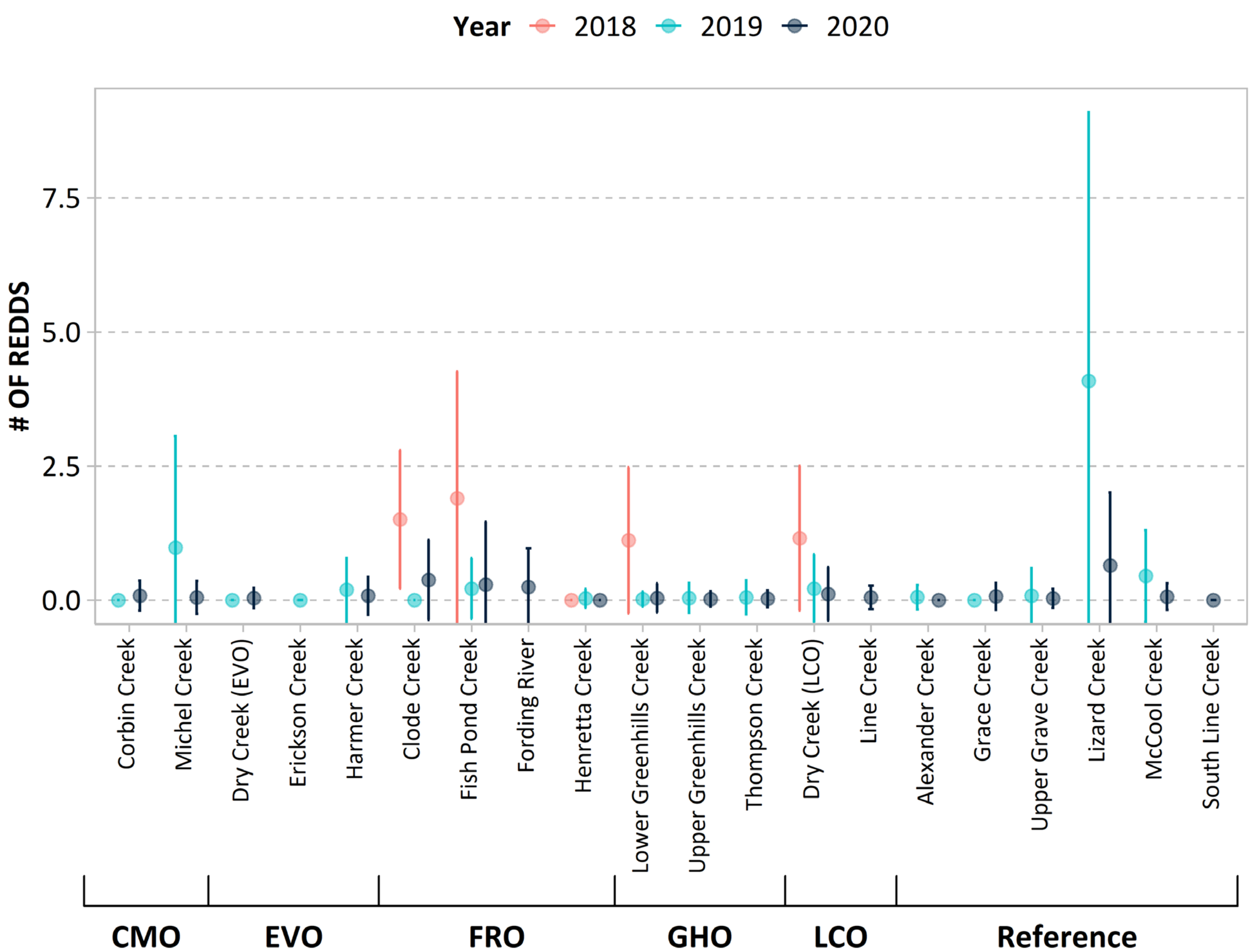


Figure 11. **Daily average flows in Fording River at confluence with Elk River from May-September 2018 (red line), 2019 (in light blue line) and 2020 (black line) and 2000 to 2020 median (dark blue line). Shaded area represents the 10th-90th percentiles of flow from 2000 to 2020.**

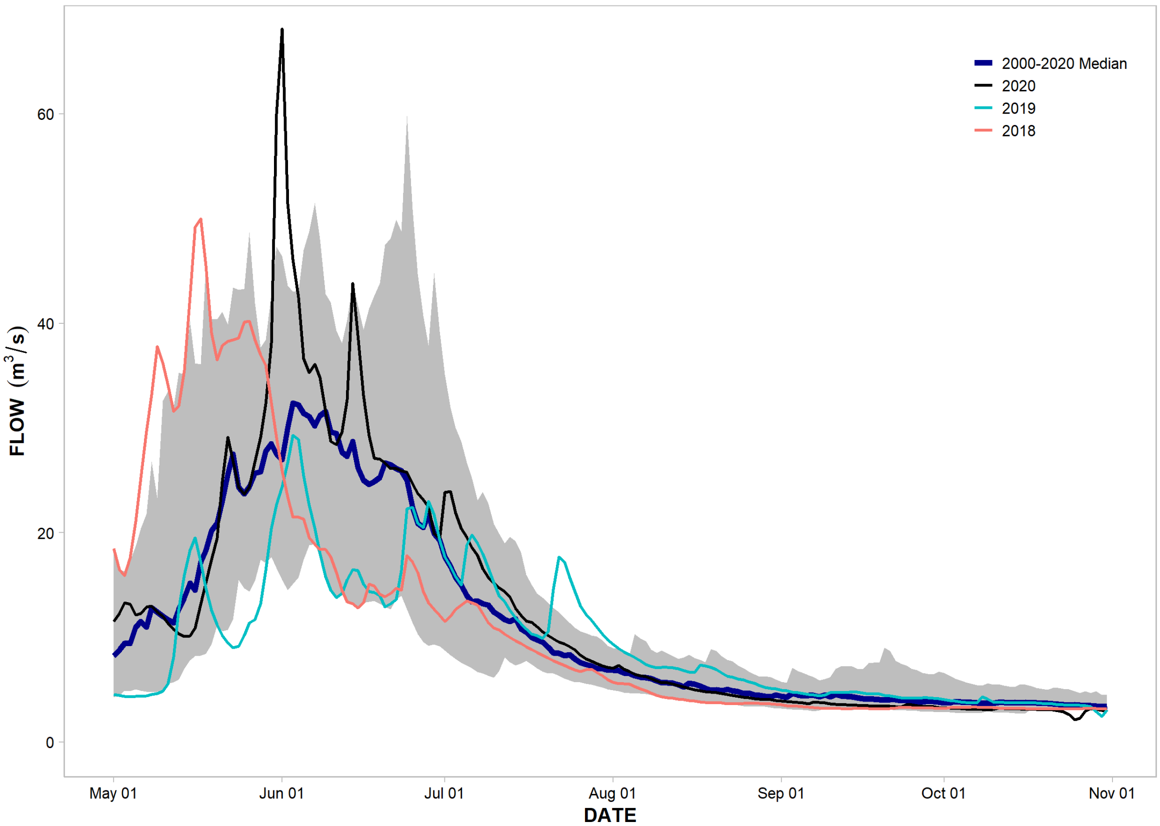
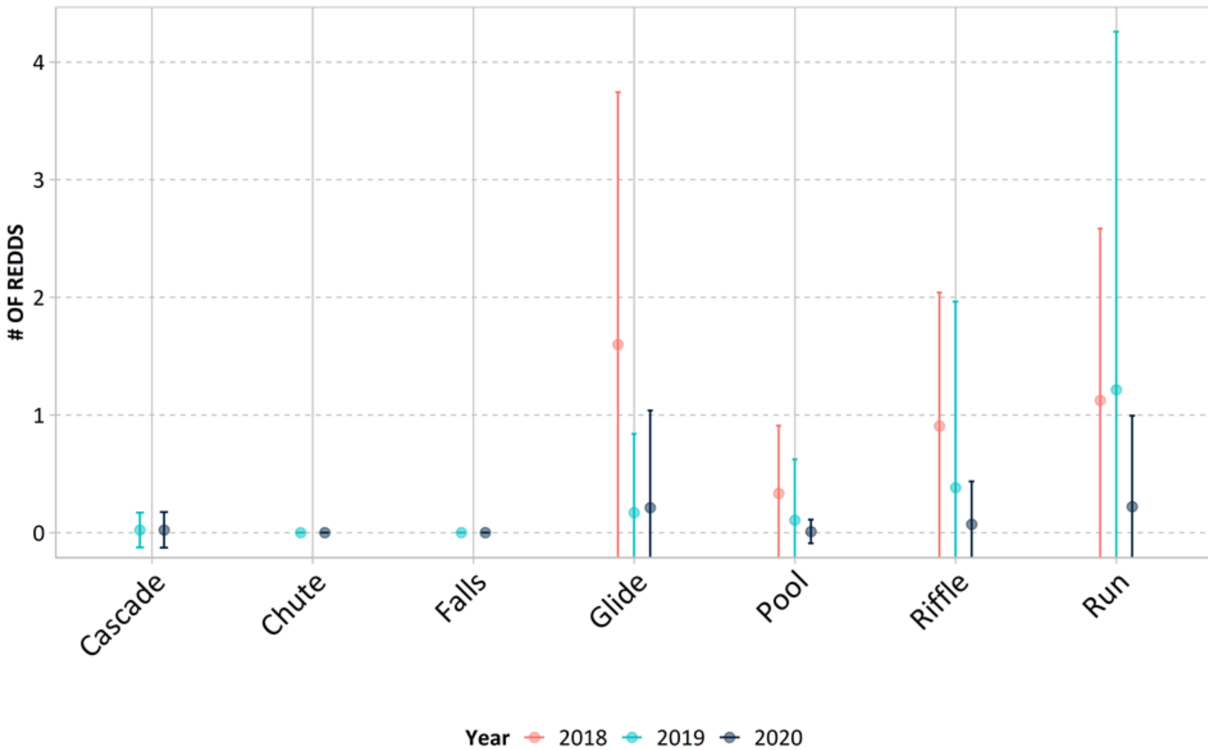


Table 8. Average stream temperature measured during WCT spawning from 2018-2020 in reference streams and mine-influenced streams in the Elk Valley.

Stream	Average Stream Temperature[1]		
	2018	2019	2020
Alexander Creek	-	7.7	5.0
Grace Creek	-	7.6	8.0
Upper Grave Creek	-	7.6	6.3
Lizard Creek	-	13.4	9.1
McCool Creek	-	7.5	6.9
South Line Creek	-	-	5.8
Clode Creek	15.1	12.6	10.9
Corbin Creek	-	10.7	7.7
Dry Creek (EVO)	-	10.4	10.1
Dry Creek (LCO)	10.4	7.3	7.3
Erickson Creek	-	7.1	-
Fish Pond Creek	9.5	7.5	6.4
Fording River	-	-	8.7
Harmer Creek	-	7.0	7.0
Henretta Creek	9.0	6.9	6.2
Line Creek	-	-	6.5
Lower Greenhills Creek	15.9	13.1	14.7
Michel Creek	-	8.5	7.8
Thompson Creek	-	13.2	13.8
Upper Greenhills Creek	-	8.1	9.1
Yearly Average[1]	12.0	9.2	8.3

[1] Average temperate at spawning season

Figure 12. Average Westslope Cutthroat Trout redd counts (± 1 SD) for each mesohabitat unit by mesohabitat type in tributaries of the Elk River, B.C. from 2018, 2019, and 2020.



3.2. Calcite Index and Fish Habitat

Calcite data are summarized by stream and mesohabitat type to provide an indication of the distribution of calcite in 2020 as compared to previous years of sampling. Calcite levels varied spatially within and among streams of the study area (Figure 13). The range of CI observed in 2020 (0 – 3) was similar to the range of CI observed in 2019 (0 – 2.87) from Hocking *et al.* (2020).

The highest calcite presence, calcite concretion, and CI were observed in Upper Greenhills, EVO Dry Creek, and Corbin Creek in 2020 (Figure 13). Average concretion in 2020 in Upper Greenhills, EVO Dry Creek and Corbin Creek was 1.54, 1.52 and 1.24, respectively. Moderate to low levels of concretion (mean concretion of ≤0.6) was observed in Clode Creek (0.59), Lower Greenhills Creek (0.32), McCool Creek (0.02), Harmer Creek (0.01) and Grace Creek (0.01). Trace levels of concretion were observed in LCO Dry Creek, Lizard Creek, Michel Creek, Fording River S8, and Fish Pond Creek with average concretion values lower than 0.01. No concretion was observed in Upper Grave Creek, Henretta Creek, Alexander Creek, Thompson Creek, Line Creek, and South Line Creek.

Moderate calcite presence (mean presence >0.5) was observed in three streams where no or trace levels of calcite concretion was recorded (Figure 13). These streams included Thompson Creek (mean CI_{Pres}=0.74), Fish Pond Creek (CI_{Pres}=0.66) and Line Creek (CI_{Pres}=0.60). In 2019, two reference streams, Lizard and McCool Creeks, where no mining developments exist upstream, showed moderate to high calcite presence values (means of CI_{Pres}=0.58 and CI_{Pres}=0.83, respectively). However, in 2020, the CI_{Pres} mean values observed for these two creeks was 0.31 for Lizard Creek and 0.20 for McCool Creek, suggesting a decrease in calcite presence levels in 2020 compared to 2019. Representative photos of high calcite presence, high calcite concretion, and low calcite presence are included in Figure 14, Figure 15, Figure 16, respectively.

Mean observed values of calcite concretion increased at least by 0.1 or more in 2020 in six streams in comparison to 2019, including Corbin, Clode, EVO Dry, Lower and Upper Greenhills, and McCool creeks (Figure 13). In contrast, calcite presence showed more inter-annual variability. It increased in four mine influenced streams, including Corbin, Fish Pond, Upper Greenhills, and Thompson creeks, and in two reference streams, Alexander and Grace creeks. Calcite presence also decreased in six mine influenced streams, including Michel, Harmer, Clode, Henretta, Lower Greenhills, and LCO Dry creeks, and in three reference streams, Lizard, Upper Grave, and McCool creeks.

Similar to 2019 and 2018, mean calcite concretion and calcite presence tended to be higher in mesohabitats with higher water velocities, such as in cascades, chutes, and falls, and lowest in pools (Figure 17).

The 20 stream reaches sampled in 2018, 2019, and 2020 differed in aquatic habitat such as water quality, habitat structure and spawning habitat availability. Average conditions per stream habitat variable sampled are shown in Appendix C. The FHAP maps with each redd location are also shown in Appendix B. Analyses of calcite coverage as compared to calcite presence are shown in Appendix D.

Figure 13. Average calcite presence, calcite concretion and CI (± 1 SD) for each mesohabitat unit by stream in 20 tributaries of the Elk River, B.C. from 2018, 2019, and 2020. CMO: Coal Mountain Operations, EVO: Elkview Operations, FRO: Fording River Operations, GHO: Greenhills Operations, LCO: Line Creek Operations.

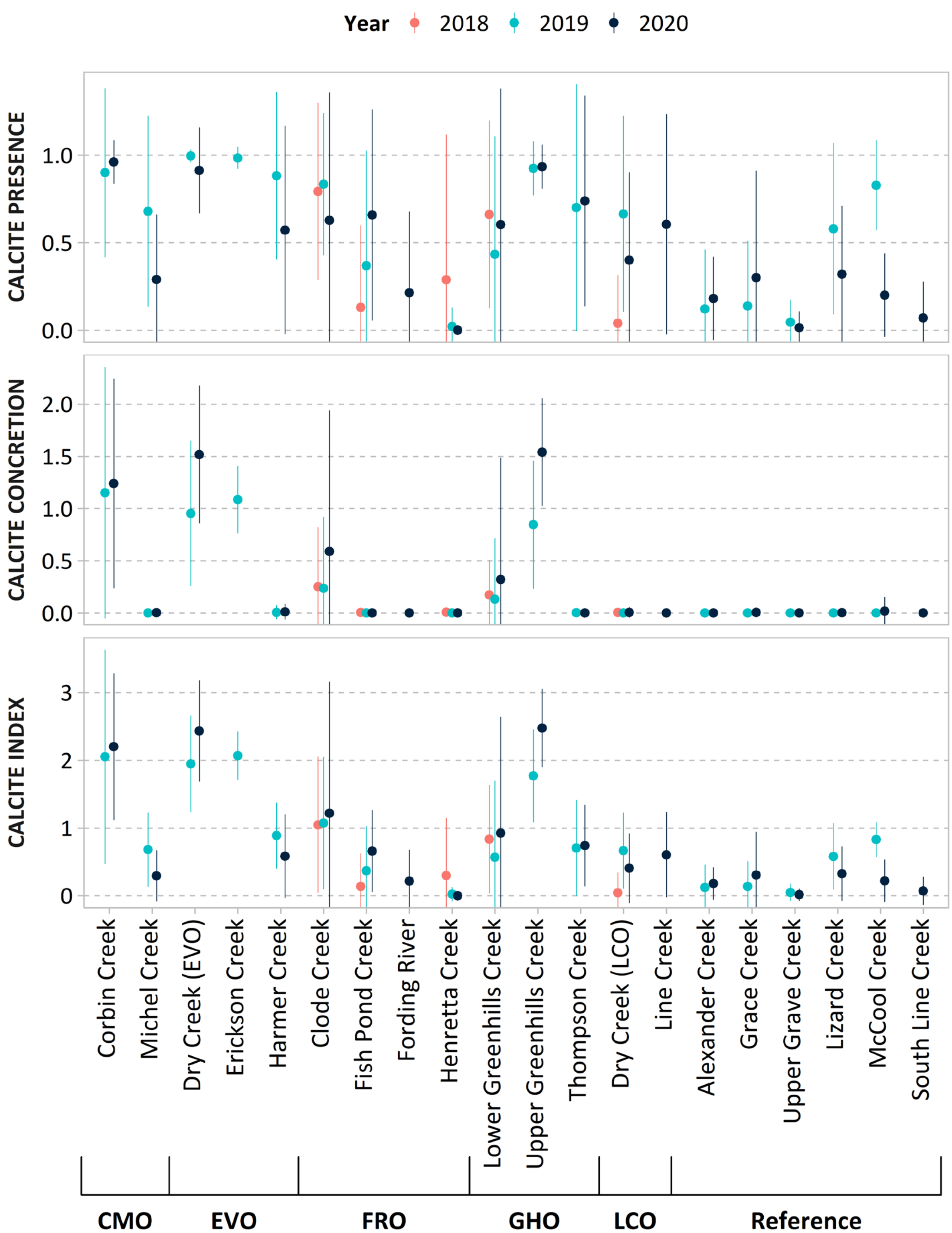
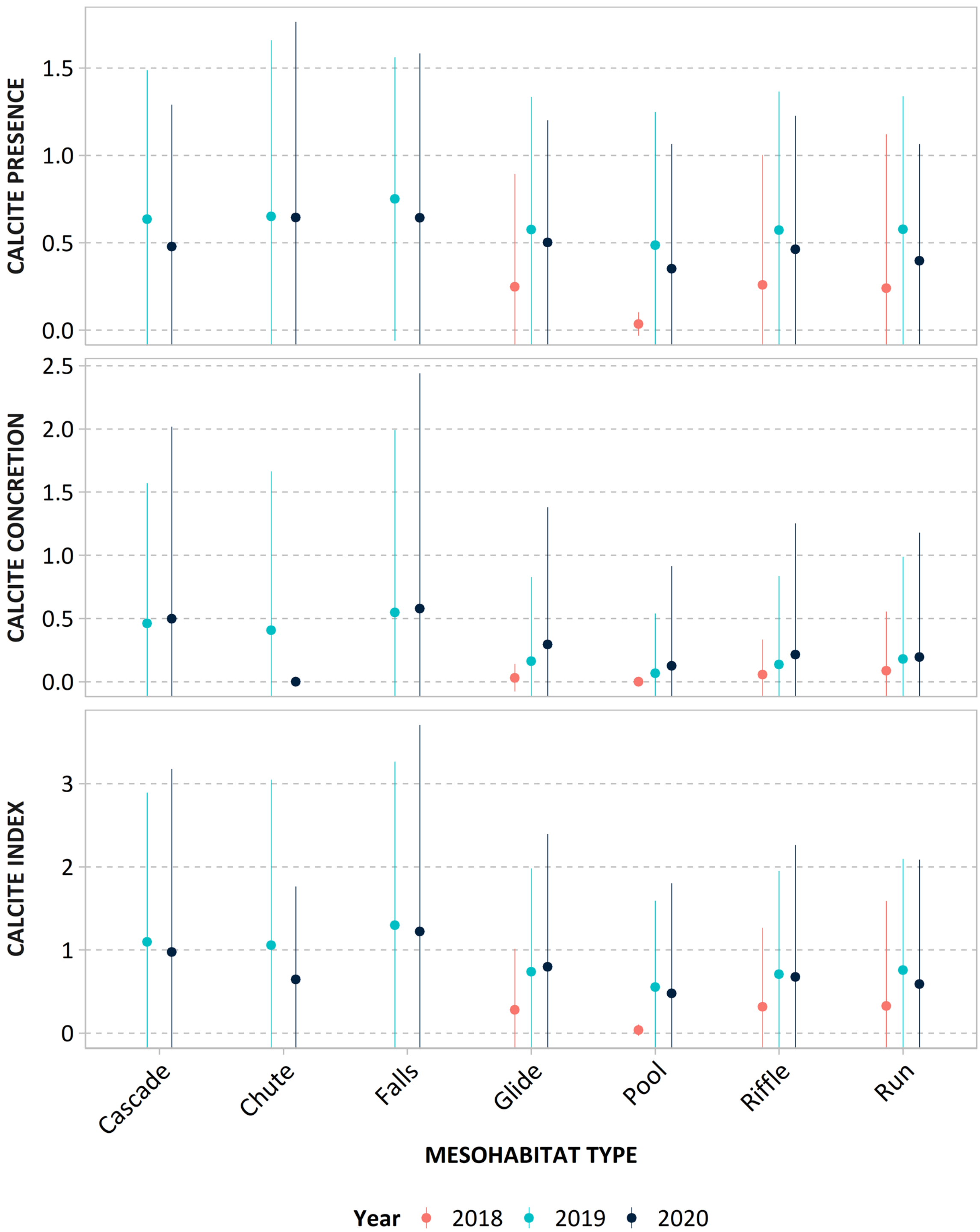


Figure 14. High calcite presence observed at a) Corbin Creek and b) Dry Creek (EVO).

Figure 15. High calcite concretion observed at a) Upper Greenhills Creek and b) Dry Creek (EVO).

Figure 16. Low calcite presence observed at Grave Creek on August 5, 2020.

Figure 17. Average calcite presence, calcite concretion and CI (± 1 SD) for each mesohabitat unit by mesohabitat type in 20 tributaries of the Elk River, B.C. from 2018, 2019, and 2020.



3.3. Redd Presence Model Selection Analysis

3.3.1. Univariate Models

Univariate models were developed between redd presence and CI, calcite presence, and calcite concretion as a simpler means to understand and visualize potential relationships between calcite and redd presence. Note that these relationships do not account for potential fish-habitat covariates, which is developed further in the GLMM and GAMM model selection analyses in Sections 3.3.2 and 3.3.3. An additional univariate model was also developed between redd presence and conductivity to better understand this relationship.

3.3.1.1. Calcite Index

A generalized additive model was applied to investigate the relationship between CI and the probability of redds being present in a mesohabitat. We observed a significant non-linear relationship between redd presence and CI (*p-value* < 0.001; (Figure 18). In particular, the model predicted an increase to a peak in the probability of redd presence at a CI score of 0.7, followed by a decrease in probability to close to zero at a CI score of 3. The curve shown in Figure 18 has a different shape than the one initially hypothesized and shown in the conceptual spawning suitability curve in Figure 2. The initial hypothesis for the relationship between CI and spawning suitability was that it would be S-shaped with an inflection point when spawning suitability begins to decline. Instead, spawning suitability may increase with increasing calcite up to a maximum and then subsequently decrease. CI is a composite of calcite presence and calcite concretion, and these two components of the calcite index may differ in their functional relationship with the probability of presence of WCT redds.

3.3.1.2. Calcite Presence

A generalized additive model was applied to investigate the effect of calcite presence on the likelihood of redds being present in a mesohabitat. Overall, we observed a significant non-linear relationship between redd presence and calcite presence (*p-value* < 0.001; Figure 19). In particular, the model suggested a hump-shaped relationship with the highest likelihood of redd presence associated with a calcite presence score of 0.70, where approximately 19% of units have redds. The probability of redd presence declined at higher values of calcite presence between 0.7 and 1.

3.3.1.3. Calcite Concretion

A univariate logistic regression was applied to investigate the effect of calcite concretion on the probability of redds being present in a mesohabitat. Overall, we observed a significant negative relationship between redd presence and calcite concretion (*p-value* = 0.008; Figure 20). The model suggested a monotonic decrease in predicted probability of redds being present with increasing values of calcite concretion. At a CI_{Conc} score of 0, the maximum predicted probability of redds being present was approximately 0.11. The probability of redd presence declined rapidly to a value close to zero at a concretion score of 2.

Figure 18. (a) Distribution of redd presence and absence by mesohabitat unit (raw points) and (a, b) the predicted probability of redd presence (solid black line – note different y-axis scales in a and b) in tributaries of the Elk River, BC as a function of CI. The solid line depicts the predicted probability of redd presence as a smoother function of CI, estimated from a generalized additive model. The points represent the observed redds by stream type (mine-influence versus reference streams).

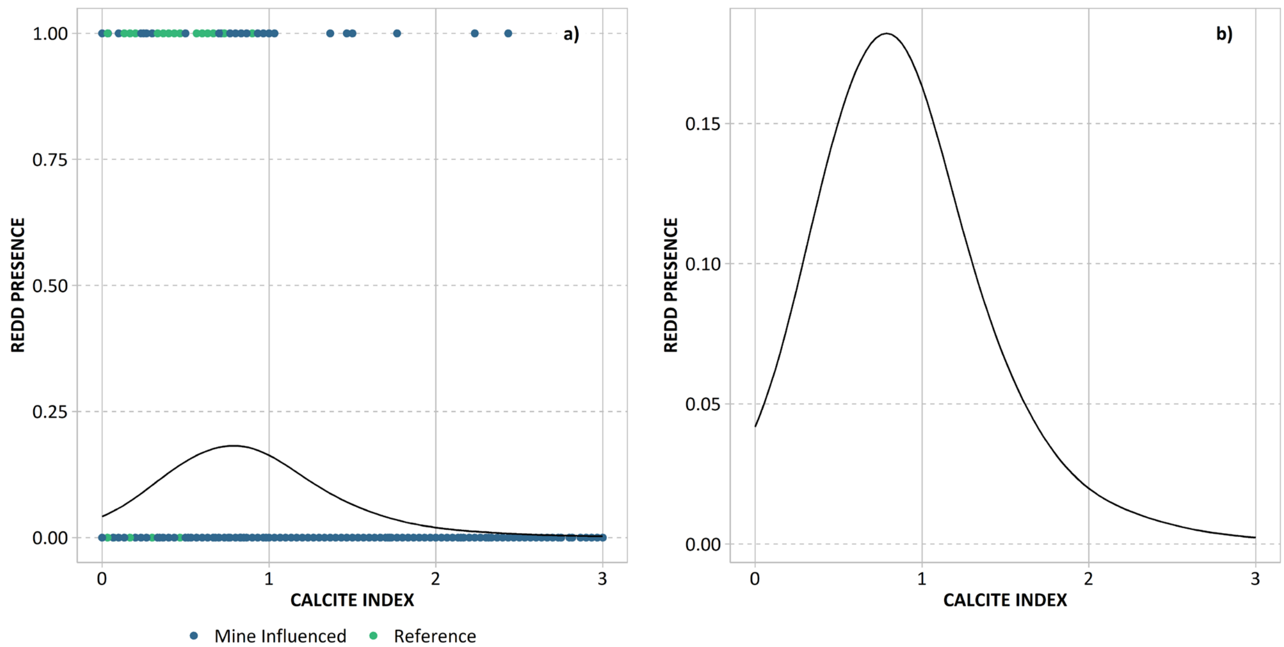


Figure 19. (a) Distribution of redd presence and absence by mesohabitat unit (raw points) and (a, b) the predicted probability of redd presence (solid black line – note different y-axis scales in a and b) in tributaries of the Elk River, BC as a function of calcite presence. The solid line depicts the predicted probability of redd presence as a smoother function of calcite presence, estimated from a generalized additive model. The points represent the observed redds by stream type (mine-influence versus reference streams).

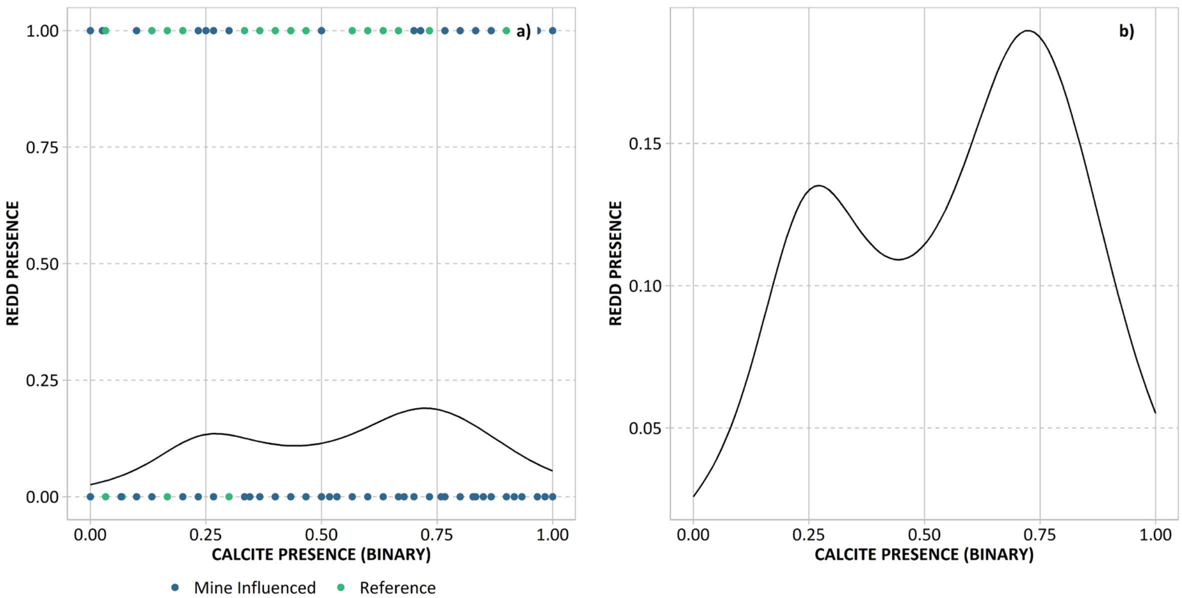
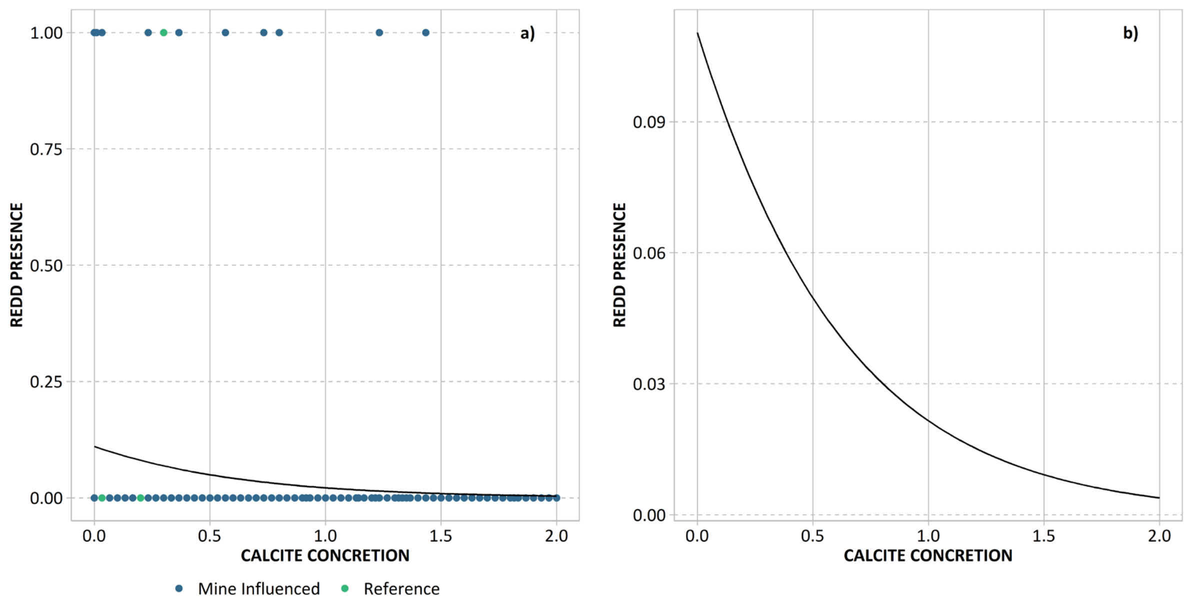


Figure 20. **(a) Distribution of redd presence and absence by mesohabitat unit (raw points) and (a, b) the predicted probability of redd presence (solid black line – note different y-axis scales in a and b) in tributaries of the Elk River, BC as a function of calcite concretion. The solid line depicts the predicted probability of redd presence as a function of calcite concretion, estimated from a logistic regression following a binomial error distribution and using a logit link function. The points represent the observed redds by stream type (mine-influence versus reference streams).**

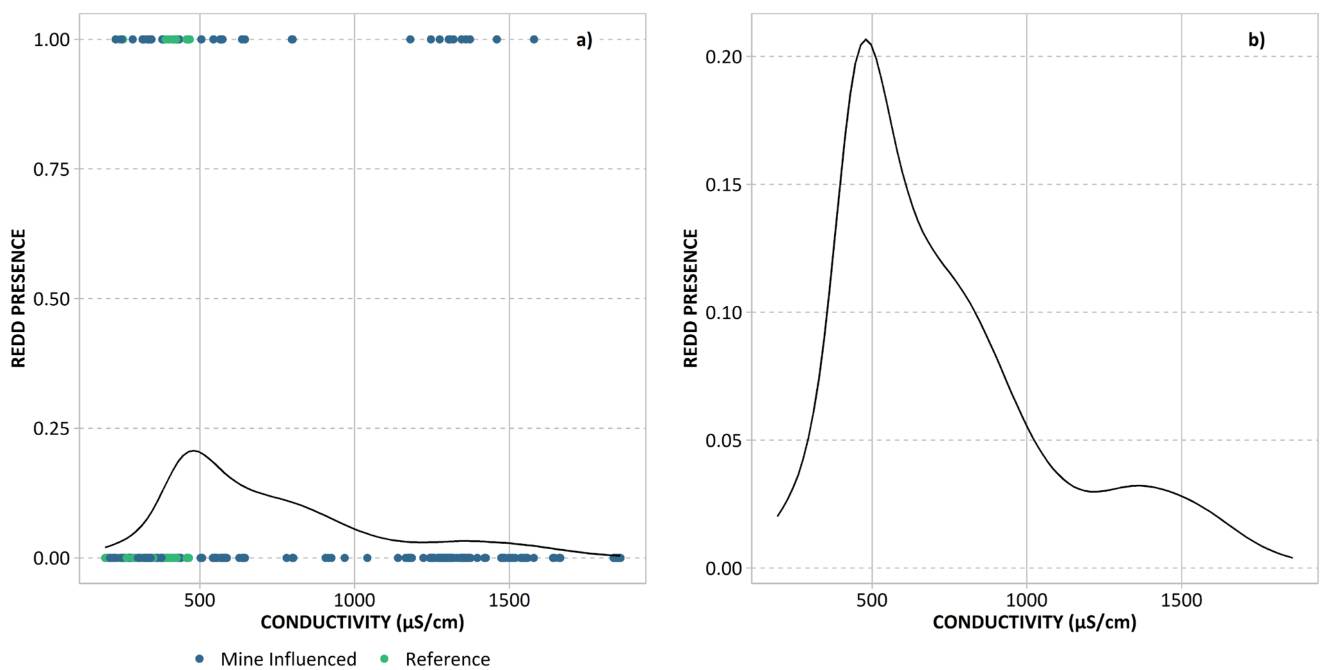


3.3.1.4. Conductivity

A generalized additive model was applied to explore the relationship between water conductivity and the probability of redds being present in a mesohabitat. We observed a significant and non-linear relationship between conductivity and redd presence (*p-value* < 0.001;

Figure 21). A highest probability (~0.20) was predicted at around 500 µS/cm, followed by a decreased in predicted probability. The lowest predicted probability of redd presence was associated with the maximum value of conductivity of 1860 µS/cm.

Figure 21. (a) Distribution of redd presence and absence by mesohabitat unit (raw points) and (a, b) the predicted probability of redd presence (solid black line – note different y-axis scales in a and b) in tributaries of the Elk River, BC as a function of water conductivity. The solid line depicts the predicted probability of redd presence as a smoother function of conductivity values, estimated from a generalized additive model. The points represent the observed redds by stream type (mine-influence versus reference streams).



3.3.2. Model Selection Analysis - GLMM

A GLMM model selection approach was used with a binomial distribution and a logit-link function to assess the relative importance of evaluated variables that explain WCT redd presence. The GLMM assesses the relationship between calcite and redd presence while accounting for additional fish-habitat variables. Separate analyses were completed across all streams (20 streams), mine-influenced streams only (14 streams), and reference streams (6 streams) to assess the sensitivity of the models to differences in the streams included in the model selection.

3.3.2.1. All-Streams

The most important variables to explain variance in redd presence across all streams among the evaluated variables were calcite concretion, calcite presence, habitat area, proportion of spawning gravel area, and pH (Figure 22). All variables within the restricted model set of those models whose ΔAICc <4 contain these terms (Table 9), and thus these variables have a relative variable importance (RVI) of 1. Mean water velocity was also marginally significant and had a RVI of 0.67.

The two retained calcite metrics, calcite concretion and presence, had opposite effects on the likelihood of redd presence. The effect of calcite concretion on the likelihood of redd presence was negative (i.e., calcite decreases the likelihood of presence), suggesting that WCT spawning is less likely to occur in concreted substrates. In comparison, calcite presence had a positive effect on the likelihood of redd presence. In combination with calcite concretion, these results suggested that WCT spawning was more likely to occur in mesohabitats where some calcite was present, but where substrate was not concreted.

CI was outcompeted by calcite presence and concretion in explaining redd presence in the study streams. Due to high collinearity between CI and calcite presence and concretion, the model selection was constrained to not allow CI in the same model with either calcite presence or concretion. Thus, the selection of calcite presence and concretion in all models suggested that these were better predictors than CI alone in explaining the variance of redd presence, which resulted in CI not being present in any of the top models (Table 9).

Mean calcite concretion scores were lower in sites where redds were present (mean CI_{Conc}=0.05, minimum CI_{Conc}=0, maximum CI_{Conc}=1.43) than sites where redds were absent (mean CI_{Conc}=0.28, minimum CI_{Conc}=0, maximum CI_{Conc}=2.00; Figure 23a). Variability in the presence of redds in the streams surveyed was explained by an exponentially decreasing function with a predicted probability of redd presence of ~0.06 at a calcite concretion score of 0 and quickly dropping to a probability close to zero by a calcite concretion value of 1 (Figure 23b). There is some uncertainty associated with this prediction; the 95% confidence interval associated with this prediction is shown in Figure 23b, c.

We summarized the observed likelihood of redd presence as a function of eight calcite concretion classes, where each class represents a calcite concretion interval (Figure 23c; Table 10). The model predictions from the all-streams average model were lower than the observed likelihood of redd presence at lower calcite classes; however, both observed and predicted likelihoods decreased exponentially at concretion levels above 0.5. Note that at low to moderate calcite concretions classes, the sample size was much smaller than at trace calcite concretion classes (< 0.01). This result highlights that there is the highest uncertainty at low to moderate levels of calcite concretion (CI_{Conc} from 0.1 to 1).

Mesohabitat area, proportion of spawning gravel area, and pH all had a positive effect on the likelihood of redd presence. Redd presence is more likely in larger mesohabitat units, in units with more suitable spawning gravel, and in mesohabitats with higher pH between 8 and 9.5. There was little evidence for an effect of bankfull depth, temperature, and functional LWD tally in predicting redd presence using this modelling approach.

Figure 22. Model averaged coefficients (with 95% confidence intervals) indicating the most important variables among the variables considered explaining redd presence in streams within the study area. Values in the x-axis are estimates of model parameters. RVI = Relative Variable Importance scores, where a score of 1 indicates that a predictor variable occurs in all top models with ΔAICc < 4.

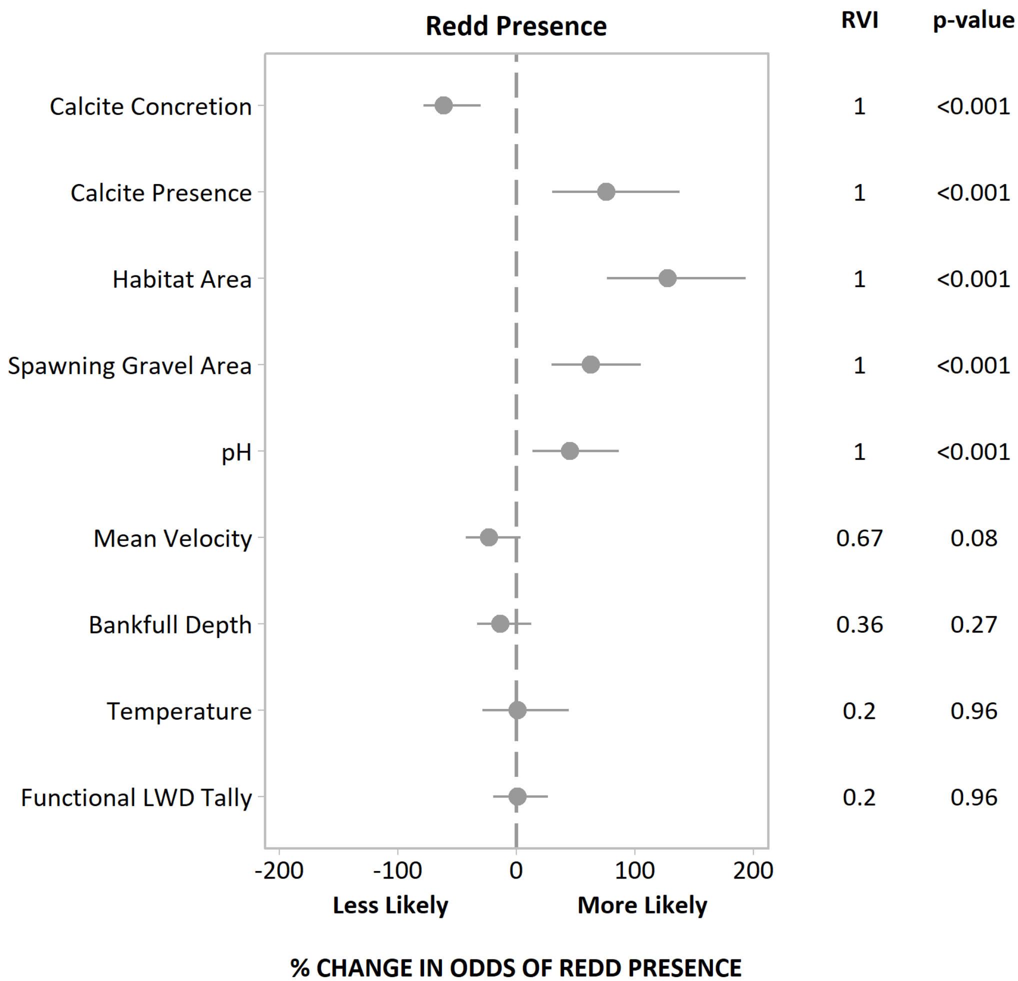


Figure 23. (a) Average calcite concretion score (± 95% confidence interval, based on bootstrapping procedure) at mesohabitat units with redds present and with redds absent in tributaries of the Elk River, B.C. (b, c) Probability of redd presence versus calcite concretion, including raw data in (b) and the average probability of redd presence by concretion class (p = # of units with redds present / total # of units by concretion class) in (c). The solid line represents the predicted probability of redd presence as a function of calcite concretion, where all other predictors are held at their means (estimated from a logistic regression model: model averaged parameter estimates for calcite shown in Figure 22). The shaded region represents the 95% confidence interval for the predicted probability of redd presence.

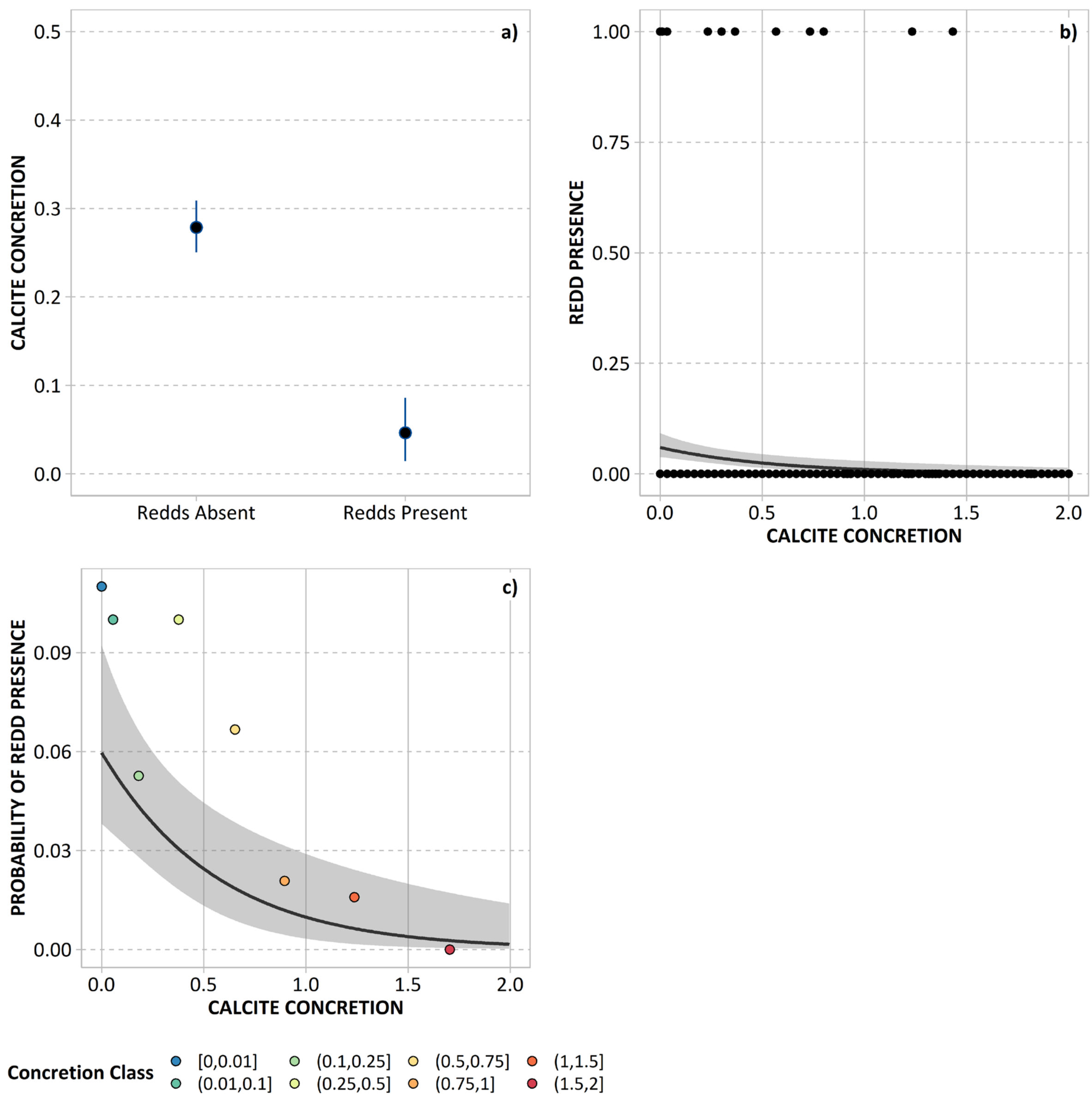


Table 9. Top models that predict Westslope Cutthroat Trout redd presence in tributaries of the Elk River, B.C. Models are ranked by Δ Akaike Information Criterion (ΔAICc) scores. The model with the lowest ΔAICc is the best model. Model weights (range 0-1) are also shown, which provide an estimate of the likelihood that a given model is the best model compared to the other top models in the model set.

Model			ΔAICc	Weight
Redd Presence	~	Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + Mean Velocity + pH	0.00	0.22
Redd Presence	~	Calcite Concretion + Calcite Presence + Bankfull Depth + Habitat Area + Spawning Gravel Area + Mean Velocity + pH	0.53	0.17
Redd Presence	~	Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + pH	0.77	0.15
Redd Presence	~	Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + Mean Velocity + pH + Temperature	2.03	0.08
Redd Presence	~	Calcite Concretion + Calcite Presence + Functional LWD Tally + Habitat Area + Spawning Gravel Area + Mean Velocity + pH	2.03	0.08
Redd Presence	~	Calcite Concretion + Calcite Presence + Bankfull Depth + Habitat Area + Spawning Gravel Area + pH	2.30	0.07
Redd Presence	~	Calcite Concretion + Calcite Presence + Functional LWD Tally + Bankfull Depth + Habitat Area + Spawning Gravel Area + Mean Velocity + pH	2.56	0.06
Redd Presence	~	Calcite Concretion + Calcite Presence + Bankfull Depth + Habitat Area + Spawning Gravel Area + Mean Velocity + pH + Temperature	2.56	0.06
Redd Presence	~	Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + pH + Temperature	2.74	0.06
Redd Presence	~	Calcite Concretion + Calcite Presence + Functional LWD Tally + Habitat Area + Spawning Gravel Area + pH	2.77	0.06

Table 10. Distribution of average of redd presence and # of mesohabitat units across calcite concretion class. The average was estimated as # of units with redds present / total # of units by concretion class.

Concretion Class	Average Redd Presence	Average Calcite Concretion	# of Mesohabitats
[0,0.01]	0.11	0.00	1036
(0.01,0.1]	0.10	0.06	20
(0.1,0.25]	0.05	0.18	19
(0.25,0.5]	0.10	0.38	20
(0.5,0.75]	0.07	0.65	30
(0.75,1]	0.02	0.90	48
(1,1.5]	0.02	1.24	128
(1.5,2]	0.00	1.70	72

3.3.2.2. Mine-Influenced Streams

To further investigate the effects of calcite on WCT spawning suitability, the same logistic regression analysis was applied to mine-influenced streams only. Mine-influenced streams include Corbin Creek, Michel Creek, EVO and LCO Dry Creeks, Erickson Creek (2019 only), Harmer Creek, Clode Creek, Fish Pond Creek, Fording River S8, Henretta Creek, Lower and Upper Greenhills Creeks, Thompson Creek and Line Creek. Mesohabitats within mine-influenced streams represented approximately 63.9% of all surveyed mesohabitats.

Based on data collected and analysis performed in mine influence streams only, the most important variables (i.e., RVI = 1) to explain the variability in the likelihood of redd presence were calcite concretion, calcite presence, habitat area, and proportion of spawning gravel (Figure 24; Table 11). Similar to the all-streams analysis (Section 3.3.2.1), the two retained calcite metrics, calcite concretion and presence, had opposite effects on the likelihood of redd presence. Model selection statistics for models within ΔAICc < 4 are detailed in Table 11. The effect of calcite concretion on the likelihood of redd presence was negative, suggesting that WCT spawning is less likely to occur in concreted substrates, whereas calcite presence had a positive effect on the likelihood of redd presence. In combination with calcite concretion, these results suggested that WCT spawning was more likely to occur in mesohabitats where calcite was present, but where substrate was not concreted within the mine-influenced streams.

Figure 24. Model averaged coefficients (with 95% confidence intervals) indicating the most important variables among the variables considered explaining redd presence in mine-influenced streams. Values in the x-axis are estimates of model parameters. RVI = Relative Variable Importance scores, where a score of 1 indicates that a predictor variable occurs in all top models with ΔAICc < 4.

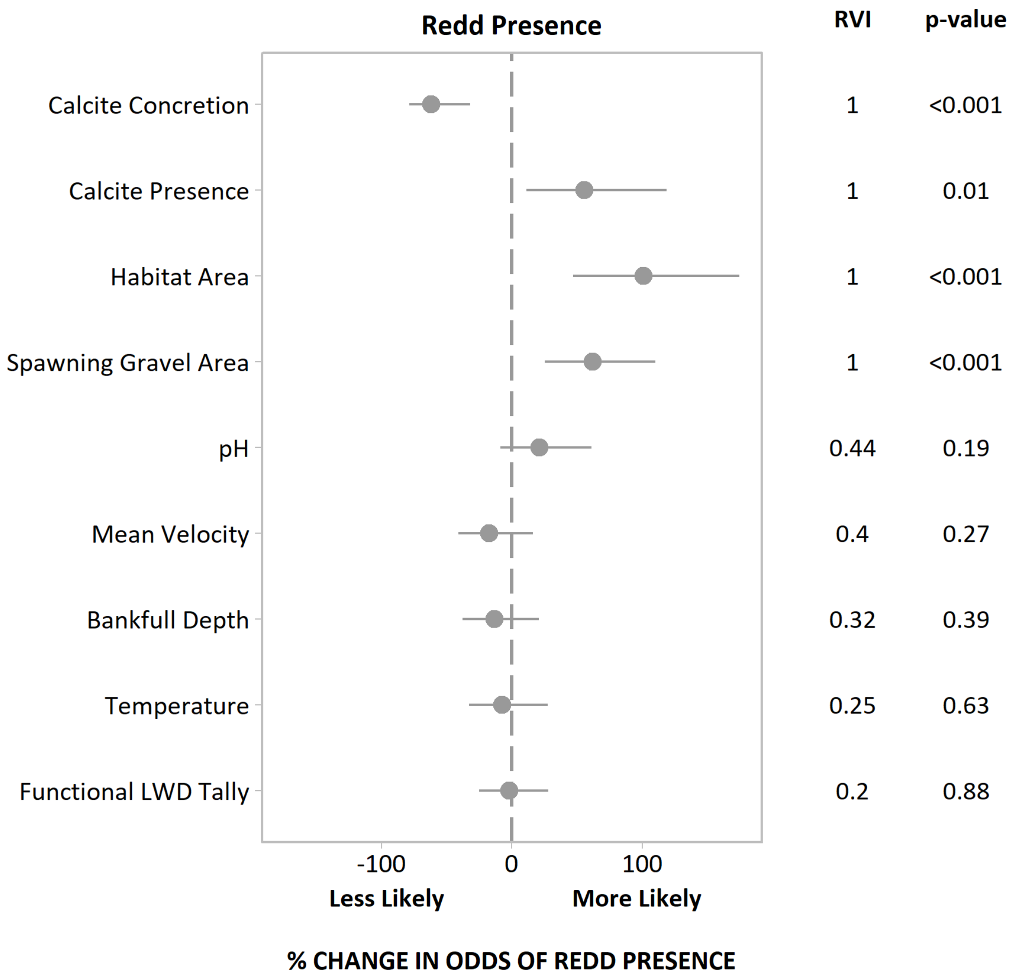


Table 11. Top models that predict Westslope Cutthroat Trout redd presence in mine influenced tributaries of the Elk River, B.C. Models are ranked by Δ Akaike Information Criterion (ΔAICc) scores. The model with the lowest ΔAICc is the best model. Model weights (range 0-1) are also shown, which provide an estimate of the likelihood that a given model is the best model compared to the other top models in the model set.

Model			ΔAICc	Weight
Redd Presence	~	Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area	0.00	0.13
Redd Presence	~	Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + pH	0.47	0.10
Redd Presence	~	Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + Mean Velocity + pH	1.08	0.07
Redd Presence	~	Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + Mean Velocity	1.21	0.07
Redd Presence	~	Calcite Concretion + Calcite Presence + Bankfull Depth + Habitat Area + Spawning Gravel Area	1.25	0.07
Redd Presence	~	Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + Temperature	1.92	0.05
Redd Presence	~	Calcite Concretion + Calcite Presence + Bankfull Depth + Habitat Area + Spawning Gravel Area + Mean Velocity	2.01	0.05
Redd Presence	~	Calcite Concretion + Calcite Presence + Functional LWD Tally + Habitat Area + Spawning Gravel Area	2.04	0.05
Redd Presence	~	Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + pH + Temperature	2.09	0.04
Redd Presence	~	Calcite Concretion + Calcite Presence + Bankfull Depth + Habitat Area + Spawning Gravel Area + pH	2.10	0.04

3.3.2.3. Reference Streams

The GLMM analysis was applied to only reference streams to assess the natural range of factors that may affect WCT spawning suitability. Reference streams include Alexander Creek, Grace Creek, McCool Creek, Lizard Creek, South Line Creek and Upper Grave Creek. Mesohabitats within reference streams represented 36.1 % of all surveyed mesohabitats between 2019 and 2020.

Contrary to all-streams and mine-influenced streams analyses, habitat availability and water quality variables were the most important predictors among the evaluated variables for redd presence within reference streams. Based on data collected and analysis performed in reference streams only, the most important variables to explain variability in the presence of redds in reference streams were habitat area (RVI = 1), and proportion of spawning gravel area (RVI = 0.96; Figure 25). Stream conductivity was also a significant positive predictor of the probability of redd presence in reference streams (RVI = 0.60). Model selection statistics for models within ΔAICc < 4 are detailed in Table 12.

Calcite metrics, such CI, presence, or concretion had low importance in explaining the likelihood of redd presence in reference stream mesohabitats (RVI scores of 0.24, 0.16 and 0.04, respectively). Note that both CI and calcite presence were significant positive predictors of redd presence (albeit their low RVI scores), which likely means that CI and calcite presence explain similar variance in the probability of redd presence in reference streams to stream conductivity (positive effect on redds). However, due to high collinearity, CI and calcite presence were prevented to be included with conductivity in the same models and were outcompeted by conductivity in predicting redd presence. In comparison, calcite concretion only occurs at trace levels within reference streams, and therefore it makes sense that concretion is not a strong predictor of redd presence in reference streams.

Figure 25. Model averaged coefficients (with 95% confidence intervals) indicating the most important variables among the variables considered explaining redd presence in reference streams. Values in the x-axis are estimates of model parameters. RVI = Relative Variable Importance scores, where a score of 1 indicates that a predictor variable occurs in all top models with ΔAICc < 4.

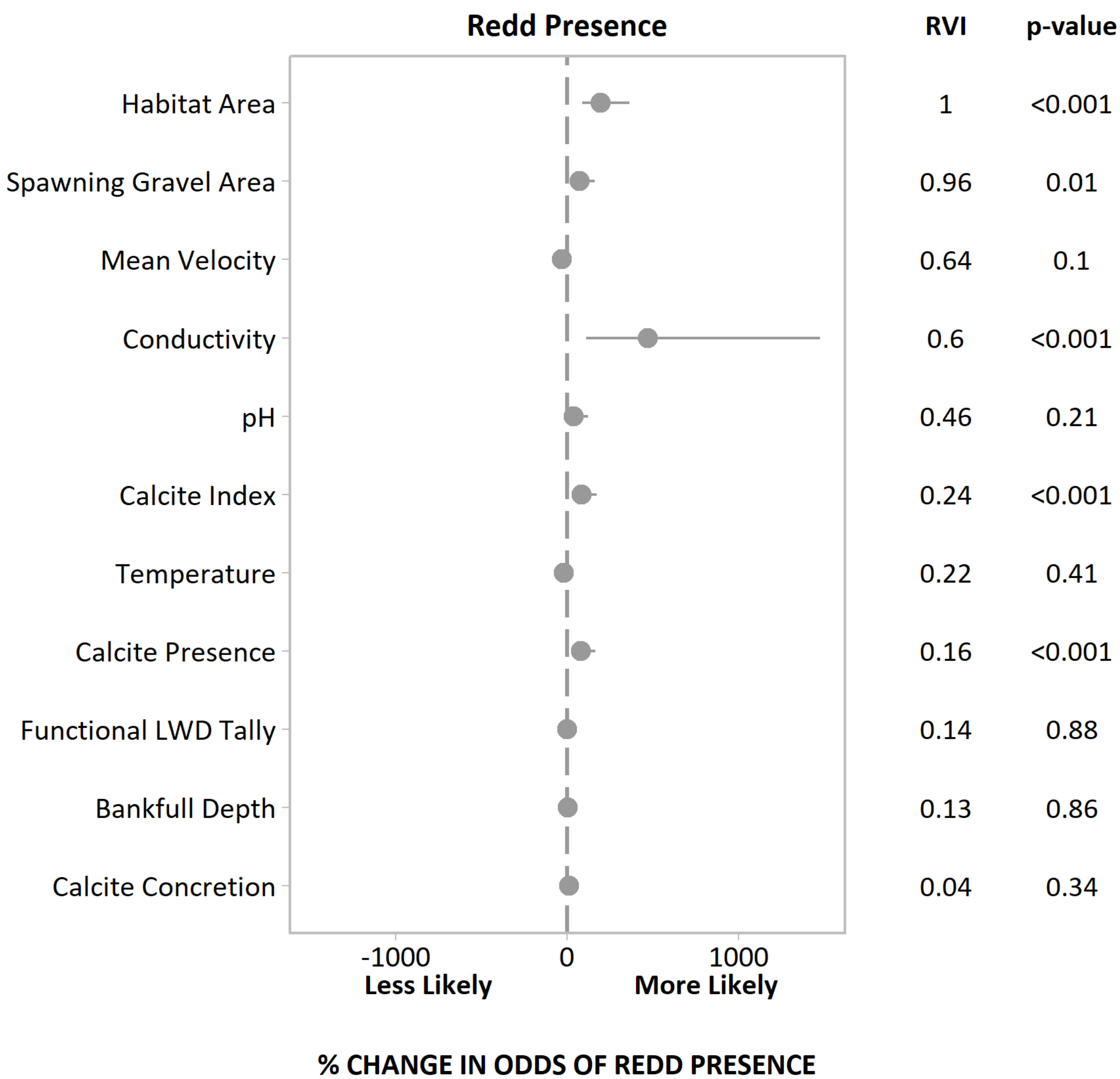


Table 12. Top models that predict Westslope Cutthroat Trout redd presence in reference tributaries of the Elk River, B.C. Models are ranked by Δ Akaike Information Criterion (ΔAICc) scores. The model with the lowest ΔAICc is the best model. Model weights (range 0-1) are also shown, which provide an estimate of the likelihood that a given model is the best model compared to the other top models in the model set.

Model			ΔAICc	Weight
Redd Presence	~	Conductivity + Habitat Area + Spawning Gravel + Mean Velocity	0.00	0.11
Redd Presence	~	Conductivity + Habitat Area + Spawning Gravel	0.81	0.07
Redd Presence	~	Conductivity + Habitat Area + Spawning Gravel + Mean Velocity + Temperature	1.40	0.06
Redd Presence	~	Calcite Index + Habitat Area + Spawning Gravel + Mean Velocity + pH	1.60	0.05
Redd Presence	~	Calcite Index + Habitat Area + Spawning Gravel + pH	1.80	0.05
Redd Presence	~	Conductivity + Functional LWD Tally + Habitat Area + Spawning Gravel + Mean Velocit	1.96	0.04
Redd Presence	~	Conductivity + Habitat Area + Spawning Gravel + Mean Velocity + pH	2.00	0.04
Redd Presence	~	Calcite Presence + Habitat Area + Spawning Gravel + Mean Velocity + pH	2.04	0.04
Redd Presence	~	Conductivity + Bankfull Depth + Habitat Area + Spawning Gravel + Mean Velocity	2.05	0.04
Redd Presence	~	Calcite Presence + Habitat Area + Spawning Gravel + pH	2.34	0.03

3.3.3. Model Selection Analysis - GAMM

We applied a GAMM model selection approach to explain the variability of the likelihood redd presence, while allowing for non-linear relationships between the predictor variables and redd presence. The GAMM assesses the relationship between calcite and redd presence while accounting for additional fish-habitat variables and potential non-linear relationships. The GAMM was applied to all streams surveyed between 2019 and 2020. In total, 768 GAMMs were designed and competed that included all possible combinations of the final set of predictors.

The final model, selected with the lowest AICc, retained the variables calcite concretion (*p-value* = 0.003; χ^2 = 9.03), calcite presence (*p-value* = 0.008; χ^2 = 7.10), habitat area (*p-value* < 0.001; χ^2 = 40.33), proportion of spawning gravel area (*p-value* = 0.002; χ^2 = 10.00), mean velocity (*p-value* = 0.004; χ^2 = 14.46) and pH (*p-value* = 0.048; χ^2 = 3.93; Figure 26), and explained 30.9% of all variance. This model is very similar to the redd presence model across all streams using the GLMM. The one exception is that the GAMM better accounts for a non-linear relationship between water velocity and spawning suitability.

Like all streams GLMM (section 3.3.2.1), the two retained calcite metrics, calcite concretion and presence, had opposite effects on the likelihood of redd presence. The calcite concretion smoother suggested a significant decrease in likelihood of redd presence with calcite concretion. In contrast, calcite presence had a positive relationship on the likelihood of redd presence. In combination with calcite concretion, these results suggested again that WCT spawning was more likely to occur in mesohabitats where calcite was present but was not concreted (Figure 26).

Other fish habitat variables, such as habitat availability and water conditions were also found to explain redd presence throughout the study streams. The smoother for mean velocity exhibited a hump-shaped relationship with redd presence, where the probability of redd presence was low at low water velocities, highest at intermediate velocities (~0.4 m/s), and then decreased to values near zero at 1 m/s water velocity or higher. The smoother for habitat area indicated a strong positive relationship between habitat area and the probability of redd presence up to a maximum threshold, where above 1000 m^2 there was no further increase in the likelihood of redds being present. Lastly, the smoother for proportion of spawning gravel area suggested a positive relationship with redd presence, where the probability of redd presence increased with increasing suitable spawning gravel.

We summarized the observed likelihood of redd presence as a function of eight calcite concretion classes, where each class represented a calcite concretion interval (Figure 27). The model predictions were similar to the observed values of redd presence. For instance, at CI_{Conc} scores of zero, the model predicts a maximum probability of approximately 0.1, and rapidly decreases to values below 0.02 above CI_{Conc} of 1. There remains significant uncertainty associated with these predictions; the 95% confidence interval associated with these predictions is shown in Figure 27.

The relationship between calcite concretion and the likelihood of redd presence was assessed under average, optimal, and sub-optimal spawning habitat conditions using the top GAMM model for redd presence (Figure 28). The three spawning habitat condition scenarios showed a consistent percent decrease as CI_{Conc} increases; however, the absolute declines in the probability of presence under optimal stream conditions was much higher than average conditions, which was higher than in sub-optimal conditions (Figure 28). At CI_{Conc} of zero, and under optimal stream conditions, the predicted probability of redd presence was 0.56, while in average conditions the predicted probability was 0.10, and under sub-optimal conditions near zero. At CI_{Conc} of 0.5, and under optimal stream conditions, the predicted the average probability of redd presence was 0.34, while under average conditions it was 0.05 and in sub-optimal approximately zero. This represented a decrease of between 40% and 50% in predicted probability of redd presence between CI_{Conc} 0 and 0.5 across the stream condition scenarios. There remains significant uncertainty with these predictions; the 95% confidence interval associated with the relationship between calcite concretion and the probability of redd presence is shown in Figure 28.

Figure 26. Predicted probability of redd presence at mesohabitat units in tributaries of the Elk River, BC. The solid line depicts the predicted probability of redd presence as a smoother function of calcite concretion (*p-value* = 0.003; χ^2 = 9.03), calcite presence (*p-value* = 0.008; χ^2 = 7.10), mesohabitat area (*p-value* < 0.001; χ^2 = 40.33), proportion of spawning gravel area (*p-value* = 0.002; χ^2 = 10.00), mean velocity (*p-value* = 0.004; χ^2 = 14.46), and pH (*p-value* = 0.048; χ^2 = 3.93), estimated from a generalized additive mixed effects model. The shaded region represents the 95% confidence interval for the predicted probability of redd presence.

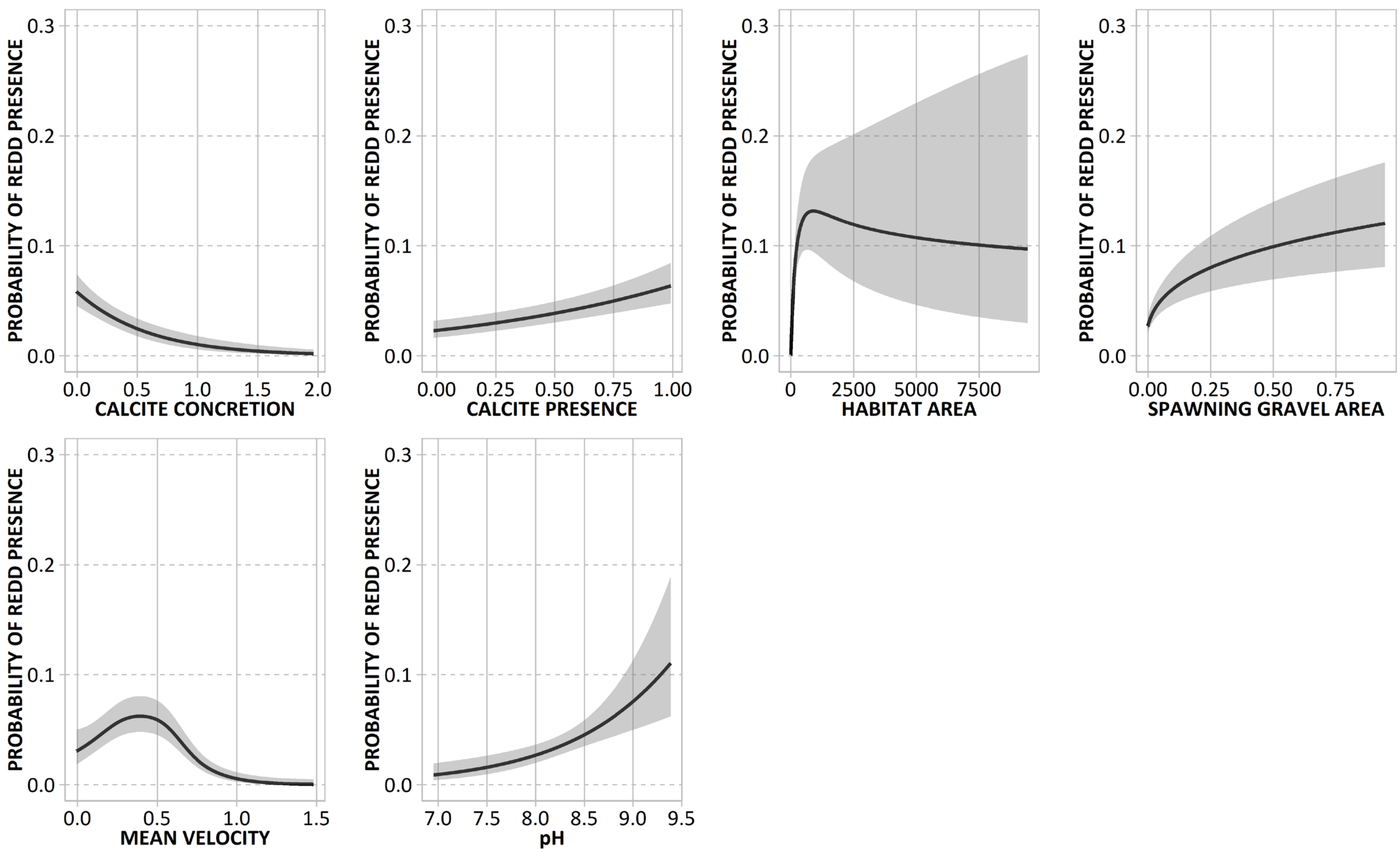


Figure 27. Average probability of redd presence by concretion class (# of units with redds present / total # of units by concretion class). The solid line represents the predicted probability of redd presence as a function of calcite concretion, where all other predictors are held at their means (estimated from a generalized additive mixed effects model shown in Figure 26). The shaded region represents the 95% confidence interval for the predicted probability of redd presence.

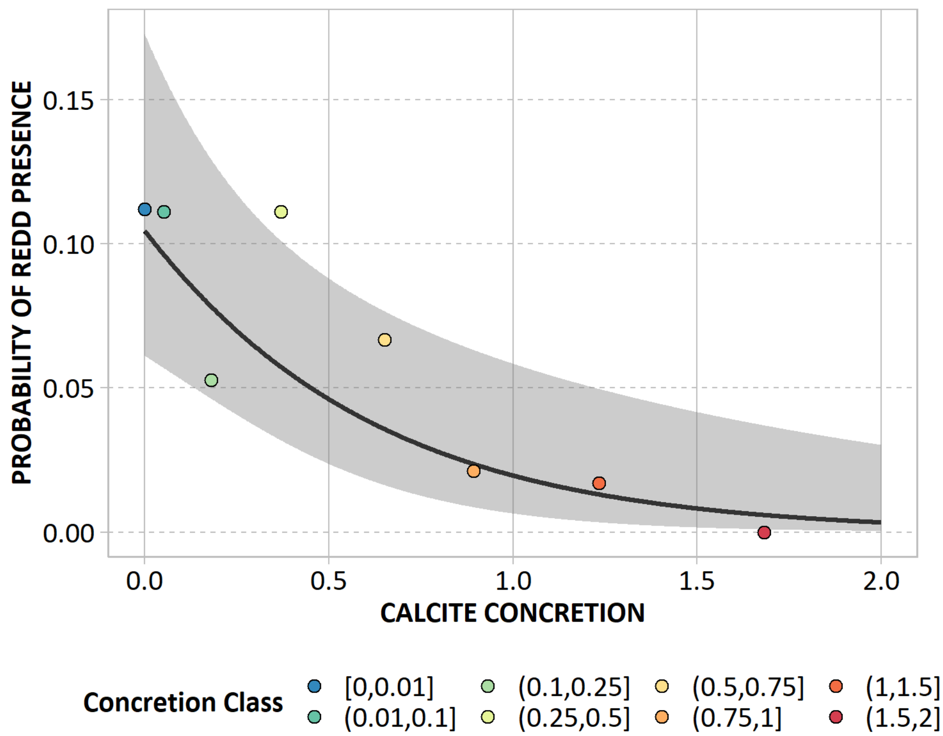
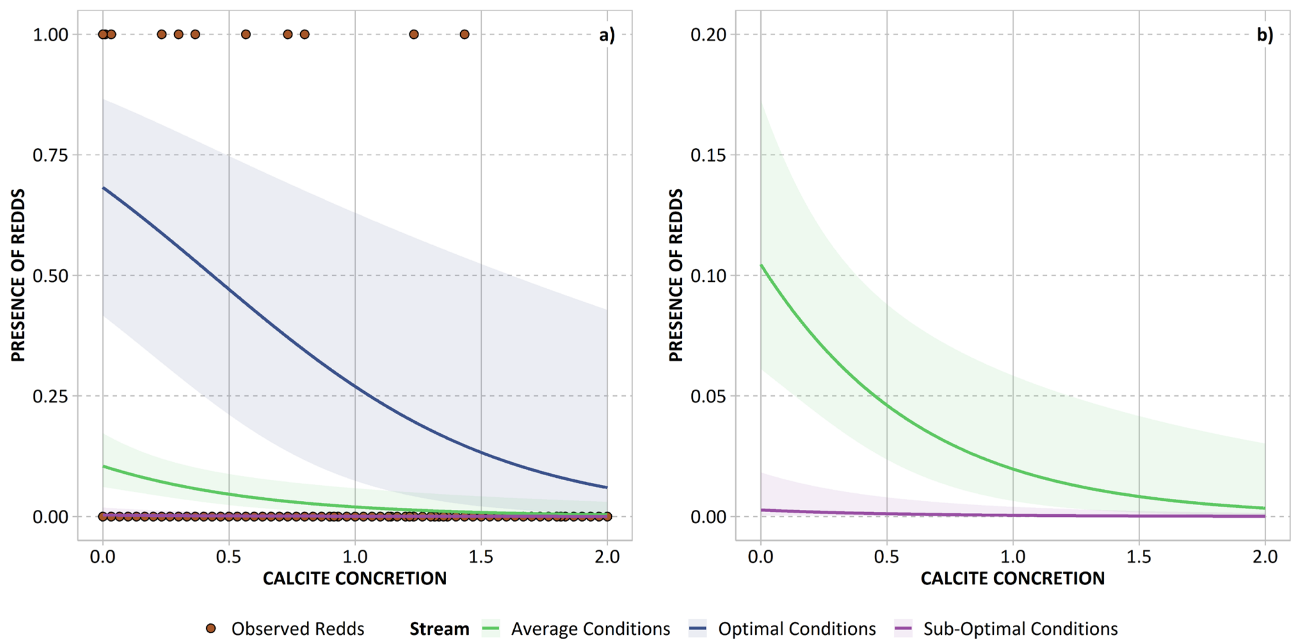


Figure 28. **Average predicted probability of redd presence as a function of calcite concretion and stream spawning habitat conditions, where all other fish habitat variables are held at their means (green line – same plot as Figure 27), held at optimal conditions (values that maximise the predicted number of redds; blue line), and in sub-optimal conditions (values that minimise the predicted number of redds; purple line). The y-axis scale differs between panel a) and b). These predictions were estimated from a generalized additive mixed effects model shown in Figure 26. The shaded regions represent the 95% confidence interval for the predicted probability of redd presence for each stream condition.**



3.4. Redd Count Model Selection Analysis

3.4.1. Univariate Models

Univariate models were developed between redd counts and CI, calcite presence, and calcite concretion as a simpler means to understand and visualize potential relationships between calcite and redd counts. Note that these relationships do not account for potential fish-habitat covariates, which is developed further in the GLMM and GAMM model selection analyses in Sections 3.4.2, 3.4.3., and 3.4.4. An additional univariate model was also developed between redd counts and conductivity to better understand this relationship.

3.4.1.1. Calcite Index

A univariate GAM was applied to investigate the effect of CI on the number of redds in a mesohabitat. We observed a significant non-linear relationship between redd counts and CI (*p-value* < 0.001; Figure 29). In particular, the model predicted a peak in number of redds of approximately 0.68 per mesohabitat at CI score of 0.66, followed by a decreased in the redd counts. This univariate model of redd counts with CI is similar to the model with redd presence shown in Section 3.3.1.1. and differs in shape from the original conceptual curve shown in Figure 2. Redd counts increase with increasing calcite presence up to a CI of 0.66 and then decrease as concretion begins to occur.

3.4.1.2. Calcite Presence

A univariate GAM was applied to investigate the effect of calcite presence on the average number of redds in a mesohabitat. Overall, we observed a significant non-linear relationship between redd counts and calcite presence (*p-value* < 0.001; Figure 30). In particular, the model suggested a hump-shaped relationship with a peak in the number of redds per mesohabitat unit at a calcite presence score of ~0.70 (approximately 0.76 redds). The position of the peak with calcite presence is similar to the peak for CI. Redd counts decline to an average of ~0.1 redd per mesohabitat unit at a calcite presence score of 1, which coincides with higher calcite concretion.

3.4.1.3. Calcite Concretion

A univariate GLM was applied to investigate the effect of calcite concretion on the average number of redds present in a mesohabitat. Overall, we observed a significant negative relationship between redd counts and calcite concretion (*p-value* < 0.0001; Figure 31). The model suggested a monotonic decrease in predicted number of redds being present with increasing values of calcite concretion. At a calcite concretion score of 0, the maximum predicted number of redds was approximately 0.4. The predicted number of redds decreased to near zero at a concretion score of 2.

Figure 29. (a) Distribution of observed redd counts by mesohabitat unit (raw points) and (a, b) the predicted average count of redds (solid black line – note different y-axis scales in a and b) in tributaries of the Elk River, BC as a function of CI. The solid line depicts the predicted average count of redds as a smoother function of CI, estimated from a generalized additive model. The points represent the observed redds by stream type (mine-influence versus reference streams).

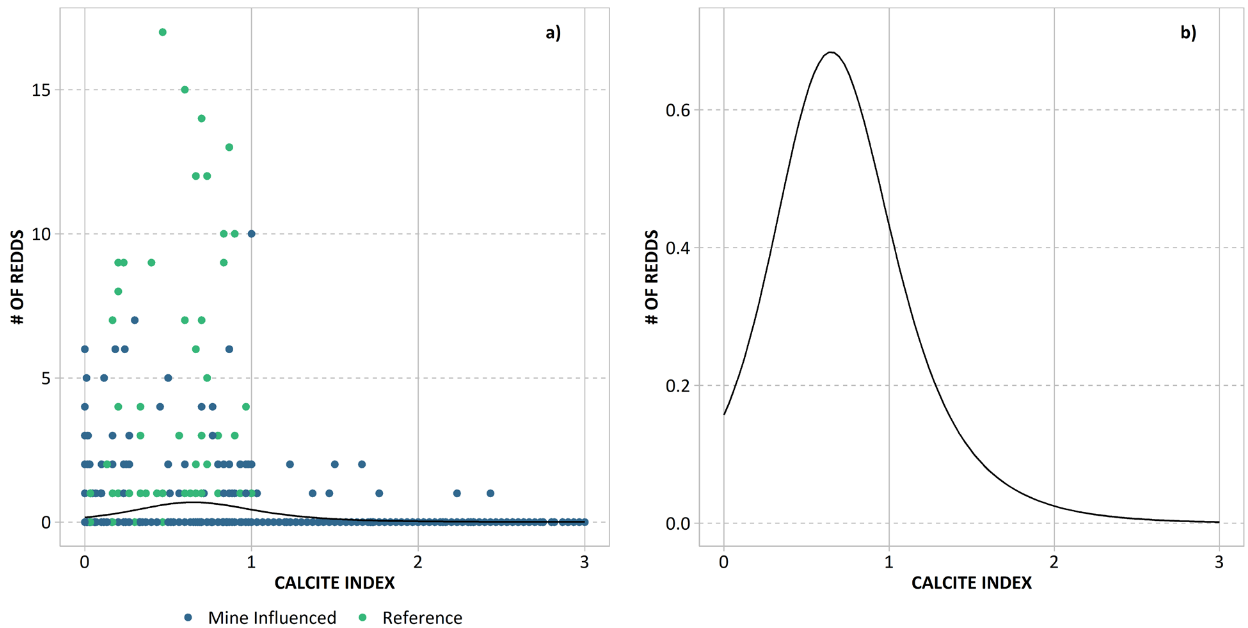


Figure 30. (a) Distribution of observed redd counts by mesohabitat unit (raw points) and (a, b) the predicted average count of redds (solid black line – note different y-axis scales in a and b) in tributaries of the Elk River, BC as a function of calcite presence. The solid line depicts the predicted average count of redds as a smoother function of calcite presence, estimated from a generalized additive model. The points represent the observed redds by stream type (mine-influence versus reference streams).

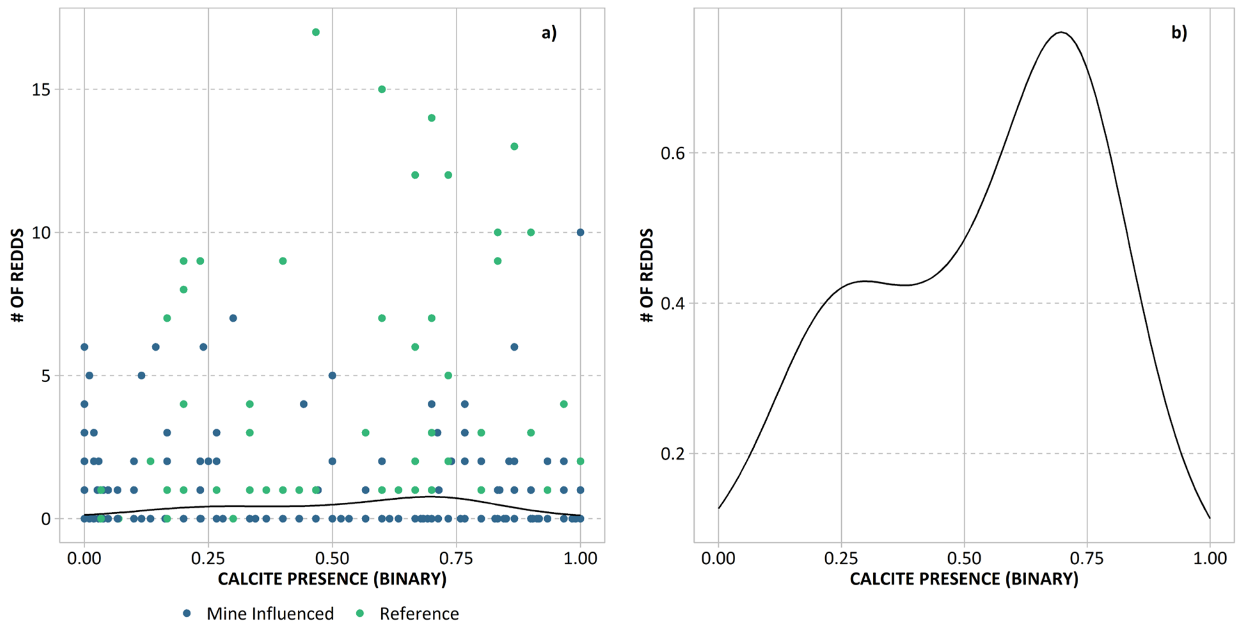
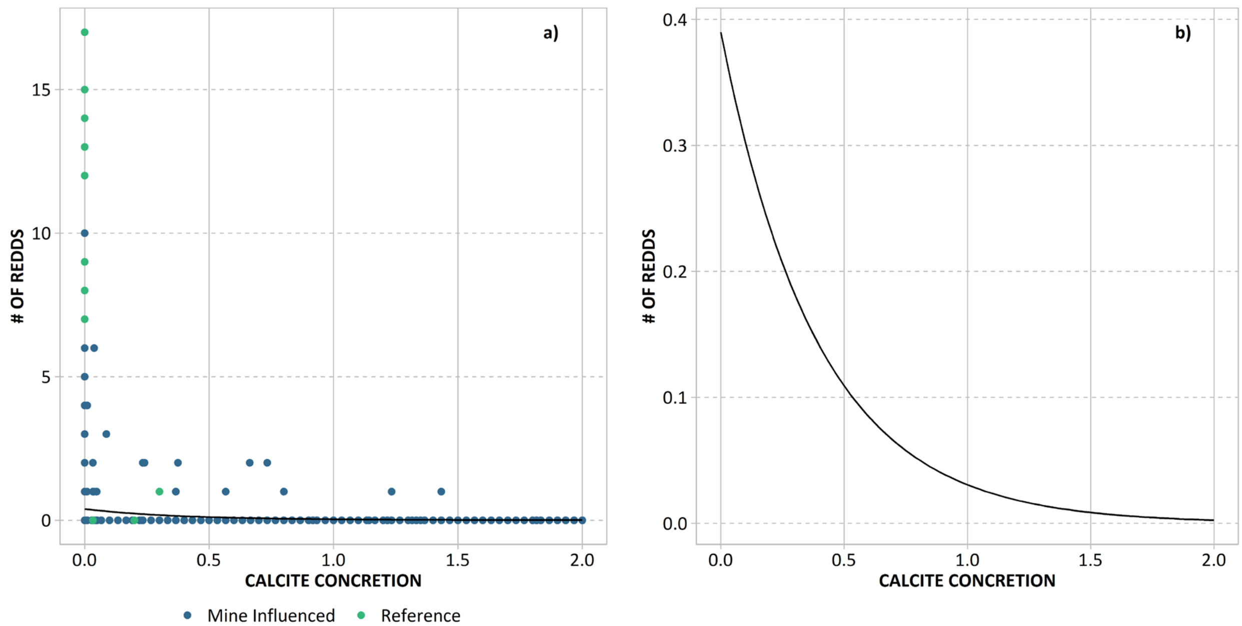


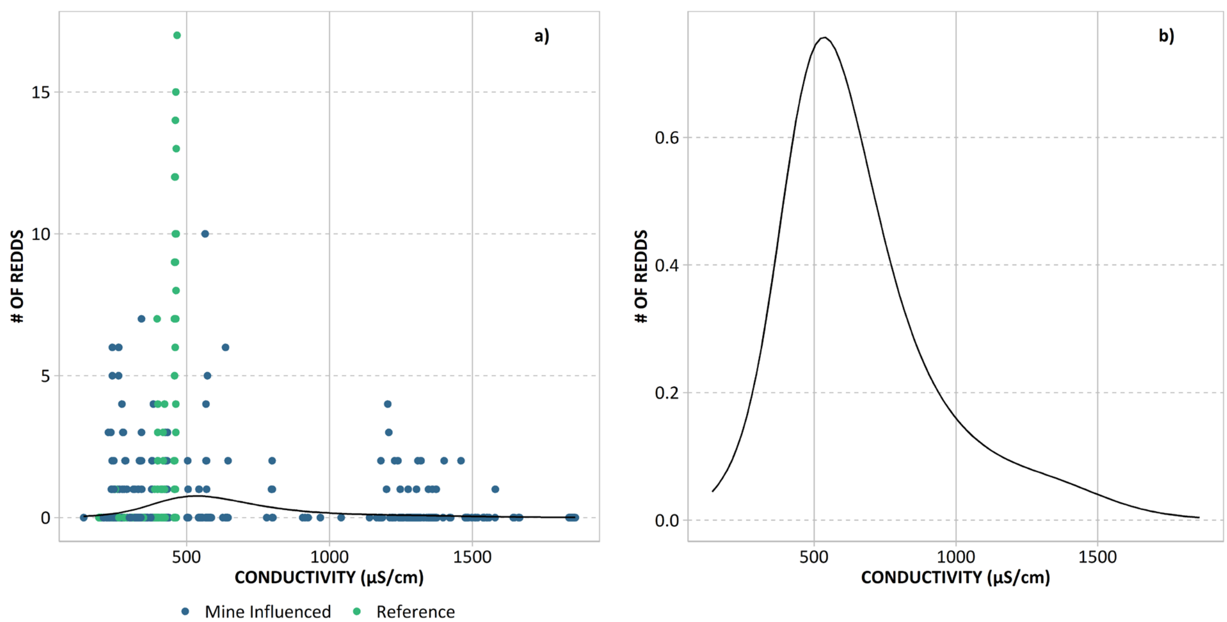
Figure 31. (a) Distribution of observed redd counts by mesohabitat unit (raw points) and (a, b) the predicted average count of redds (solid black line – note different y-axis scales in a and b) in tributaries of the Elk River, BC as a function of calcite concretion. The solid line depicts the predicted average count of redds as a smoother function of calcite concretion, estimated from a generalized linear model with a poisson link-function. The points represent the observed redds by stream type (mine-influence versus reference streams).



3.4.1.4. Conductivity

A univariate GAM was applied to explore the effect of water conductivity on the average number of redds present in a mesohabitat. We observed a significant and non-linear relationship between conductivity and redd counts (*p-value* < 0.001; Figure 32). The highest predicted number of redds (~0.97 redds) was observed at around 500 µS/cm, followed by a decrease in predicted probability, reaching approximately zero redds at around 1800 µS/cm. The relationship between conductivity and WCT redd counts is thought to represent a productivity gradient up to ~500 µS/cm (increases in redds), followed by effects of increased mine-influence up to ~1800 µS/cm (decreases in redds).

Figure 32. (a) Distribution of observed redd counts by mesohabitat unit (raw points) and (a, b) the predicted average count of redds (solid black line – note different y-axis scales in a and b) in tributaries of the Elk River, BC as a function of water conductivity. The solid line depicts the predicted average count of redds as a smoother function of conductivity, estimated from a generalized additive model. The points represent the observed redds by stream type (mine-influence versus reference streams).



3.4.2. Model Selection Analysis - GLMM

A GLMM model selection approach was used with a negative binomial distribution and a log link function to assess the relative importance of evaluated variables that explain WCT redd counts. The GLMM assesses the relationship between calcite and redd counts while accounting for additional fish-habitat variables. Separate analyses were completed across all streams (20 streams), mine-influenced streams only (14 streams), and reference streams (6 streams) to assess the sensitivity of the models to differences in the streams included in the model selection.

3.4.2.1. All-Streams

The most important variables to explain variability in the mean number of redds across all streams among the evaluated variables were calcite concretion (RVI = 1), mesohabitat area (RVI = 1), proportion of spawning gravel (RVI = 1), and to a lesser extent water temperature (RVI = 0.88) and calcite presence (RVI = 0.81) (Figure 33). Model selection statistics for models within ΔAICc <4 are detailed in Table 13.

The two retained calcite metrics, calcite concretion and presence, had opposite effects on the mean number of redds. The effect of calcite concretion on the mean number of redds was negative (i.e., calcite concretion decreases the mean number of redds), suggesting that WCT redds occur in lower numbers in concreted substrates. In contrast, calcite presence had a positive effect on the mean number of redds presence. In combination with calcite concretion, these results suggested that higher number of WCT redds were associated in mesohabitats where calcite was present, and where substrate was not concreted.

Similar to redd presence analysis, calcite concretion outcompeted CI in explaining the mean number of redds, which resulted in CI not being present in any of the top models (Figure 33; Table 13). Note that due to high collinearity between CI and calcite presence and concretion, the model selection was constrained to not allow CI in the same model with either calcite presence or concretion. The selection of calcite presence and concretion in all models suggested that these were better predictors than CI alone in explaining the variance of redd counts across all streams.

Variability in the mean number of redds in the streams was explained by the averaged model as an exponentially decreasing relationship, with mean number of redds of ~0.16 redds at a calcite concretion score of 0 and quickly dropping to close to zero by a calcite concretion score of 1 (Figure 34a). We further summarized the observed number of redds as a function of eight calcite concretion classes, where each class represents a calcite concretion interval (Figure 34b). The predicted mean number of redds were lower than the observed mean number of redds at lower calcite classes; however, both observed and predicted values decreased exponentially at concretion levels around 1.

Mesohabitat area, proportion of spawning gravel area, and temperature all had a positive effect on the mean number of redds present per mesohabitat unit. Redd counts were higher in larger mesohabitat units, in units with more suitable spawning gravel, and in mesohabitats with higher temperatures during spawning. There was some evidence for effects of water velocity and pH on the counts of redds per mesohabitat unit (RVI = 0.61 and 0.60, respectively). In contrast, there was little evidence for an effect of bankfull depth and functional LWD tally in predicting redd counts using this modelling approach.

Figure 33. Model averaged coefficients (with 95% confidence intervals) indicating the most important variables among the variables considered explaining Westslope Cutthroat Trout redd counts in tributaries of the Elk River, B.C. Values in the x-axis are estimates of model parameters. RVI = Relative Variable Importance scores, where a score of 1 indicates that a predictor variable occurs in all top models with ΔAICc < 4.

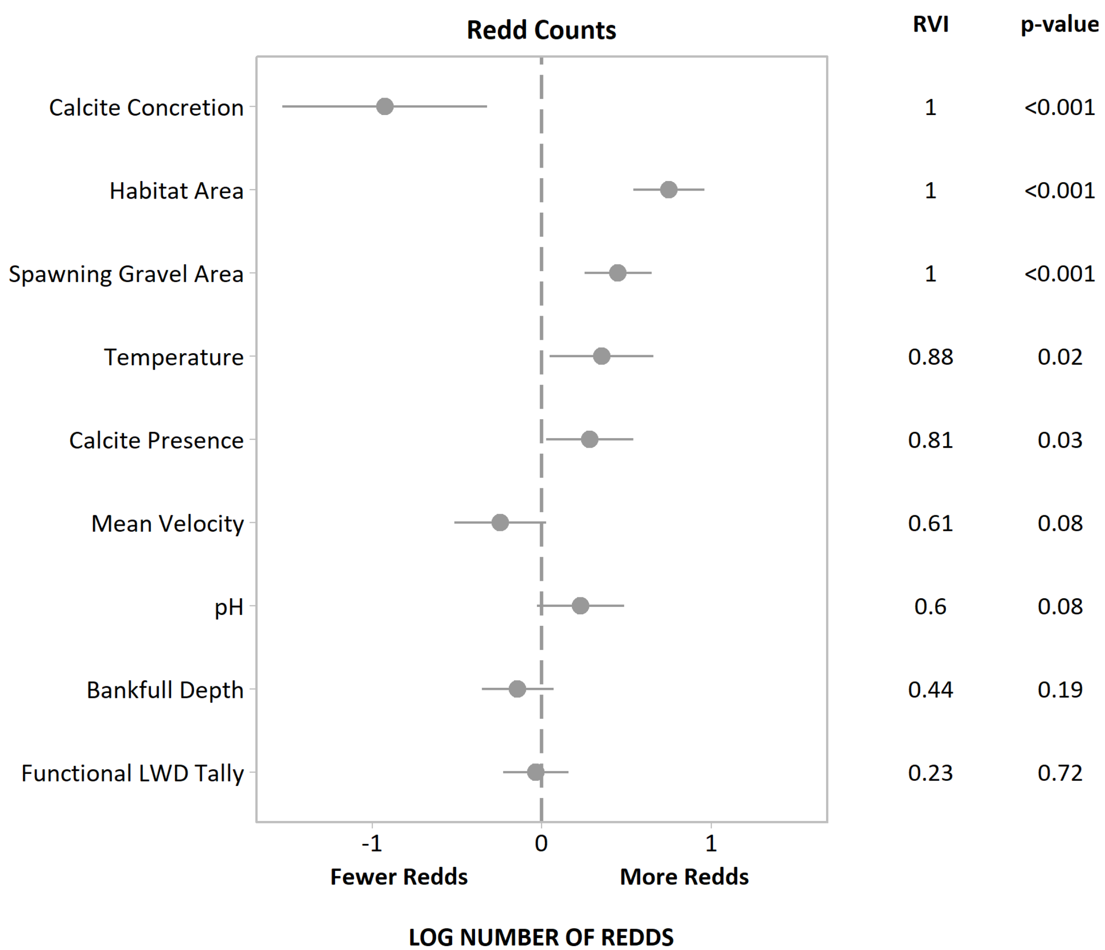


Figure 34. Westslope Cutthroat Trout redd counts as a function of calcite concretion and the mean regression fit to the data, with all other predictors held at their means. The shaded region represents the 95% confidence interval of predicted mean redd count. (a) shows the raw redd count data. (b) shows the average redd count per mesohabitat by concretion class (# of redds present at each mesohabitat unit / total # of units by concretion class).

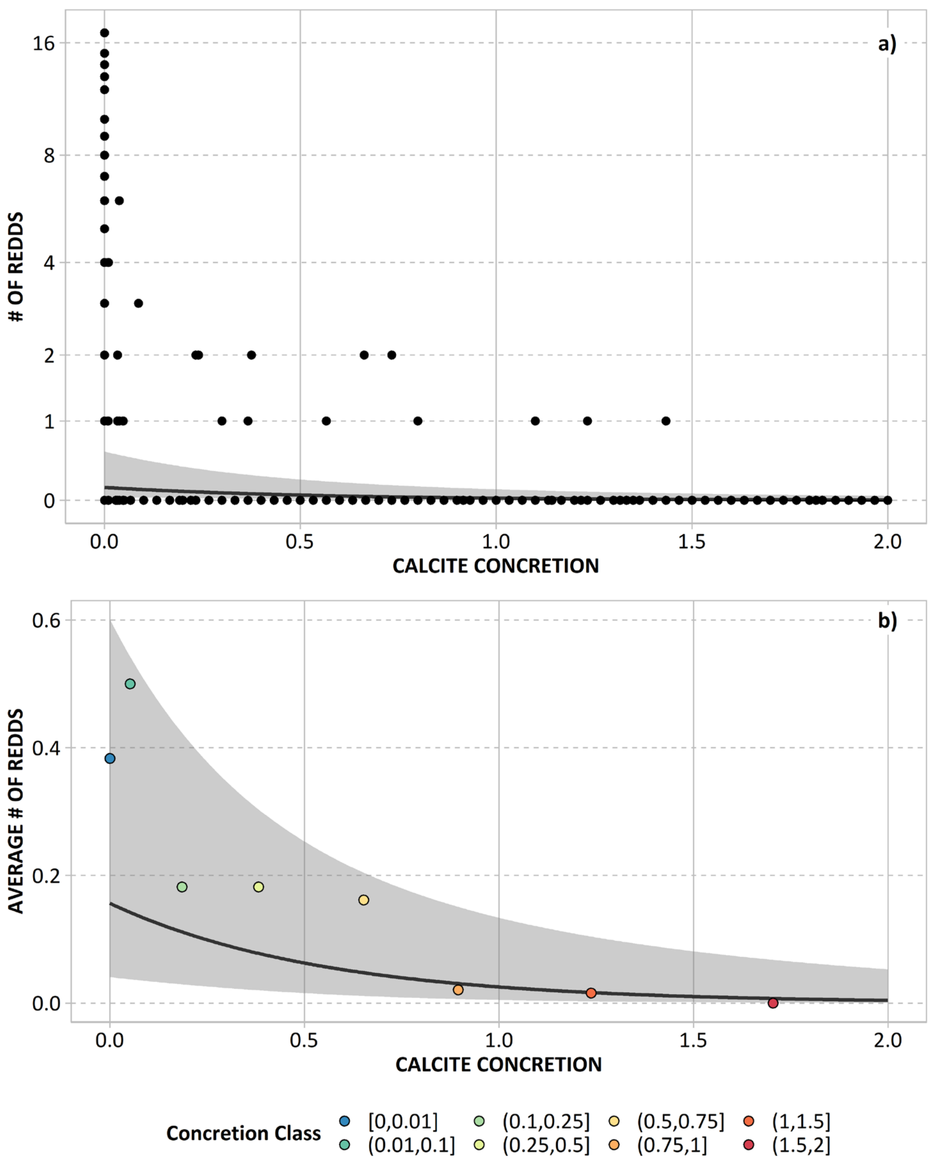


Table 13. Top models that predict Westslope Cutthroat Trout mean redd counts (using negative binomial mixed effects model) in tributaries of the Elk River, B.C. Models are ranked by Δ Akaike Information Criterion (ΔAICc) scores. The model with the lowest ΔAICc is the best model. Model weights (range 0-1) are also shown, which provide an estimate of the likelihood that a given model is the best model compared to the other top models in the model set.

Model		ΔAICc	Weight
Mean Redd Counts	~ Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + Mean Velocity + pH + Temperature	0.00	0.09
Mean Redd Counts	~ Calcite Concretion + Calcite Presence + Bankfull Depth + Habitat Area + Spawning Gravel Area + Mean Velocity + pH + Temperature	0.17	0.08
Mean Redd Counts	~ Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + Temperature	0.49	0.07
Mean Redd Counts	~ Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + Mean Velocity + Temperature	0.62	0.06
Mean Redd Counts	~ Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + pH + Temperature	0.64	0.06
Mean Redd Counts	~ Calcite Concretion + Calcite Presence + Bankfull Depth + Habitat Area + Spawning Gravel Area + Mean Velocity + Temperature	0.87	0.06
Mean Redd Counts	~ Calcite Concretion + Calcite Presence + Bankfull Depth + Habitat Area + Spawning Gravel Area + Temperature	1.48	0.04
Mean Redd Counts	~ Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + Mean Velocity + pH	1.62	0.04
Mean Redd Counts	~ Calcite Concretion + Calcite Presence + Bankfull Depth + Habitat Area + Spawning Gravel Area + pH + Temperature	1.70	0.04
Mean Redd Counts	~ Calcite Concretion + Calcite Presence + Functional LWD Tally + Habitat Area + Spawning Gravel Area + Mean Velocity + pH + Temperature	1.79	0.04

3.4.2.2. Mine-Influenced Streams

To further investigate the effects of calcite on WCT spawning suitability, the same GLMM analysis was applied to mine-influenced streams only. Mine-influenced streams include Corbin Creek, Michel Creek, EVO and LCO Dry Creeks, Erickson Creek (2019 only), Harmer Creek, Clode Creek, Fish Pond Creek, Fording River S8, Henretta Creek, Lower and Upper Greenhills Creeks, Thompson Creek and Line Creek. Mesohabitats within mine influenced streams represented approximately 65.4% of all surveyed mesohabitats between 2018 and 2020.

Based on data collected and analysis performed in mine influence streams only, the most important variables to explain variance in the mean redd counts among the evaluated variables were calcite concretion (RVI = 1), mesohabitat area (RVI = 1), proportion of spawning gravel (RVI = 1), and water temperature (RVI = 0.84; Figure 35; Table 14). The effect of concretion was similar to results across all streams, where calcite concretion negatively affects the mean number of redds, suggesting that WCT redds occur in lower numbers in concreted substrates of the mine-influenced mesohabitats. The relationship between calcite presence and redd counts was again positive but was less apparent than in the all-streams model (RVI = 0.47). The high importance and positive coefficients of mesohabitat area, proportion of spawning gravel area, and temperature suggested an important positive relationship with redd counts, where larger habitats, higher amounts of suitable spawning habitat for spawning, and higher temperatures during spawning positively affect the mean number of redds observed.

Figure 35. Model averaged coefficients (with 95% confidence intervals) indicating the most important variables predicting Westslope Cutthroat Trout redd counts in mine-influenced tributaries of the Elk River, B.C. Values in the x-axis are estimates of model parameters. RVI = Relative Variable Importance scores, where a score of 1 indicates that a predictor variable occurs in all top models with ΔAICc < 4.

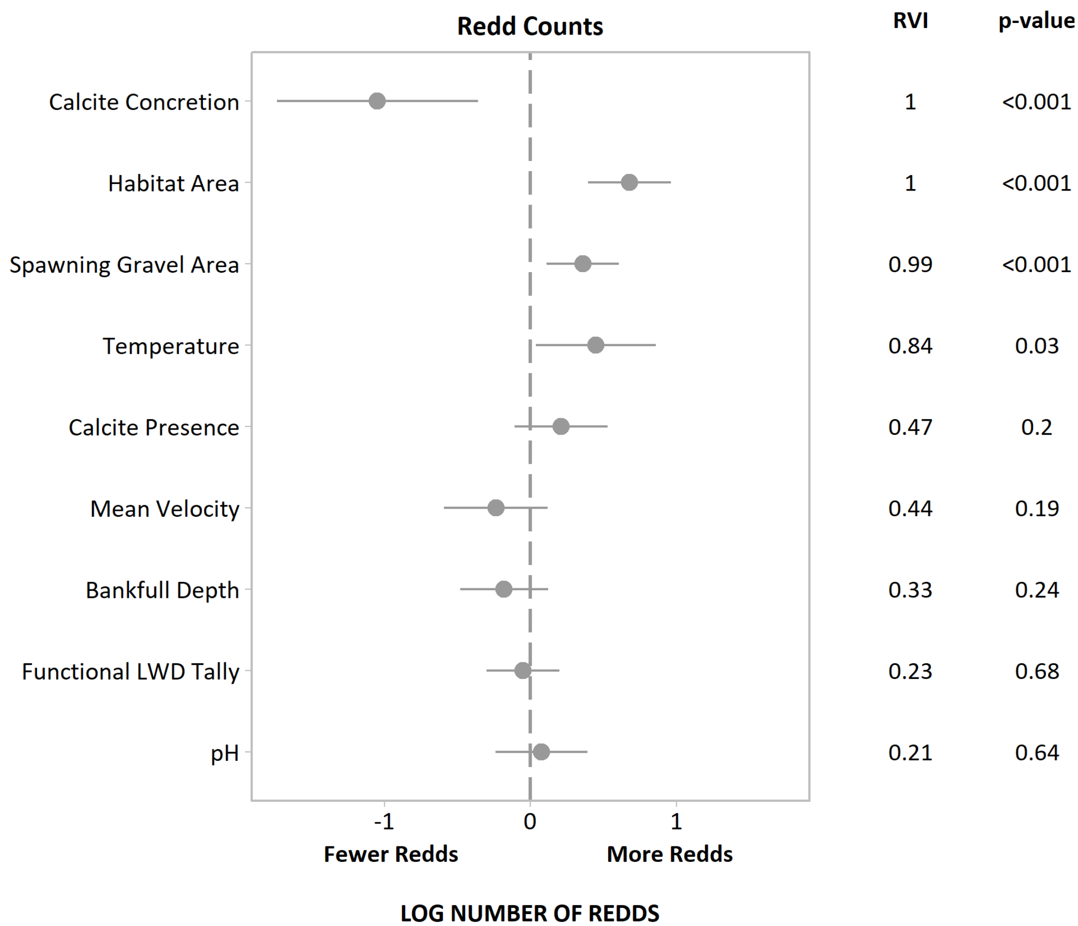


Table 14. Top models that best predict Westslope Cutthroat Trout redd counts in mine-influenced tributaries of the Elk River, B.C. Models are ranked by Δ Akaike Information Criterion (ΔAICc) scores. The model with the lowest ΔAICc is the best model. Model weights (range 0-1) are also shown, which provide an estimate of the likelihood that a given model is the best model compared to the other top models in the model set.

Model			ΔAICc	Weight
Mean Redd Counts	~	Calcite Concretion + Habitat Area + Spawning Gravel Area + Temperature	0.00	0.12
Mean Redd Counts	~	Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + Temperature	0.85	0.08
Mean Redd Counts	~	Calcite Concretion + Habitat Area + Spawning Gravel Area + Mean Velocity + Temperature	0.93	0.08
Mean Redd Counts	~	Calcite Concretion + Bankfull Depth + Habitat Area + Spawning Gravel Area + Temperature	1.02	0.07
Mean Redd Counts	~	Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area + Mean Velocity + Temperature	1.56	0.06
Mean Redd Counts	~	Calcite Concretion + Functional LWD Tally + Habitat Area + Spawning Gravel Area + Temperature	1.84	0.05
Mean Redd Counts	~	Calcite Concretion + Calcite Presence + Bankfull Depth + Habitat Area + Spawning Gravel Area + Mean Velocity + Temperature	2.10	0.04
Mean Redd Counts	~	Calcite Concretion + Calcite Presence + Habitat Area + Spawning Gravel Area	2.42	0.04
Mean Redd Counts	~	Calcite Concretion + Functional LWD Tally + Habitat Area + Spawning Gravel Area + Mean Velocity + Temperature	2.66	0.03
Mean Redd Counts	~	Calcite Concretion + Habitat Area + Spawning Gravel Area + Mean Velocity + pH + Temperature	2.72	0.03

3.4.2.3. Reference Streams

The GLMM model selection analysis was also applied to only reference streams to assess the natural range of factors that may affect WCT redd counts. Reference streams include Alexander Creek, Grace Creek, McCool Creek, Lizard Creek, South Line Creek and Upper Grave Creek. Mesohabitats within reference streams represented 34.6 % of all surveyed mesohabitats between 2018 and 2020.

The most important variables to explain variability in the count of redds by mesohabitat unit in reference streams among the evaluated variables were water conductivity (RVI = 1), mesohabitat area (RVI = 1), and proportion of spawning gravel (RVI = 1; Figure 36). Model selection statistics for models within ΔAICc < 4 are detailed in Table 15. The effects of conductivity, mesohabitat area, and proportion of spawning gravel were positive (i.e., higher values of these variables were associated with higher count of redds in any given mesohabitat). Contrary to all-streams and mine-influenced streams analyses, calcite metrics, such CI, presence, or concretion were outcompeted by conductivity.

Figure 36. Model averaged coefficients (with 95% confidence intervals) indicating the most important variables among the variables considered explaining redd counts in reference streams. Values in the x-axis are estimates of model parameters. RVI = Relative Variable Importance scores, where a score of 1 indicates that a predictor variable occurs in all top models with ΔAICc < 4.

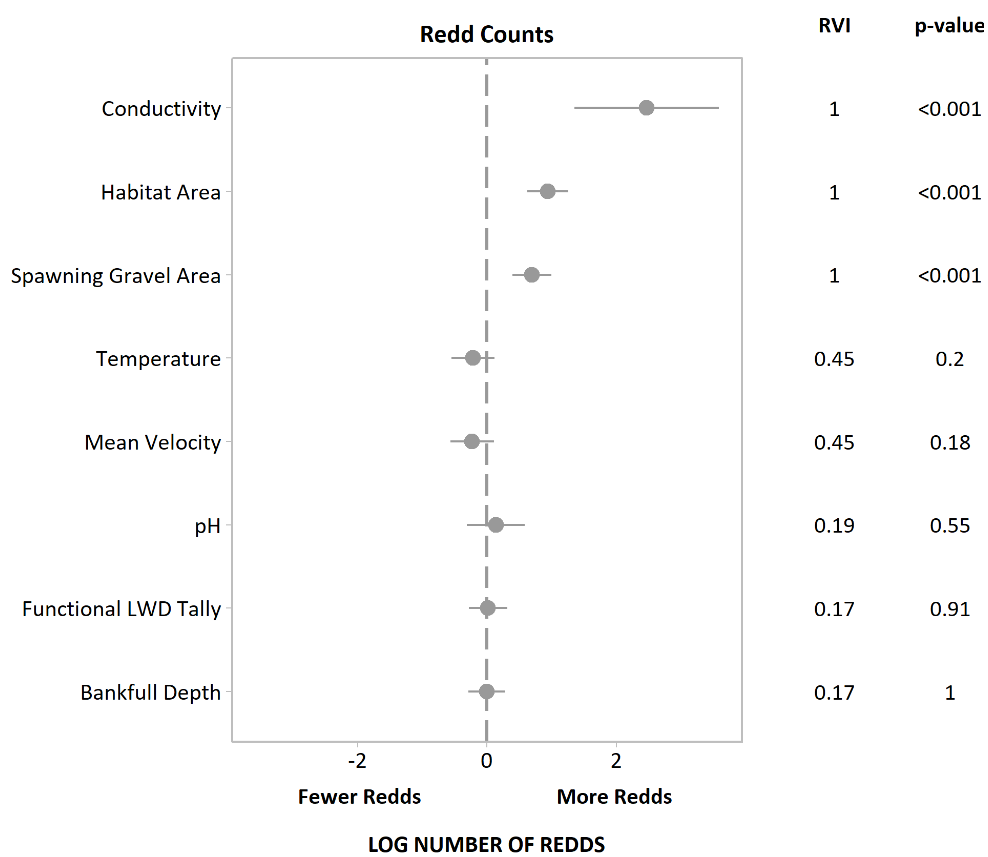


Table 15. Top models that predict Westslope Cutthroat Trout redd counts in reference tributaries of the Elk River, B.C. Models are ranked by Δ Akaike Information Criterion (ΔAICc) scores. The model with the lowest ΔAICc is the best model. Model weights (range 0-1) are also shown, which provide an estimate of the likelihood that a given model is the best model compared to the other top models in the model set.

Model			ΔAICc	Weight
Mean Redd Counts	~	Conductivity + Habitat Area + Spawning Gravel Area	0.00	0.15
Mean Redd Counts	~	Conductivity + Habitat Area + Spawning Gravel Area + Temperature	0.52	0.11
Mean Redd Counts	~	Conductivity + Habitat Area + Spawning Gravel Area + Mean Velocity	0.53	0.11
Mean Redd Counts	~	Conductivity + Habitat Area + Spawning Gravel Area + Mean Velocity + Temperature	0.97	0.09
Mean Redd Counts	~	Conductivity + Functional LWD Tally + Habitat Area + Spawning Gravel Area	2.03	0.05
Mean Redd Counts	~	Conductivity + Bankfull Depth + Habitat Area + Spawning Gravel Area	2.04	0.05
Mean Redd Counts	~	Conductivity + Habitat Area + Spawning Gravel Area + pH	2.05	0.05
Mean Redd Counts	~	Conductivity + Habitat Area + Spawning Gravel Area + Mean Velocity + pH + Temperature	2.16	0.05
Mean Redd Counts	~	Conductivity + Habitat Area + Spawning Gravel Area + pH + Temperature	2.26	0.05
Mean Redd Counts	~	Conductivity + Habitat Area + Spawning Gravel Area + Mean Velocity + pH	2.47	0.04

3.4.3. Model Selection Analysis - GAMM

We applied a GAMM model selection approach to explain the variability of mean redd counts per mesohabitat unit, while allowing for non-linear relationships between predictor variables and redd counts. The GAMM assesses the relationship between calcite and redd counts while accounting for additional fish-habitat variables and potential non-linear relationships. The GAMM model was applied to all streams surveyed between 2018 and 2020. In total, 768 GAMMs were designed that included all possible combinations of the final set of predictors.

The final model, selected with the lowest AICc, retained the variables calcite concretion (*p-value* = 0.002; χ^2 = 8.98), calcite presence (*p-value* < 0.001; χ^2 = 28.08), mesohabitat area (*p-value* < 0.001; χ^2 = 90.58), proportion of spawning gravel area (*p-value* < 0.001; χ^2 = 73.13), mean velocity (*p-value* < 0.00; χ^2 = 32.15), pH (*p-value* = 0.034; χ^2 = 4.48), and water temperature (*p-value* = 0.15; χ^2 = 4.10), and explained 62.8% of all variance. This model is very similar to the redd count model across all streams using the GLMM. One clear exception is that the GAMM better accounts for a non-linear relationship between water velocity and spawning suitability.

Similar to all-streams GLMM analysis (Section 3.4.2.1), the two retained calcite metrics, calcite concretion and presence, had different effects on the mean number of redds. The calcite concretion smoother suggested a significant exponential decrease in number of redds with calcite concretion. This reinforced the overall result that WCT spawning is reduced in concreted substrates. In contrast, calcite presence had a significant non-monotonic relationship with mean redd counts, where higher predicted number of redds occurred at calcite presence scores of 0.25 and 0.75 (Figure 37). These results are similar to the previous univariate and multivariate models of calcite presence on the mean number of redds, which support the finding that higher number of redds may occur moderate to high levels of calcite presence, but not where the substrate becomes concreted (Figure 31; Figure 34).

Other fish habitat variables, such as habitat availability and water conditions were also found to strongly explain redd counts throughout the Elk River tributaries. The smoothers for mean velocity, habitat area and proportion of spawning gravel area exhibited hump-shaped relationships with redd counts, suggesting potential optimal conditions for WCT spawning (Figure 37).

We summarized the observed number of redds as a function of eight calcite concretion classes, where each class represented a calcite concretion interval. The predicted mean number of redds were in general lower than the observed mean number of redds at lower calcite classes; however, both observed and predicted values decreased exponentially and overlapped at concretion levels around 1. There remains significant uncertainty with these predictions; the 95% confidence interval associated with the relationship between calcite concretion and redd counts is shown in Figure 38.

The relationship between calcite concretion and mean redd count was assessed under average, optimal, and sub-optimal spawning habitat conditions using the top GAMM model for redd counts (Figure 39). The three spawning habitat condition scenarios showed a consistent percent decrease in redd count as CI_{Conc} increases; however, the absolute declines redd counts under optimal stream conditions was much higher than average conditions, which was higher than in sub-optimal conditions

(Figure 39). At CI_{Conc} of zero, and under optimal stream conditions, the predicted mean redd count per mesohabitat unit was 6.8, while in average conditions the predicted redd count was 0.11, and under sub-optimal conditions near zero. At CI_{Conc} of 0.5, and under optimal stream conditions, the predicted the mean redd count was 2.9, while under average conditions it was 0.05, and in sub-optimal approximately zero. This represented a decrease of approximately 60% of redd counts between CI_{Conc} 0 and 0.5 across the stream condition scenarios. There remains significant uncertainty with these predictions; the 95% confidence interval associated with the relationship between calcite concretion and redd counts is shown in Figure 39.

Figure 37. **Predicted mean number of redds at mesohabitat units in tributaries of the Elk River, BC. The solid line depicts the predicted probability of redd presence as a smoother function of calcite concretion (*p-value* = 0.002; χ^2 = 8.98), calcite presence (*p-value* < 0.001; χ^2 = 28.08), habitat area (*p-value* < 0.001; χ^2 = 90.58), proportion of spawning gravel area (*p-value* < 0.001; χ^2 = 73.13), mean velocity (*p-value* < 0.00; χ^2 = 32.15), pH (*p-value* = 0.034; χ^2 = 4.48) and water temperature (*p-value* = 0.15; χ^2 = 4.10), estimated from a generalized additive mixed effects model. The shaded region represents the 95% confidence interval for the predicted number of redds.**

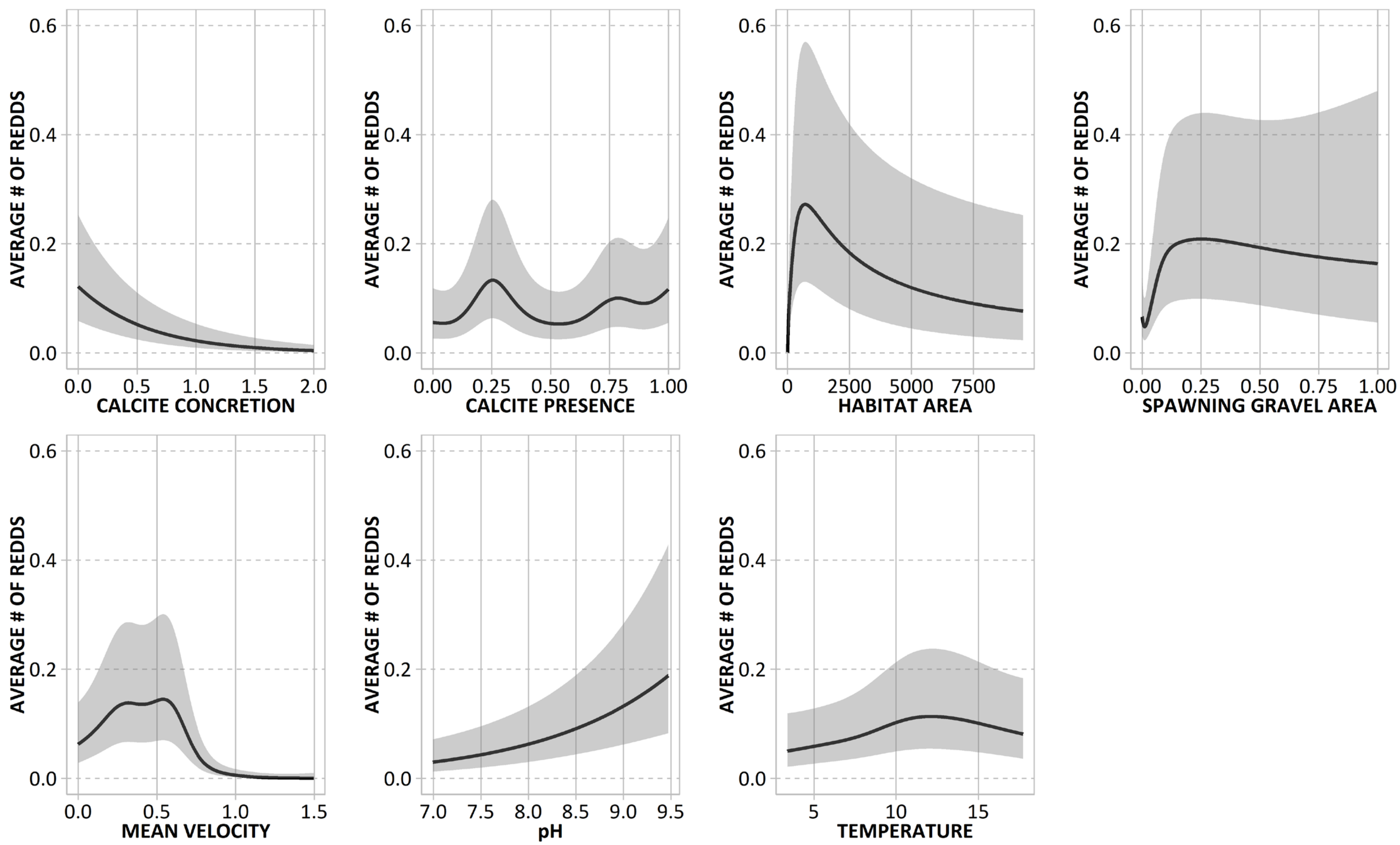


Figure 38. Average mean number of redds by concretion class (# of units with redds present / total # of units by concretion class). The solid line represents the predicted mean of redd counts as a function of calcite concretion, where all other predictors are held at their means (estimated from a generalized additive mixed effects model shown in Figure 37). The shaded region represents the 95% confidence interval for the predicted probability of redd presence.

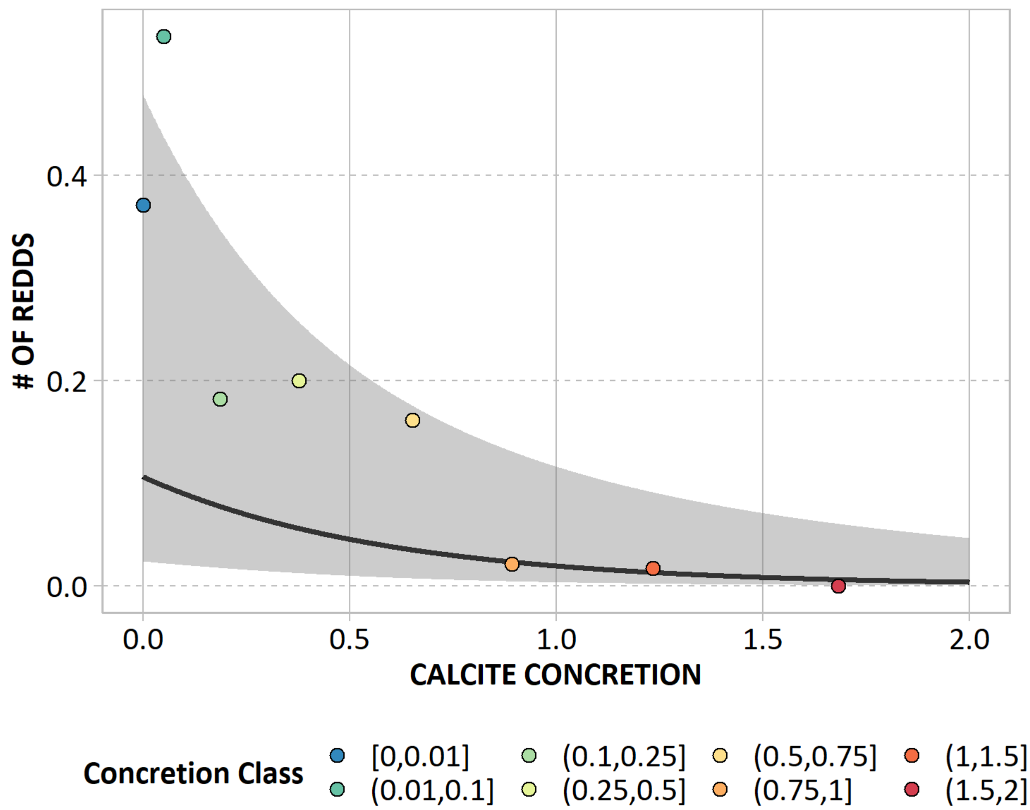
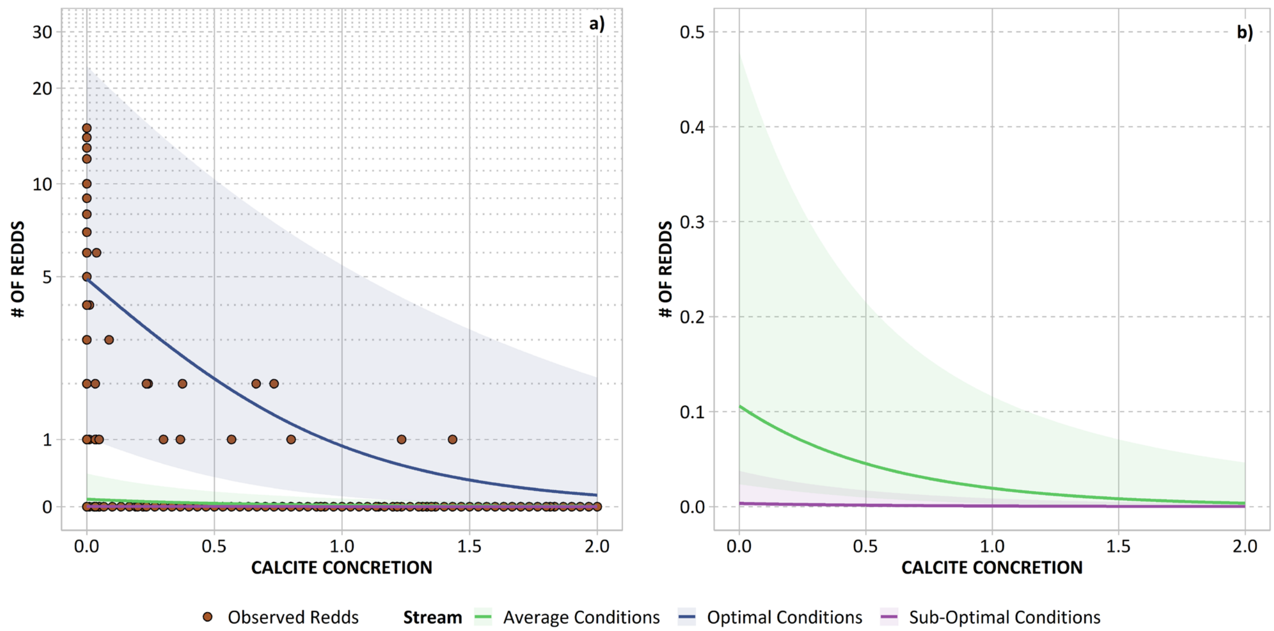


Figure 39. Average predicted redd counts as a function of calcite concretion and stream spawning habitat conditions, where all other fish habitat variables are held at their means (green line – same plot as Figure 38), held at optimal conditions (values that maximise the predicted number of redds; blue line), and in sub-optimal conditions (values that minimise the predicted number of redds; purple line). The y-axis scale differs between panel a) and b). These predictions were estimated from a generalized additive mixed effects model shown in Figure 37. The shaded regions represent the 95% confidence interval for the predicted mean redd count for each stream condition.



3.4.4. Model Selection Analysis - 95th Quantile Regression

We applied model selection techniques to obtain the best 95th quantile regression model to explain the variability in the highest number of redds observed by mesohabitat unit. The 95th quantile model was applied to all streams surveyed between 2018 and 2020. In total, we considered 767 95th quantile regression models that included all possible combination of the final set of predictors.

Based on data collected and analysis performed herein, the significant variables to explain variability in the 95th quantile of redd counts were calcite concretion, temperature, mesohabitat area, and pH (Figure 40). Additional habitat variables included in the best model, but not significant were proportion of spawning gravel, mean velocity, calcite presence, functional LWD tally, and bankfull depth. The effect of calcite concretion on the 95th quantile of redds was negative (i.e., calcite decreases the number of redds), whereas the rest of the significant predictors had a positive effect on the 95th quantile of redds. The top models that best predict the 95th quantile of redd counts are shown in Table 16.

Variability in the 95th quantile of redd counts in the streams was explained by the averaged model as an exponentially decreasing function with 95th quantile of redds close to 1.5 redds at a calcite concretion score of 0 and quickly dropping to approximately zero by calcite concretion score of 1 (Figure 41).

Similar to the redd presence and mean redd count models, calcite concretion outcompeted CI in explaining the 95th quantile of redd counts, which resulted in CI not being present in the best model. Due to high collinearity between CI and the other calcite metrics (concretion and calcite presence), our model selection constrained the presence of multiple calcite variables within a same model to either one calcite variable or both concretion and calcite presence or none at all. The selection of calcite presence and concretion in the top model suggested that these were better predictors than CI in explaining the variance of the 95th quantile number of redds present at each mesohabitat.

Figure 40. Model averaged coefficients (with 95% confidence intervals) for the top model describing redd count, modelled using 95th quantile regression models. Values in the x-axis are estimates of model parameters.

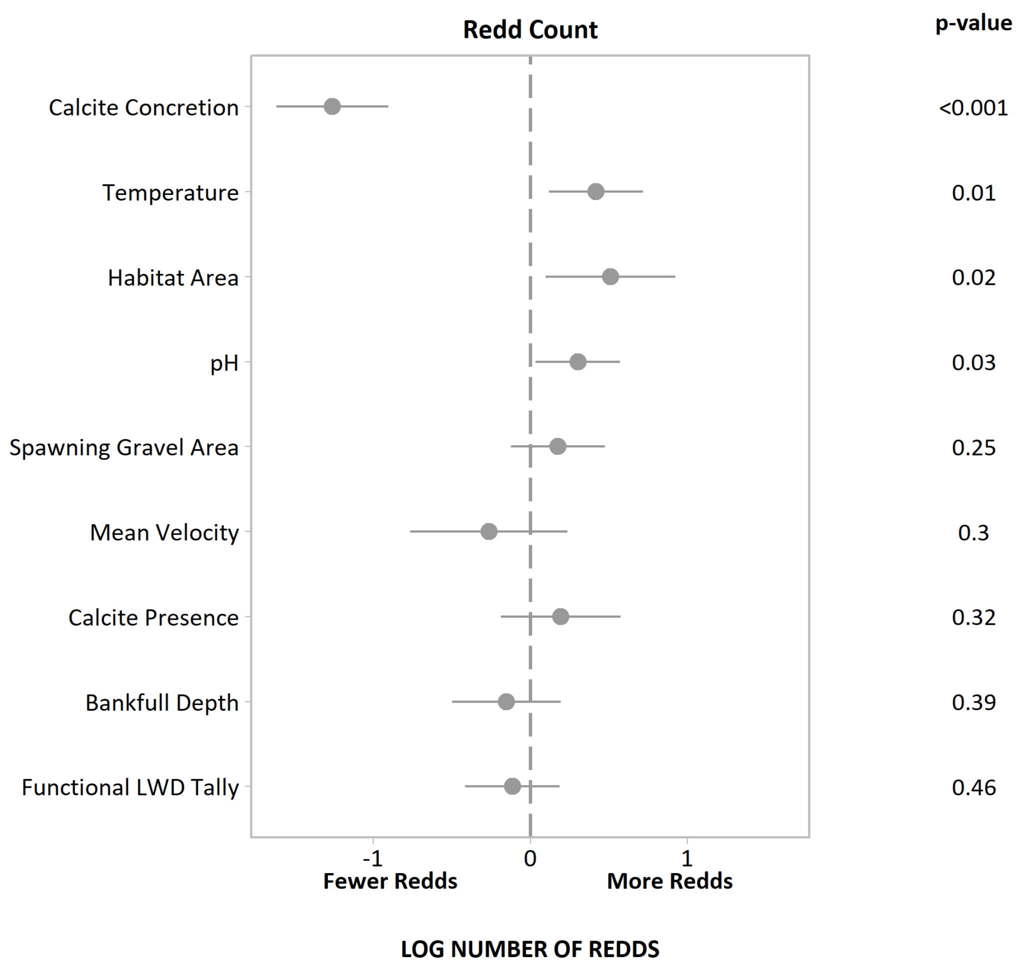


Figure 41. Westslope Cutthroat Trout redd count as a function of calcite concretion and the 95th quantile regression fit to the data, with all other predictors held at their means. The shaded region represents the 95% confidence interval of predicted 95th percentile redd count.

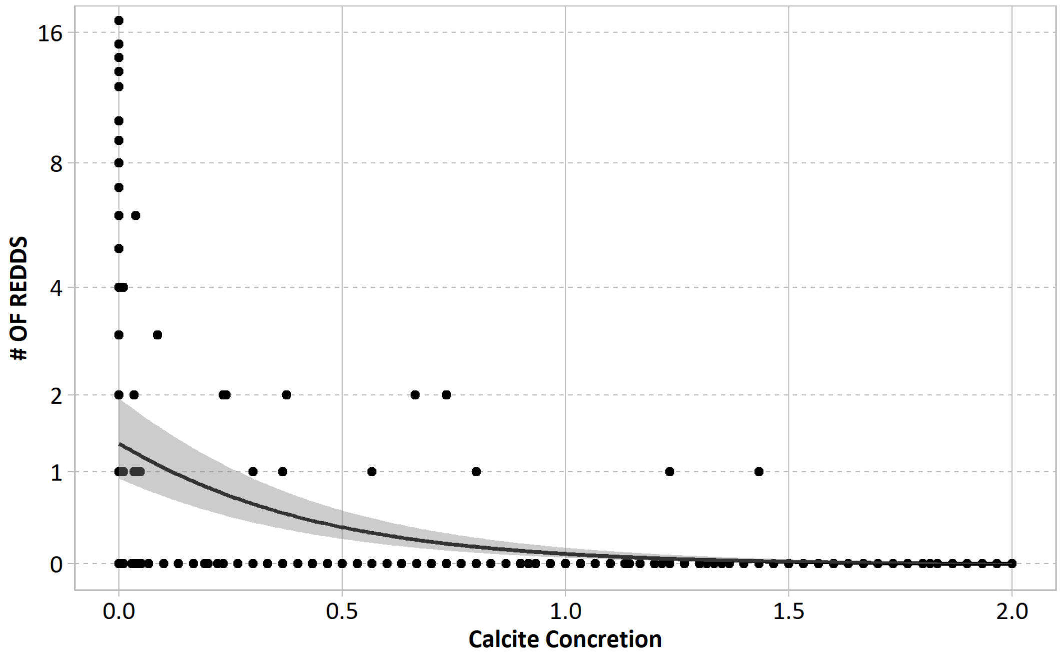


Table 16. Top models that predict Westslope Cutthroat Trout redd counts in tributaries of the Elk River, B.C., modelled using 95th quantile regression. The model with the lowest ΔAICc is the best model. Model weights (range 0-1) are also shown, which provide an estimate of the likelihood that a given model is the best model compared to the other top models in the model set.

Model		ΔAICc	Weight
95th Quantile Redd Counts ~	Calcite Concretion + Calcite Presence + Bankfull Depth + Habitat Area + Mean Velocity + Temperature + pH + Spawning Gravel Area + Functional LWD Tally	0.00	0.40
95th Quantile Redd Counts ~	Calcite Concretion + Calcite Presence + Bankfull Depth + Habitat Area + Mean Velocity + Temperature + pH + Spawning Gravel Area	1.90	0.15
95th Quantile Redd Counts ~	Calcite Concretion + Calcite Presence + Habitat Area + Mean Velocity + Temperature + pH + Spawning Gravel Area + Functional LWD Tally	2.21	0.13
95th Quantile Redd Counts ~	Calcite Concretion + Calcite Presence + Habitat Area + Mean Velocity + Temperature + pH + Spawning Gravel Area	3.43	0.07

3.5. Boosted Regression Trees Analysis

Through a cross validation model selection procedure, we identified a top model set for redd presence and counts that had seven variables: calcite concretion and presence, FHAP area, mean velocity, proportion of resident gravel, mean velocity, functional LWD tally, and bankfull width. Overall, the respective top models had high predictive power for redd presence (mean cross validation AUC = 0.85) and redd counts (Mean Absolute Error (MAE)= 0.33). The absolute influence of individual variables (|% Change in Prediction|) on redd presence and counts varied strongly by stream (Figure 42). The most influential variables were FHAP area, mean velocity, bankfull width, and calcite presence. Overall, calcite concretion had a low relative influence compared with the other predictors, but its influence was much higher in streams with higher values of calcite concretion. Because the relative influence of calcite concretion varied by stream and was higher in streams with higher concretion, the effects for all variables were presented for streams broken down into 3 levels of maximum concretion:

- Low - maximum concretion > 0 and ≤ 0.1;
- Medium - maximum concretion >0.1 and ≤ 0.5; and
- High - maximum concretion >0.5.

Consistent with the mixed model analyses, the probability of redd presence decreased with increasing levels of calcite concretion in high concretion streams (i.e., reduction in spawning suitability for units with higher levels of calcite). The predicted decline, however, was not as sharp with a drop from a high of 5.9 % positive influence on suitability for units with low concretion (<0.5) to a low of -4.0% negative influence on suitability (~10% drop) for units with concretion above 0.5 (Figure 43). Further, the shape of the decline varied from the mixed models, as most of the drop was observed for concretion values higher than 0.5. Directional plots also pointed to the importance of a number of other variables. Mesohabitats with a mean velocity between 0.1 and 0.7 m/s and bankfull widths between 4.0 and 12.6 m had higher probabilities of redd presence. Proportion of resident spawning gravel, FHAP area, calcite presence and counts of large woody debris all had positive associations with redd presence. This suggested higher probabilities of redds with increasing values for all these variables.

Within the medium concretion streams, concretion had a lower relative influence (Figure 42), but directional plots suggested a small negative relationship (Figure 44) with calcite concretion in some streams, but there was a lack of consistent data above a concretion score 0 making it difficult to draw any conclusions. The relationships with other variables were generally stronger and displayed similar patterns to the high concretion streams (Figure 44). The influence of calcite in low concretion streams was minimal, but the patterns with other variables remained consistent (Appendix F).

The breakdown analysis was also summarized for reference streams, mine-exposed streams and all streams combined (Appendix F). The general patterns for all parameters remained the same, but the drop for calcite concretion quantified with the loess smoothing decreased slightly from a high of 4.52% to a low of -3.62% and an overall drop of 8.15 % (Figure 45).

Redd count models displayed similar patterns to the redd presence models for most variables (Appendix F). Consistent with the mixed and redd presence models, there was a negative relationship with calcite concretion in high calcite streams (Figure 46). The decrease, however, was more consistent with the mixed models and there was a decrease in predicted redd counts from a high positive influence of 19% to low influence of -19% (~38% drop in predicted redd counts), for concretion values greater than 0.5 - 0.7 (Figure 46). Again the shape of this decline differed from the mixed models, with more of a threshold drop observed rather than a steady decline from zero to two. In the medium concretion streams, there was a more gradual 7 % decrease from no concretion to a value of 0.3, but there was a lack of data within this range (Appendix F). Similar patterns were found for models built using all mine-exposed streams, but the overall drop was much less likely due to presence of mine-exposed streams with low levels of calcite concretion (Appendix F).

In addition to concretion, there was an apparent non-linear relationship with mean velocity and bankfull width, with higher predicted redd counts within the range of 0.1 and 0.7 m/s for mean velocity and a bankfull width between 4.0 and 12.6 m (Figure 45, Appendix F). This pattern was consistent across all calcite concretion groupings (Appendix F). Further, there were positive associations with proportion of resident spawning gravel, FHAP area, calcite presence and counts of large woody debris, which was consistent across levels concretion and with the redd presence models (Appendix F).

Consistent with the mixed model analyses, the BRT models found an increase in redd presence and counts with higher calcite presence and a decrease in redds with increasing concretion. The extent and shape of the decline, however, was less extreme. This difference is likely related to a greater influence of other predictors, particularly in streams with lower levels of concretion. More detailed results of the BRT model selection and variable influence are presented in Appendix F.

Figure 42. Absolute relative change for boosted regression tree model parameters describing WCT redd presence in high (purple), medium (yellow) and low (grey) calcite streams in the Elk Valley, 2018 to 2020. Streams with zero concretion or no observed redds were excluded from this figure.

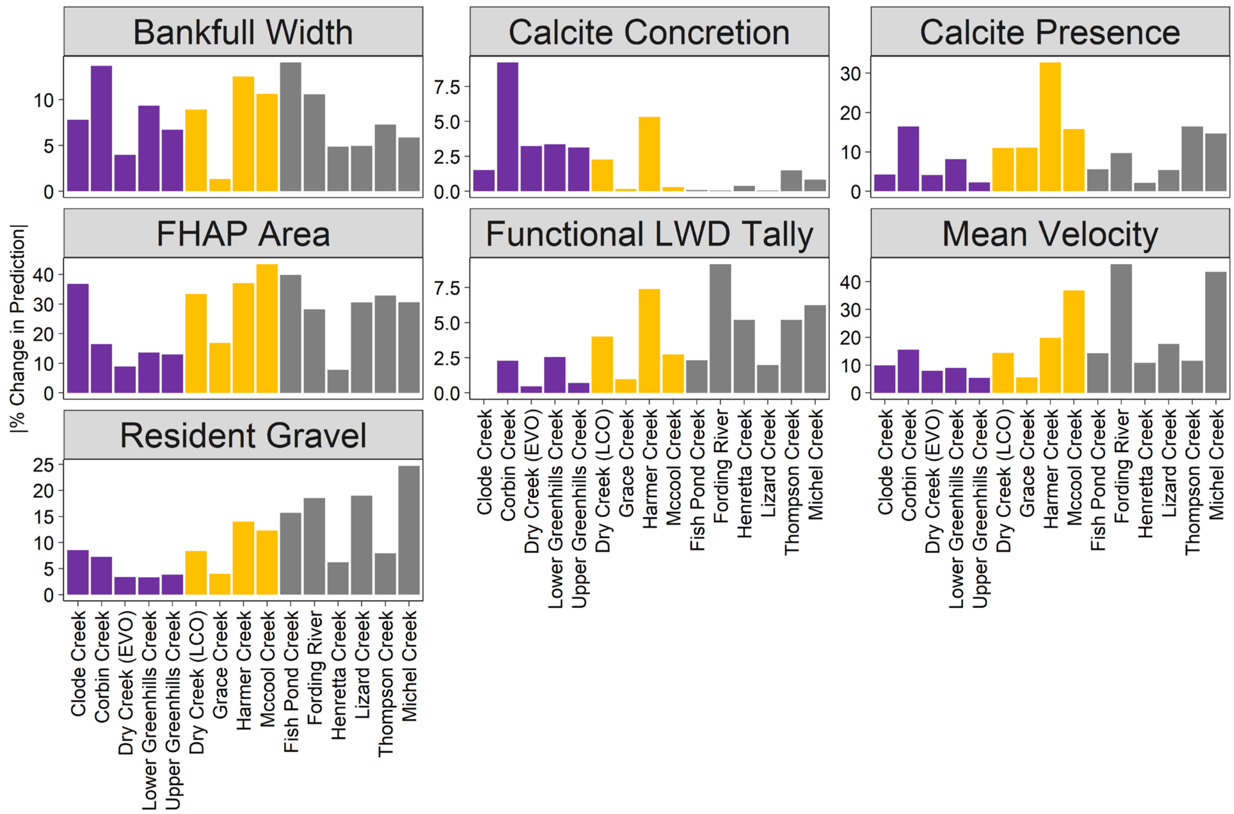


Figure 43. Percent change in prediction for boosted regression tree model parameters describing WCT redd presence for high calcite (> 0.5 maximum concretion) streams in the Elk Valley, 2018 to 2020.

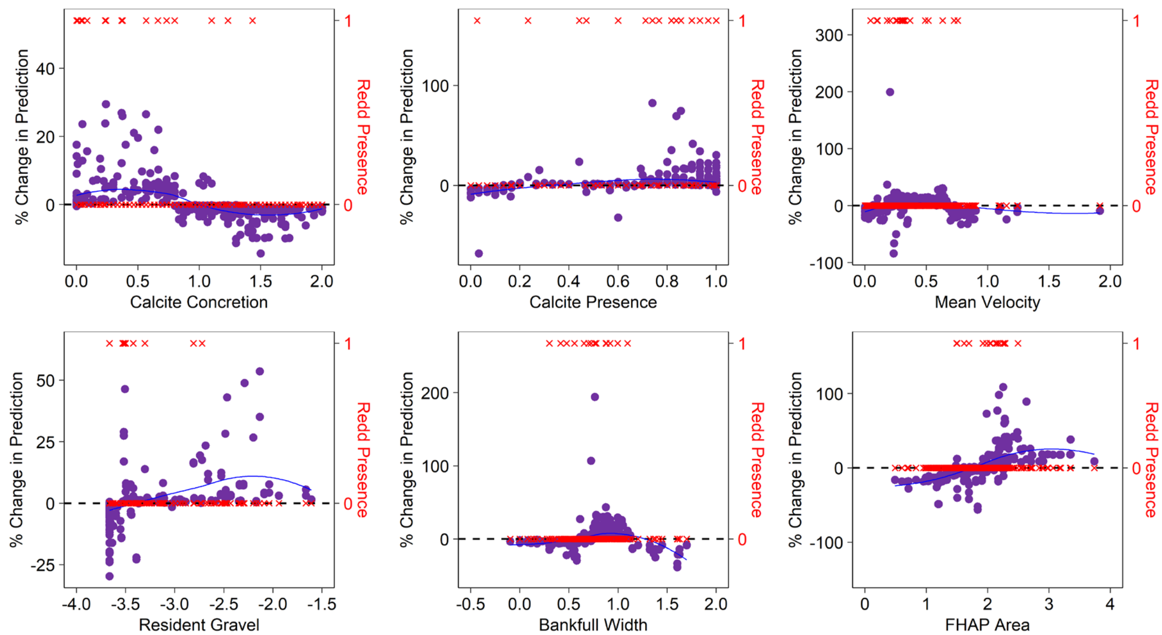


Figure 44. Percent change in prediction for boosted regression tree model parameters describing WCT redd presence for medium calcite (>0.1 and ≤ 0.5 maximum concretion) streams in the Elk Valley, 2018 to 2020.

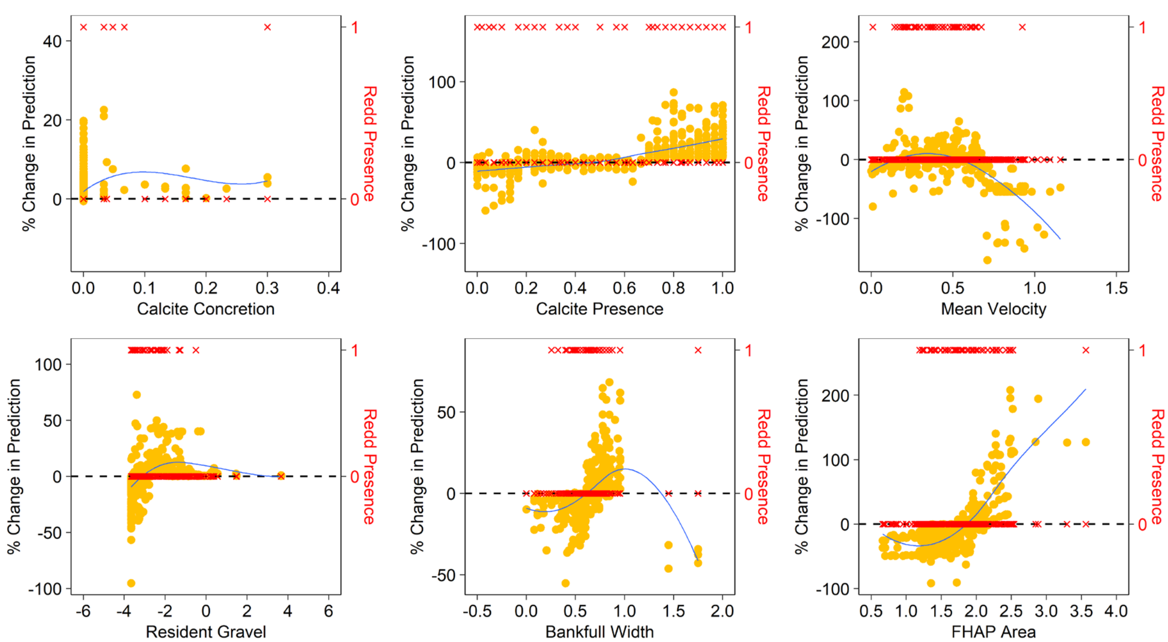


Figure 45. **Percent change in prediction for boosted regression tree model parameters describing WCT redd presence for all streams in the Elk Valley, 2018 to 2020.**

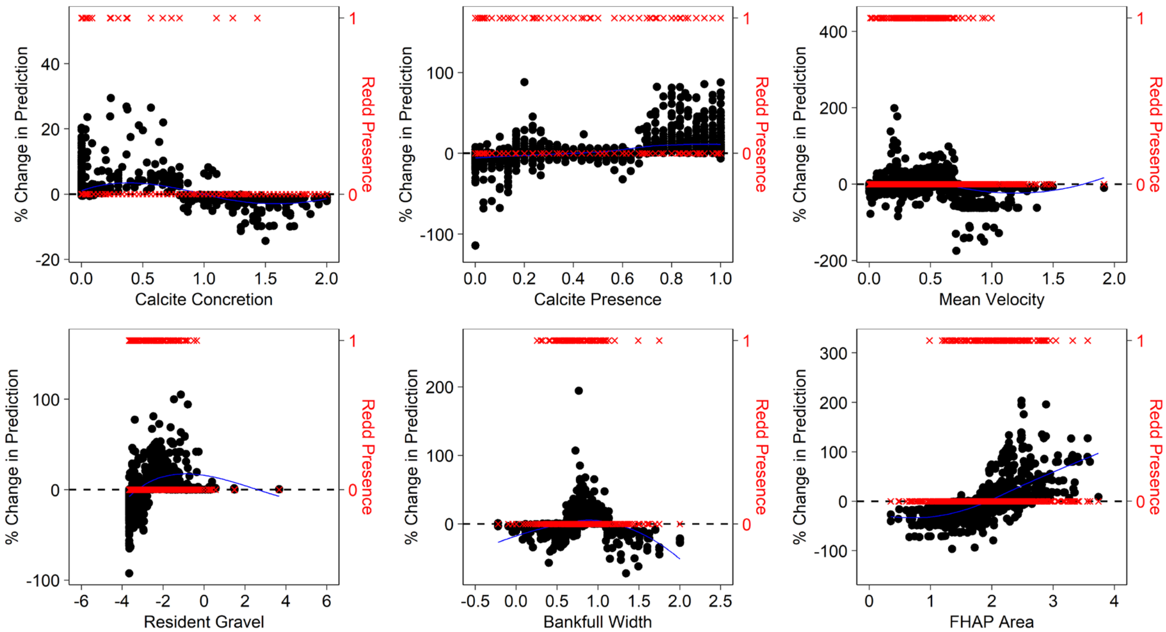
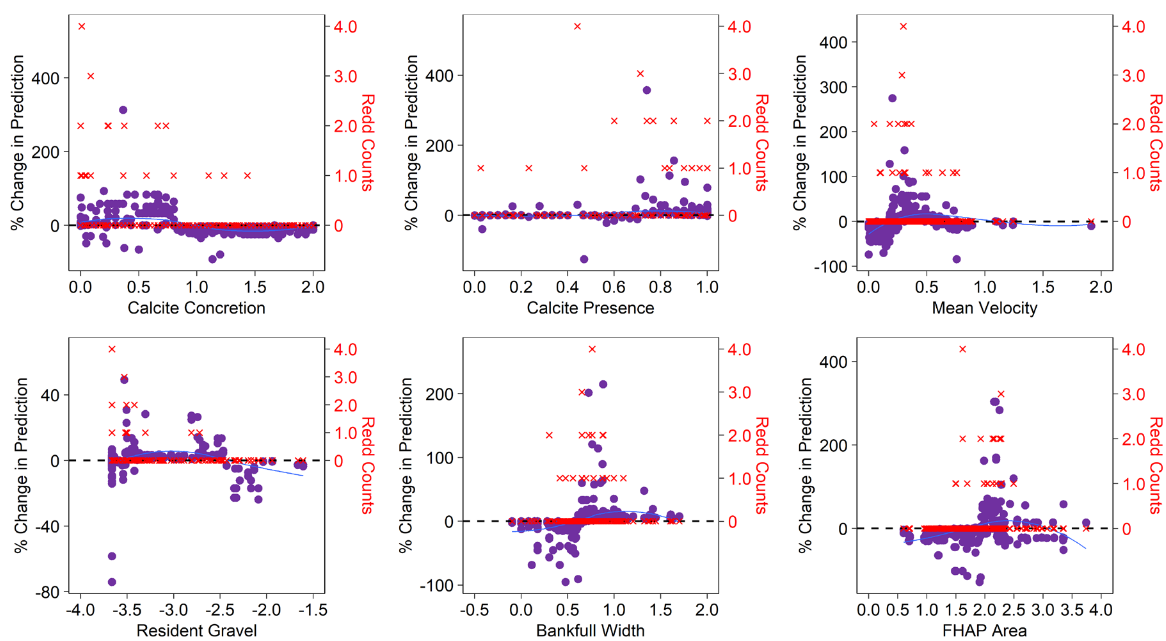


Figure 46. **Percent change in prediction for boosted regression tree model parameters describing WCT redd counts for high calcite (> 0.5 maximum concretion) streams in the Elk Valley, 2018 to 2020**



3.6. Draft Spawning Suitability Curves with Calcite Concretion

Draft spawning suitability curves were developed to describe the relationship between redd presence and counts and calcite concretion using the modeled predictions in the GLMM, GAMM, and 95th quantile models presented above.

Based on data collected and analysis performed herein, calcite concretion is inferred to have a negative effect on the WCT redd presence and counts in tributary streams of the Elk River, including three metrics analyzed in this study of likelihood of redd presence, mean count of redds, and 95th quantile of count of redds. Analyses redd presence and mean redd counts were conducted using several statistical methods to confirm the result, including univariate models, GLMMs, and non-linear GAMMs. The percentage decrease in predicted likelihood of redd presence and redd counts from a calcite concretion score of zero to calcite concretion levels of 0.25, 0.5, 0.75, 1, 1.5 and 2 is presented below for each of the analyses completed (except for the univariate models) (Table 17). In consideration of the uncertainty and resulting variability in the model, the below-listed projections should be cautiously interpreted and not considered as definitive.

The predicted likelihood of redd presence using a GLMM decreased exponentially with increasing calcite concretion, reaching approximately 41% (i.e., decreasing by 59%) of its predicted value when calcite concretion increases from 0 to 0.5, and reaching bellow 10% (i.e., decreasing by 90%) by a calcite concretion of 1.27 (Table 17, Table 18).

The predicted likelihood of redd presence using a non-linear GAMM decreased exponentially with increasing calcite concretion, reaching ~44% (i.e., decreasing by 56%) of its predicted value when calcite concretion increases from 0 to 0.5, and reaching bellow 10% (i.e., decreasing by 90%) by a calcite concretion of 1.37 (Table 17, Table 18).

The predicted mean number of redds using a GLMM decreased exponentially with increasing calcite concretion, reaching approximately 43% (i.e., decreasing by 57%) of its predicted value when calcite concretion increases from 0 to 0.5, and reaching bellow 10% (i.e., decreasing by 90%) by a calcite concretion of 1.26 (Table 17, Table 19).

The predicted mean number of redds using a non-linear GAMM decreased exponentially with increasing calcite concretion, reaching approximately 40% (i.e., decreasing by 60%) of its predicted value when calcite concretion increases from 0 to 0.5, and reaching bellow 10% (i.e., decreasing by 90%) by a calcite concretion of 1.36 (Table 17, Table 19).

The predicted 95th quantile of redd counts decreased exponentially with increasing calcite concretion, reaching approximately 29% (i.e., decreasing by 71%) of its predicted value when calcite concretion increases from 0 to 0.5, and reaching bellow 10% (i.e., decreasing by 90%) by a calcite concretion of 0.9 (Table 17, Table 19).

The predicted declines in redd presence and counts with calcite concretion can be visualized as draft spawning suitability curves for WCT with increases in calcite concretion (Figure 47). The predicted declines of redd presence and redd counts with concretion presented in this study were less steep with narrower 95% confidence intervals as compared to the 2019 spawning suitability curves presented in Hocking *et al.* (2020) (Figure 48). The redd presence spawning suitability curve was markedly less steep with the 2020 data included compared to the response curve in 2019 (Figure 48a). The spawning suitability curve for mean redd count was also less steep with an 80% decline in suitability predicted at a calcite concretion value of 0.5 in 2019 versus a 60% decline after inclusion of the 2020 data (Figure 48b). The GAMMs for redd presence and counts are new in 2020 and cannot be compared to curves in 2019 (Figure 48c,d). Finally, the quantile regression showed relatively similar response curves between this year and 2019 (Figure 48e).

The BRT model set-up included stream as a predictor variable and allowed for the influence of habitat predictor variables on redds to vary by stream and with the values of other predictors. Because of this model set-up the influence of calcite concretion needs to be put in the context of the other predictors including which stream the habitat unit is located in, and cannot be directly compared to the GLMM response curves presented here. Summarizing over the mesohabitat units in all streams, however, the shape of the decline in predicted redd presence and redd counts varied from the GLMM models and was not as steep (e.g., ~ 10 % decline in redd presence for concretion > 0.5 versus 59 % for the GLMMs and ~38 % decline in redd counts versus 57% for the GLMMs). The estimated drops, however, would not include any potential stream level declines resulting from concretion. For this to be accomplished the *Stream* factor would need to be dropped from the models and additional validation steps would be needed (e.g., test the ability of the models to predict to streams not included in the model development).

Table 17. Predicted probability of redd presence (GLMM and GAMM) and redd counts (GLMM, GAMM, and 95th quantile) per mesohabitat unit from 20 tributary streams of the Elk River, B.C. across a range of calcite concretion (0, 0.25, 0.5, 0.75, 1, 1.5, 2). These projections should not be interpreted as definitive due to variability in the model.

Calcite Concretion (CI_{Conc})	Predicted Probability of Redd Presence (GLMM)	% of Probability of Redd Presence (GLMM)	Predicted Mean Redd Count (GLMM)	% of Mean Redd Count (GLMM)	Predicted 95th %tile Redd Count	% of 95th %tile Redd Count	Predicted Probability of Redd Presence (GAMM)	% of Probability of Redd Presence (GAMM)	Predicted Mean Redd Count (GAMM)	% of Mean Redd Count (GAMM)
0.00	0.06	100.0	0.16	100.0	1.34	100.0	0.10	100.0	0.11	100.0
0.25	0.04	64.3	0.10	63.4	0.72	53.8	0.07	66.9	0.07	65.4
0.50	0.02	41.0	0.06	40.1	0.39	28.8	0.05	44.2	0.05	42.7
0.75	0.02	26.0	0.04	25.4	0.20	15.2	0.03	28.9	0.03	27.9
1.00	0.01	16.5	0.03	16.1	0.11	7.9	0.02	18.8	0.02	18.2
1.50	0.00	6.5	0.01	6.5	0.02	1.8	0.01	7.9	0.01	7.8
2.00	0.00	2.6	0.00	2.6	0.00	0.0	0.00	3.3	0.00	3.3

Predicted probabilities and redd counts assume all other preditors are held at their mean values.

Table 18. Mean predicted probability of redd presence per mesohabitat unit at a calcite concretion score of 0 and 0.5 using a GLMM and GAMM from 20 tributary streams of the Elk River, B.C. The lower and upper confidence interval of the estimates at calcite concretion of 0.5 are shown along with the mean % of probability of redd presence at a calcite concretion score of 0.5.

Model Type	Mean Predicted Probability of Redd Presence at $CI_{Conc} = 0$	Mean Predicted Probability of Redd Presence at $CI_{Conc} = 0.5$	Confidence Interval Lower Limit (2.5%) at $CI_{Conc} = 0.5$	Confidence Interval Upper Limit (97.5%) at $CI_{Conc} = 0.5$	% of Probability of Redd Presence at $CI_{Conc} = 0.5$
Redd Presence (GLMM Logit)	0.060	0.024	0.013	0.045	41.0%
Redd Presence (GAMM)	0.105	0.046	0.024	0.088	44.2%

Predicted probabilities assume all other preditors are held at their mean values.

Table 19. Mean predicted redd count per mesohabitat unit at a calcite concretion score of 0 and 0.5 using a GLMM, GAMM, and 95th quantile model from 20 tributary streams of the Elk River, B.C. The lower and upper confidence interval of the estimates at calcite concretion of 0.5 are shown along with the mean % of redd count at a calcite concretion score of 0.5.

Model Type	Mean Predicted Number of Redds at $CI_{Conc} = 0$	Mean Predicted Number of Redds at $CI_{Conc} = 0.5$	Confidence Interval Lower Limit (2.5%) at $CI_{Conc} = 0.5$	Confidence Interval Upper Limit (97.5%) at $CI_{Conc} = 0.5$	% of Mean Redd Counts at $CI_{Conc} = 0.5$
Mean Redd Count (GLMM Neg. Binom.)	0.156	0.063	0.016	0.253	40.1%
Mean Redd Count (GAMM)	0.106	0.045	0.010	0.215	42.7%
95th %tile Redd Count	1.342	0.386	0.262	0.567	28.8%

Predicted redd counts assume all other preditors are held at their mean values.

Figure 47. Draft Westslope Cutthroat Trout spawning suitability curves for calcite concretion based on data collected in 2018, 2019, and 2020 from 20 tributary streams of the Elk River, B.C. Curves are model averaged predictions of the effects of calcite concretion on redd presence and redd counts from five different analyses conducted herein. The y-axis should be interpreted as the percentage of maximum predicted response of redd presence and redd counts, which occurs at a calcite concretion score of zero. The individual suitability curves for each model and confidence intervals for each can be seen in Figure 23, Figure 27, Figure 34, Figure 34, Figure 38, and Figure 41.

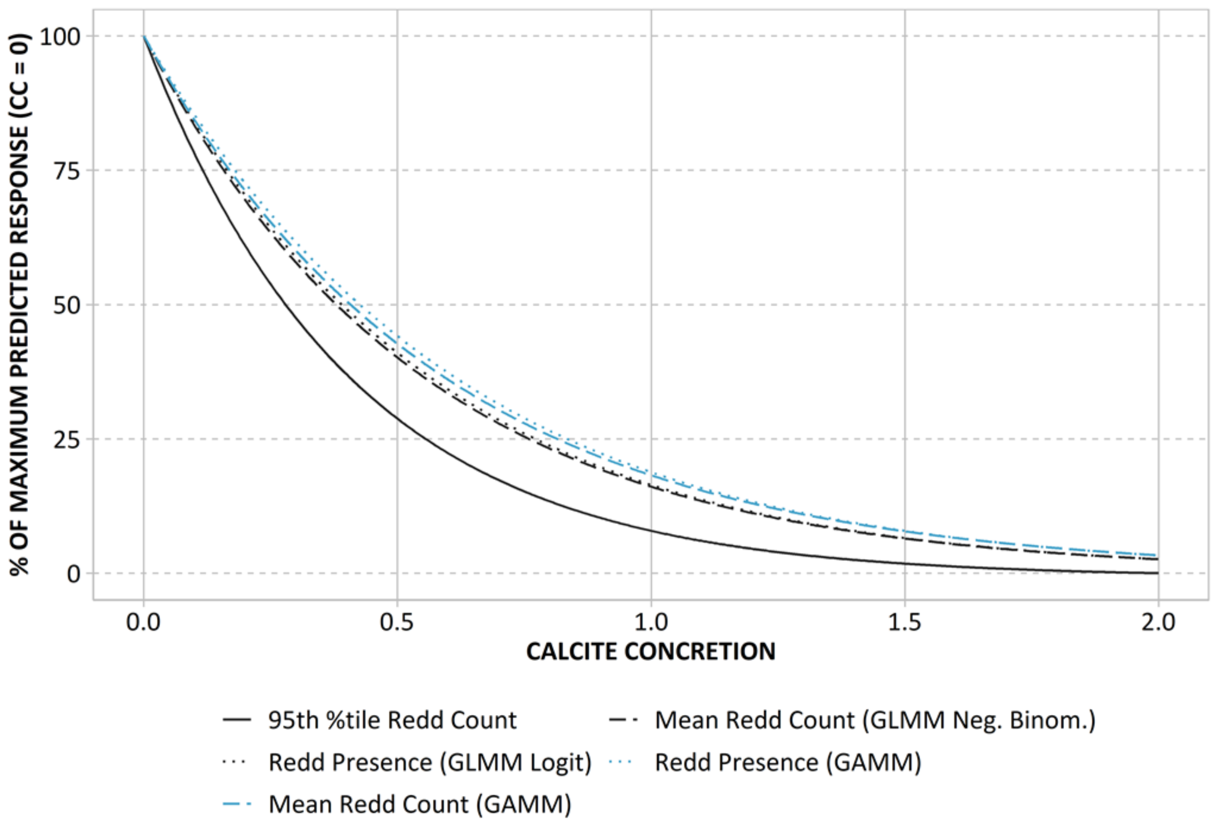
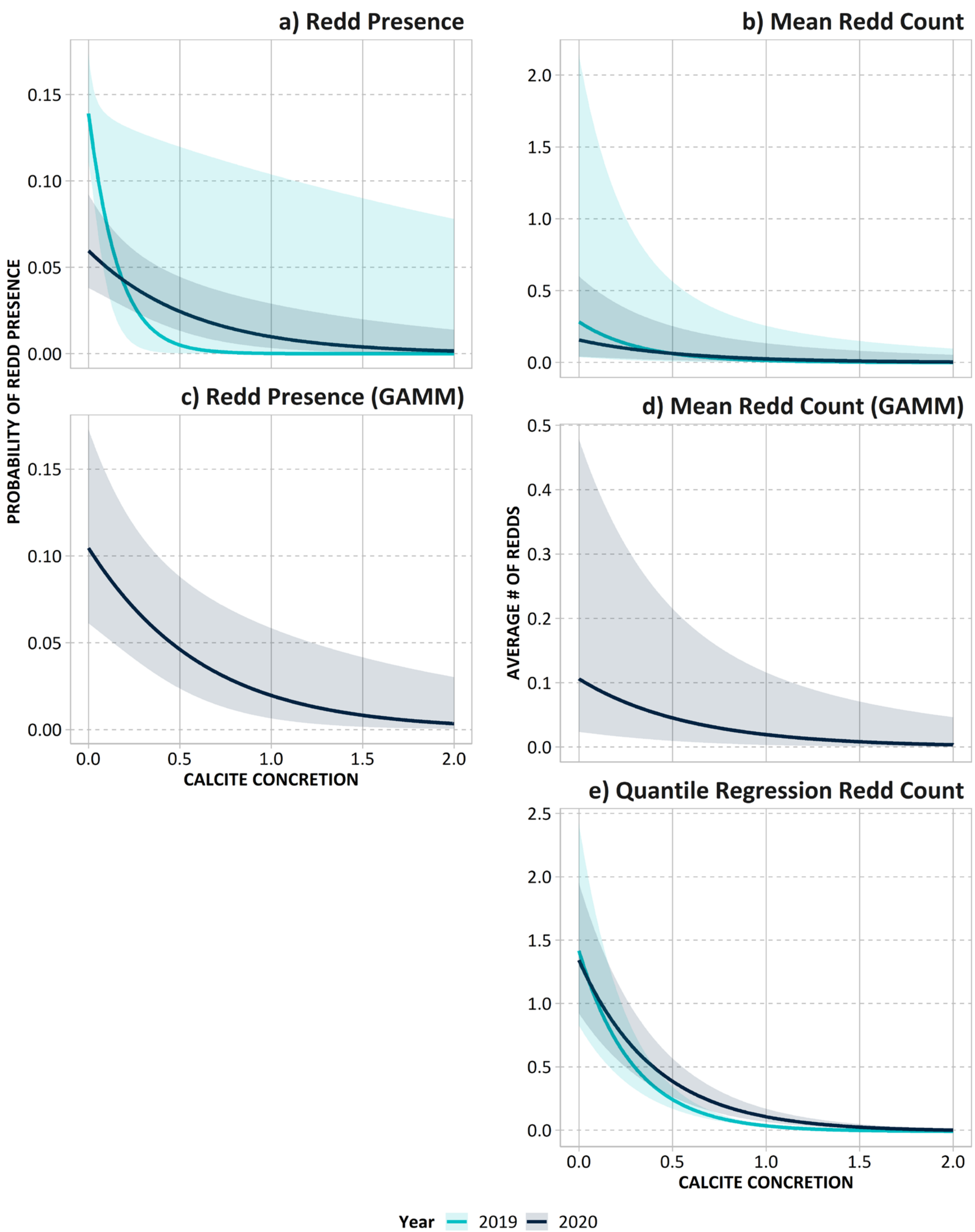


Figure 48. **Draft Westslope Cutthroat Trout spawning suitability curves for calcite concretion based on analyses performed in 2019 (in blue; Hocking *et al.* 2020), and 2020 (current study; in black) from 20 tributary streams of the Elk River, B.C. Curves are model averaged predictions with respective confidence intervals of the effects of calcite concretion on redd presence (panels a) and c) and redd counts (panels b), d) and e)).**



4. DISCUSSION

4.1. Testing the Research Hypothesis H2

Relationships between calcite and WCT redd presence and redd counts are used to develop a WCT spawning suitability response curve for calcite that may be applied to calcite management in the Elk Valley. Data collected between 2018 and 2020 came from WCT redd surveys, calcite surveys, fish habitat assessments, and assessment of water quality and velocity from 1,581 mesohabitat units (901 independent units) in 20 tributary streams of the Elk River watershed. A total of 476 redds were observed over the three years of the program, although zero redds were observed in 89.3% of all mesohabitats sampled. These data were used to test research hypothesis H2:

$H_0 2$ (null): Observed calcite conditions on stream substrates have no effect on suitability of fish spawning habitat.

$H_A 2$ (alternate): Observed calcite conditions on stream substrates have an effect on suitability of fish spawning habitat.

The basic premise of the study is that calcite accumulation on a streambed may influence the suitability of spawning substrate and thereby the carrying capacity of fish habitat. Tributary streams included in the study were observed to support WCT spawning in previous years (Russell and Oliver 1996; Windward Environmental *et al.* 2014; Cope *et al.* 2016; Minnow Environmental 2016a,b; Faulkner *et al.* 2018; Lamson 2018; Hocking *et al.* 2019; 2020; Robinson, pers. comm. 2019).

The study design in 2020 built on the outcomes of previous studies in the Elk Valley, including the two previous studies on the effects of calcite to spawning habitat suitability carried out in 2018 and 2019 (Hocking *et al.* 2019; Hocking *et al.* 2020), as well as studies implemented in 2016 and 2017 that measured hyporheic flow and dissolved oxygen at mesohabitat units that differ in calcite (Wright *et al.* 2017; 2018). The studies in 2016 and 2017 observed that stream sites with high levels of calcite may experience some reduction in hyporheic DO, although effects are predicted to be greatest at depths greater than typical WCT spawning depths and at CI scores higher than may be useable for spawning. For example, the greatest effects on incubation conditions were predicted at sites with CI scores higher than ~1.25, high % fines, and at depths deeper than typical redd depths (Wright *et al.* 2018). Therefore, a key outcome from the studies in 2016 and 2017 was that research hypothesis H1 related to incubation conditions may be less important than research hypothesis H2 related to spawning substrate suitability for salmonids.

A preliminary test of H2 was carried out in 2018 (Hocking *et al.* 2019) using data from five streams in the upper Fording River watershed; data from these streams did not span the full range of calcite conditions possible (i.e., the maximum CI recorded was CI = 1.66). Hocking *et al.* (2019) did not find a strong relationship between mean presence or density of redds and CI but found a negative relationship between the 90th quantile of redd density and CI, which suggested that high densities of redds are found in streams with lower CI. Hocking *et al.* (2019) did not find a clear relationship between the likelihood of redd presence and CI.

The sampling design was expanded in 2019 to include 17 tributary streams across the Elk River valley, with more intensive sampling of all mesohabitat units within ~ 1 km reaches in each stream that were accessible to WCT spawners (e.g., each riffle, pool, glide mesohabitat) (Hocking *et al.* 2020). This increased the range of CI previously observed and enabled greater inference on the relationship between calcite and spawning habitat suitability. In 2020, the number of sampled streams was expanded further to a total of 20 streams sampled across the Elk Valley, which now includes 14 mine-influenced streams and six reference streams across the full range of CI (0 to 3).

In 2020, the effects of calcite on redd presence and counts were tested using several statistical modelling approaches that vary from simpler to more complex. This was completed to increase the confidence in the results observed and to account for the hierarchical structure of the dataset, the importance of fish-habitat covariates, the high numbers of mesohabitats with zero redds, potential interactions and non-linear relationships among the predictor variables, and the binomial and count-based distributions of the response variables. The data analyses included the following:

- Univariate GLM and GAM analyses to test the individual effects of CI, calcite concretion, and calcite presence on the likelihood of redd presence and redd counts (Section 3.3.1 and 3.4.1).
- GLMM model selection analyses to test the combined effects of calcite and fish-habitat variables on WCT redd presence and counts, including analyses across all streams, mine influenced streams, and reference streams (Section 3.3.2 and 3.4.2).
- GAMM model selection analysis to account for potential non-linear relationships between calcite, fish-habitat variables, and WCT redd presence and counts (Section 3.3.3 and 3.4.3).
- Model selection analysis on the 95th quantile of redd counts to assess effects of calcite and fish-habitat variables on high counts of redds (Section 3.4.4).
- Boosted regression tree (BRT) analysis to test of the effects of calcite and fish-habitat variables on redd presence and counts within streams while accounting for potential interactions (Section 3.5).

This methodological expansion allowed for a comprehensive evaluation of the effect of calcite on WCT spawning across multiple contexts of calcite exposure and statistical assumptions, while still being directly comparable with the approach used in 2018 and 2019. WCT spawning suitability response curves with calcite concretion were generated and compared across five of the different modelling approaches.

Based on mixed-model analysis performed herein, calcite concretion was one of the most important variables to describe variance in redd presence, mean redd count, and the 95th quantile of redd counts (the latter two are measures of redd abundance). Calcite concretion outcompeted CI in explaining redd presence and redd counts across all-streams and mine-influenced streams. The influence of calcite concretion on redd presence and counts was negative and the mixed-model spawning habitat suitability curves for WCT decreased exponentially with increasing levels of calcite concretion. An approximately 50% decline in WCT spawning suitability was observed at a calcite concretion score of 0.5. The BRT analyses similarly found declines in suitability with increases in calcite concretion beyond values of 0.5, but the extent of the decline was not as large with an estimated 10% decline in presence and 38% decline in counts beyond this range. Further, there appeared to be more of a threshold drop is suitability rather than an exponential decline.

Overall, the results suggest that the null hypothesis $H_0 2$ should be rejected in favour of the alternate hypothesis $H_A 2$. The convergence of the effect of calcite concretion across models and when models were discretized into all-streams and mine-influenced streams analyses, provided a substantial weight of evidence for an effect of calcite concretion on redd presence and counts. However, it is important to note that the confidence interval surrounding the predicted effect size remains high, which leads to uncertainty in the mean predicted slope of the draft spawning suitability curves shown in Figure 47 and Figure 48, and some uncertainty in the effects prediction at low to moderate values of calcite concretion. In addition, the BRT analysis found that calcite concretion was not always a strong predictor for redd presence and counts within streams and that the effect of concretion is most pronounced above a calcite concretion score of 0.5. Based on data collected and the analysis performed the slope between redd presence and redd abundance and calcite concretion was found to be negative. However, the confidence intervals of the slopes of the mixed model curves shown in Figure 47 and results of the BRT analysis suggest that there remains uncertainty estimated from the models. Some redds were observed in concreted habitats, including up to a CI score = 2.43 and a calcite concretion score = 1.43. Further discussion of uncertainties and potential next steps is developed below in Section 4.2.

Calcite is one of many influences on fish and fish habitat, and these other influences (e.g., substrate, cover, water depth, velocity, water quality) need to be considered as potential covariates when developing the spawning suitability versus calcite response curve. Therefore, a number of fish-habitat variables were included in the modelling to account for different habitat conditions and to build a comprehensive model. After a detailed data exploration procedure (following Zuur *et al.* 2010) the final set of explanatory variables considered as inputs in the modelling approaches included CI, calcite concretion, calcite presence, conductivity, water velocity, proportion of spawning gravel area, bankfull depth and width, mesohabitat area, functional LWD tally, water temperature during spawning, and pH (Table 6). All of these habitat variables were hypothesized to affect spawning suitability and were measured at the mesohabitat scale.

A new and important result for this year was the observed positive relationship between calcite presence and both redd presence and redd counts. The univariate analysis describes a non-linear relationship between calcite presence and WCT redds, with a peak in redd presence and counts at a calcite presence score of 0.70 to 0.75, which is when concretion begins to occur (Hocking *et al.* 2021). The GLMM, GAMM and BRT models that analyzed both calcite presence and concretion in the same models found a positive relationship with calcite presence and a negative relationship with calcite concretion. The mechanism underlying the positive relationship with calcite presence is somewhat unclear, but potentially represents a benthic productivity gradient driven by inputs of nutrients and possibly higher stream temperatures. Calcite presence is positively correlated to stream conductivity and pH (Atherton 2017, Hocking *et al*. 2021), which both increase in mine-affected streams with inputs of dissolved salts such as derived from sodium, potassium and calcium. However, increases in conductivity and pH are also related to natural gradients in productivity (e.g., increased alkalinity downstream of limestone deposits), which subsequently promotes periphyton growth and can increase fish production (Ptolemy 2005; McGrath *et al*. 2008). In reference streams only conductivity was a strong positive predictor of redd presence and counts and typically out-competed calcite presence in the model selection process. Only when both calcite presence and concretion were included together in mine-influenced and all-streams analysis did both calcite metrics out-compete conductivity in the presence and abundance of WCT redds. Further work would be required to better understand the linkage between increased calcite presence and WCT production, but current data suggest that increases in calcite presence may be an indicator of higher WCT production up to the point that calcite concretion begins to occur.

Some habitat variables were found to positively influence WCT spawning. Within reference streams, calcite metrics were outcompeted by habitat and other water quality variables, such as habitat area and proportion of spawning gravel area and conductivity. Habitat availability, both mesohabitat area and the proportion of spawning gravel area had a strong positive influence on the likelihood of redd presence and redd counts (including the 95th quantile) across all methods. Increases in mesohabitat area and spawning gravel area intuitively reflect that as the area available for spawning increases so does the number of redds (e.g., Magee *et al.* 1996). Water temperature during spawning was also found to positively influenced the mean and the 95th quantile of redd counts. The non-linear GAMM models also indicated a non-linear relationship with temperature with a peak in redd counts at 11-12 ºC. The mechanism is not clear, but cold water temperatures may limit distribution of spawning and rearing WCT in the highest elevation tributaries (Heinle *et al.* 2021). For example, one of the coldest streams, Henretta Creek, had only one redd observed across both years of sampling, while one of the warmest streams, Lizard Creek, had the highest observed redd counts. Another important variable observed to have a strong non-linear association with both redd presence and redd counts was water velocity. Peak redd presence and counts occurred in water velocities of ~0.25 to 0.6 m/s, which aligns with the observation of redds being more common in glides, runs, and riffles, less common in pools, and rarely found in chutes and cascades and consistent with other studies (Thurow and King 1994). The BRT analyses also found a non-linear relationship with bankfull width and redd presence and counts were higher with values that ranged between 4.0 and 12.6 m. Rosenfeld *et al.* (2000) similarly found the positive association with channel bankfull width to be one of the strongest predictors of juvenile cutthroat trout densities.

4.2. Uncertainties and potential next steps

This study across a range of calcite conditions in 20 tributaries of the Elk and Fording River watersheds suggests that calcite concretion limits spawning habitat suitability for WCT. The predicted decreases in redd presence and counts with calcite concretion can be visualized as draft spawning habitat suitability curves (Figure 47, Figure 48). Calcite concretion is inferred to have negative effects on redd presence and the number of redds in a stream. Other habitat variables measured in this study also influence spawning habitat suitability, such as mesohabitat area, spawning habitat area, conductivity, temperature, pH, and water velocity. The relationships found for these fish-habitat variables could also be considered as spawning habitat suitability response curves such as shown in Figure 26 for redd presence and Figure 37 for redd counts. It is acknowledged that the there are other potentially important fish habitat variables that were not measured in this study. There also remains uncertainty with respect to the slopes of the response curves as reflected by the broad confidence intervals.

The range of CI observed has increased across the three-year program and now includes mesohabitats across the full range of CI (CI range of 0 to 3). The majority of the mesohabitats sampled occur at low levels of CI (CI < 1) at calcite concretion scores of 0 to 0.01 (Table 10). Highly concreted mesohabitats are fairly well represented with 200 mesohabitat units sampled with concretion scores between 1 and 2 (i.e., CI between roughly 2 and 3). However, only 137 mesohabitat units have been sampled across all three years that have low to moderate concretion between 0.01 and 1, which roughly overlaps with moderate CI scores of 1 to 2. This highlights an uncertainty associated with the effects prediction at low to moderate levels of concretion and the need for more effort to assess the relationship between calcite and spawning suitability at concretion scores between 0 and 1.

Although there were many congruencies between the mixed-modelling and BRT results, there were some differences between the approaches that further point to uncertainty in the relationship between redds and concretion at low levels (<0.5). In particular, the relative influence of concretion compared to other predictors and the shape and extent of the decline in redds with calcite. The BRT analysis suggest that in comparison to other parameters, calcite concretion had a much lower influence for streams with low-to-medium levels of calcite concretion. Some of these discrepancies are likely due to underlying differences in the model structure and a general lack of data in this range. For example, the mixed-modelling approaches fit a model with an assumed underlying relationship between the response and predictors. By including a random intercept for stream, the baseline probability of presence or counts of redds can vary among streams but the slope of the relationship is assumed to be the same for all streams. The BRT models differ from the GLMMs in the fact that individual trees are built and combined to maximize their potential to predict the response variable. Because stream is in the BRT model, the influence and effect of concretion can vary by stream. For streams with low levels of calcite concretion the restricted range of this parameter does not offer much power in separating the response variable (redd presence or counts) in comparison to the other parameters where there is a greater variability among the habitat units within these streams. Thus, the overall influence of concretion may be reduced if there is a stream level influence of concretion on redds. Continued sampling with an emphasis on expanding the dataset for streams with low-to-medium levels of concretion will likely help to reduce this uncertainty and guide any potential changes to the SPOs.

Because the BRT analysis focused on predictions of effects within streams, the between stream effects were not assessed. Redd presence and counts varied widely by stream and across years and in both the BRT and the GLMM models, stream and year explained a significant proportion of the variation. This is evidenced by the fact that including predictor variables only led to modest improvements in validation statistics (AUC for redd presence and MAE for redd counts) over null models that only included stream and year. Further work in 2021 and 2022 will include across-stream analyses using the BRT approach and potential development of BRT-based spawning suitability curves reflective of within and among stream differences. This will potentially require the inclusion of additional landscape scale predictors (i.e., landcover characteristics, stream temperature regimes) that have been shown to correlate with differences in redd densities and WCT abundance among tributaries (Baxter and Hauer 2000; Steel *et al.* 2004; Heinle *et al.* 2021).

Another important finding in this study was that WCT spawn in mine-affected and reference streams with moderate to high calcite presence, but little to no calcite concretion. For example, in 2019 and 2020 sampling at reference streams (Lizard and McCool Creeks) was conducted that support WCT spawning, to allow comparison of the natural range in redd presence and redd densities to streams influenced by mining. We found high calcite presence (up to 1) in Lizard and McCool creeks in 2019 in particular, with almost no calcite concretion across both years. For these streams, when calcite was present on a rock, coverage was variable; occasionally, small patches (<1 cm^2) were observed that did not completely cover the rock, despite that calcite was present on most rocks.

Another important finding and resulting uncertainty was that overall redd counts were considerably lower in 2020 compared to 2019 on streams in throughout the Elk Valley. For example, more redds were observed in 2019 versus 2020 in Alexander Creek (3 *versus* 0), Upper Grave Creek (5 *versus* 2), Lizard Creek (196 *versus* 31), McCool Creek (21 *versus* 3), LCO Dry Creek (15 *versus* 8), Harmer Creek (15 *versus* 7), Henretta Creek (1 *versus* 0), and Michel Creek (41 *versus* 2). The lower abundance in redds may be caused by higher stream flows and lower temperatures during the typical peak spawning period in mid to late June and early July in these streams that can reduce spawning as well as observer efficiency. Widespread declines in WCT in the Upper Fording River and Grave-Harmer watersheds has also been documented in recent years (Cope 2019; Cope and Cope 2020). It is unclear if a lower spawner abundance influences the predicted spawning suitability relationships; it is possible that the suitability curves would differ when fish abundance is greater since fish may alter their decisions based on density dependence. Additional sampling during a year of higher WCT spawning productivity would aid in understanding this uncertainty.

Another uncertainty is the extent to which spawning habitat suitability with calcite elicits a WCT population response. This study has not assessed how decreased likelihood of presence and abundance of redds may translate into total fish production in the system. If spawning is not the limiting life stage for WCT then the relationship between stream calcite and population abundance is likely to be less steep than spawning suitability, or perhaps follow a different form. Potential spawners may simply go elsewhere to spawn, or the loss of some spawning events may not lead to lower recruitment (and thereby lower total abundance) if another factor is more limiting. Ongoing work to develop a

WCT population model may help to explore the population effect of spawning suitability and other limiting factors at the population level.

This study presents data on spawning suitability relationships for WCT in relation to calcite; the models are less steep with reduced confidence intervals than the models developed in 2018 and 2019 (Hocking *et al.* 2019, Hocking *et al.* 2020) (Figure 48). Nevertheless, additional sampling may be required to resolve the uncertainties discussed here. The highest priority for future sampling would be on streams and mesohabitats with moderate CI and low to moderate levels of calcite concretion, especially calcite concretion scores between 0 and 1. Field sampling for 2021 is underway and additional streams and reaches with low to moderate concretion have been prioritized.

5. CONCLUSION

A range of linear and non-linear statistical approaches were applied to a three-year dataset to test if calcite conditions influence spawning habitat suitability for WCT in tributaries streams of the Elk River, B.C. Relationships between calcite and WCT redd presence and redd counts were used to develop a draft WCT spawning suitability response curve for calcite that may be applied to calcite management in the Elk Valley. The study in 2020 builds upon similar data collected in 2018 and 2019, and now includes 901 unique mesohabitat units in 20 streams across the full range of calcite conditions (CI range = 0 to 3). The total number of redds observed in 2020 was 88 from 17 streams, which represents a 71% decrease in the number of redds compared to 2019 (311 redds), also from 17 streams. In 2018, 77 redds were observed from five streams in the Upper Fording River watershed. Declines in redd counts have been observed in many individual streams, which may represent a combination of poor spawning conditions (high flows and low temperatures) and poor observer efficiency in 2020, and broad-based declines in WCT beginning in 2018.

Overall, based on the streams sampled across all years, redd presence and counts are negatively influenced by calcite concretion; few redds were observed in Erickson Creek, EVO Dry Creek, Corbin Creek, Upper Greenhills Creek, Lower Greenhills Creek, and Clode Creek where high levels of concretion were observed. In contrast, a broad range of redd counts (low to high) were observed in both mine-affected and reference streams with moderate to high calcite presence ($CI_{Pres} > 0.5$) but limited to no concretion. This means that multiple environmental variables limit spawning suitability within and across streams in addition to calcite. In all models, calcite concretion and calcite presence outcompeted CI in explaining redd presence and counts, with a negative relationship observed with calcite concretion and a positive relationship observed with calcite presence. This result suggests that calcite presence and concretion differ in their functional relationship with the probability of presence and count of WCT redds. CI is a composite of calcite presence and calcite concretion, and these two components of the calcite index could thus be used differently for calcite management in the Elk Valley. Further work is required to better understand the linkage between increased calcite presence and WCT spawning suitability, but current data suggest that increases in calcite presence may be an indicator of higher stream productivity and higher WCT production up to the point that calcite concretion begins to occur.

While the results presented here indicate a response relationship that is similar but less steep with reduced confidence intervals than those presented in 2018 and 2019 (Hocking *et al*. 2019; 2020), there remains uncertainty in the spawning suitability curves based on the broad confidence intervals. The BRT analysis found less of a steep relationship between calcite and redds and found other predictors to be more influential in streams with low-to-medium levels of calcite. The different results between the GLMMs and GAMMs and the BRT approach is likely driven by the within-stream analysis structure of the BRT models, which suggests that a substantial amount of the variation in redd presence and counts is explained by differences in calcite and other fish habitat variables across streams rather than solely within streams. Additional field work and analysis would be required to reduce uncertainties in the results presented and to improve the predictive ability of the spawning suitability response curves, particularly at low to moderate levels of concretion. At this time, the 2021 work is advancing, which will focus on expanding surveys in areas with low to moderate calcite concretion. Additional analyses in 2021 and 2022 will also focus on confirming the drivers of redd presence and abundance across streams and WCT populations.

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APPENDICES

Appendix A. Summary of 2020 Calcite Study Sampling by Date and Waypoints of Study Streams

LIST OF TABLES

Table 1. Start and end waypoints of calcite study sample reaches in the Elk Valley.

Project	Stream Name	Study Reach Length	Downstream UTM Coordinates			Upstream UTM Coordinates		
			Zone	Easting	Northing	Zone	Easting	Northing
CMO	Corbin Creek	1,117	11U	668205	5487121	11U	669052	5487348
	Michel Creek	1,104	11U	667947	5487337	11U	668120	5486774
EVO	Dry Creek (EVO)	982	11U	659456	5517585	11U	659222	5517164
	Grave Creek	1,490	11U	657319	5522628	11U	658020	5523315
	Harmer Creek (Middle)	843	11U	657194	5521983	11U	657701	5521600
	Harmer Creek (Upper)	242	11U	659187	5518196	11U	659256	5518026
FRO	Clode Creek	172	11U	650807	5564239	11U	650864	5564280
	Fish Pond Creek	1,015	11U	650824	5564656	11U	651123	5564972
	Fording River	1,088	11U	650899	5563288	11U	650946	5563682
	Henretta Creek	825	11U	652176	5566455	11U	652982	5566552
GHO	Lower Greenhills Creek	841	11U	653311	5545452	11U	653572	5545865
	Thompson Creek	1,097	11U	648330	5550231	11U	648945	5550413
	Upper Greenhills Creek	1,006	11U	653707	5546112	11U	653980	5546843
LCO	Dry Creek (LCO)	1,113	11U	655865	5544783	11U	656333	5544922
	Line Creek	589	11U	659435	5530770	11U	660111	5532202
	South Line Creek	242	11U	659936	5531529	11U	659961	5531561
SRO	Alexander Creek	1,059	11U	664753	5518573	11U	664747	5519480
	Grace Creek	892	11U	653687	5538330	11U	653418	5538970
	Lizard Creek	891	11U	638042	5483169	11U	637572	5483342
	McCool Creek	837	11U	648204	5499803	11U	648213	5500574

Study reach lengths and waypoints reflect 2020 surveys. Data collected in 2018 and 2019 is included in the analysis and presented in Hocking *et al*. 2020.

Table 2. Sampling dates for habitat, water quality, gravel, calcite, and spawning surveys performed on calcite study streams in the Elk Valley.

Project	Waterbody	Sampling Type and Date[1]				
		FHAP	Redd Surveys[2]	WQ and Velocity	Gravel	Calcite
CMO	Corbin Creek		18-Jun 07-Jul	18-Jun 07-Jul		10-Aug 12-Aug
	Michel Creek		07-Jul 19-Jul	19-Jun 06-Jul		10-Aug
EVO	Dry Creek (EVO)		15-Jun*	22-Jun		05-Aug
	Grave Creek		30-Jun*	24-Jun		05-Aug 26-Aug
	Harmer Creek (Middle)		16-Jun* 23-Jun	23-Jun		05-Aug
	Harmer Creek (Upper)	23-Sep	15-Jun* 29-Jun*	23-Sep	23-Sep	23-Sep
FRO	Clode Creek		09-Jun*	24-Jun		14-Sep
	Fish Pond Creek		09-Jun* 25-Jun* 03-Jul*	24-Jun		14-Sep 15-Sep
	Fording River	10-Jul 15-Sep	09-Jun* 03-Jul* 10-Jul	10-Jul 15-Sep	15-Sep	30-Jul
	Henretta Creek		Unk.* 25-Jun* 08-Jul	25-Jun 08-Jul		27-Aug
GHO	Lower Greenhills Creek		25-Jun*	25-Jun		07-Aug
	Thompson Creek		28-May 12-Jun	12-Jun		07-Aug
	Greenhills Creek (Upper)		28-May** 03-Jun** 23-Jun** 26-Jun	26-Jun		07-Aug

[1] All dates are 2020 unless otherwise indicated.
[2] * = Date of redd observations reported by Westslope Fisheries (survey dates unknown). Unk. = Unknown. ** = Redd surveys completed by Minnow Environmental. No * indicates redd surveys completed by Ecofish. Dates of Water Quality and Velocity sampling are included for streams surveyed by Westslope Fisheries and Minnow Environmental if Ecofish identified unmarked redds.

Table 2. Continued (2 of 2).

Project	Waterbody	Sampling Type and Date[1]				
		FHAP	**Redd Surveys[2]**	**WQ and Velocity**	**Gravel**	**Calcite**
LCO	Dry Creek (LCO)		02-Jul* 06-Jul	06-Jul		06-Aug
	Line Creek	09-Jul	29-Jun 09-Jul	29-Jun 09-Jul	06-Aug	06-Aug
	South Line Creek	09-Jul	29-Jun 09-Jul	29-Jun 09-Jul	06-Aug	06-Aug
SRO	Alexander Creek		20-Jun 03-Jul	20-Jun 03-Jul		09-Aug
	Grace Creek	09-Aug	19-Jun 27-Jun	19-Jun 27-Jun	09-Aug	09-Aug 13-Aug
	Lizard Creek		13-Jun 28-Jun	13-Jun 28-Jun		08-Aug
	McCool Creek		11-Jun 30-Jun	11-Jun 30-Jun		08-Aug

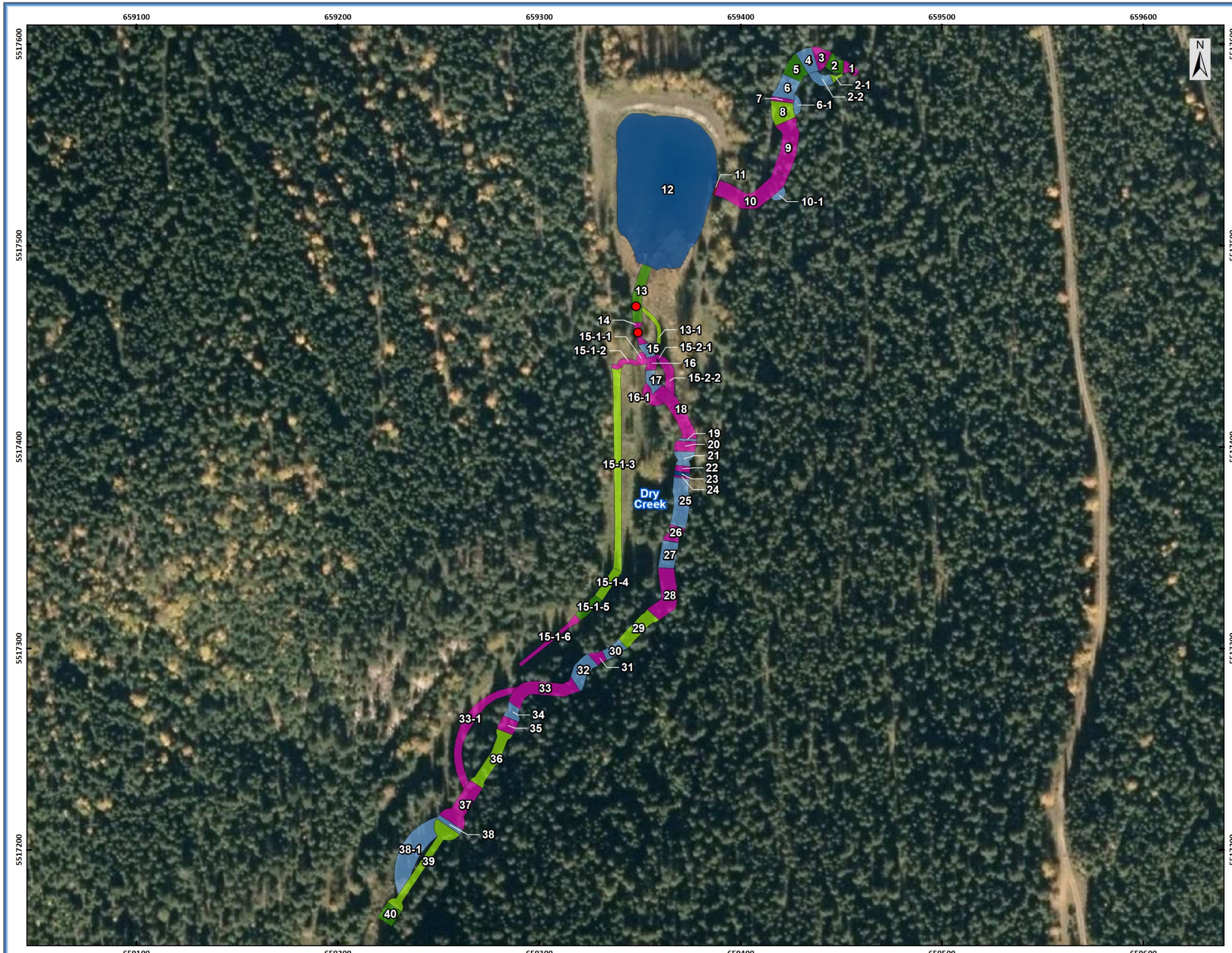
[1]All dates are 2020 unless otherwise indicated.
[2]* = Date of redd observations reported by Westslope Fisheries (survey dates unknown). Unk. = Unknown. ** = Redd surveys completed by Minnow Environmental. No * indicates redd surveys completed by Ecofish. Dates of Water Quality and Velocity sampling are included for streams surveyed by Westslope Fisheries and Minnow Environmental if Ecofish identified unmarked redds.

Appendix B. Summary Maps of FHAP, Redd and Calcite Surveys Completed in Tributaries of the Fording and Elk Rivers, 2020

LIST OF MAPS

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_CBN_FHAPRedds_4054_20210114.mxd

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_MIC_FHAPRedds_4054_20210114.mxd



TECK COAL LTD.

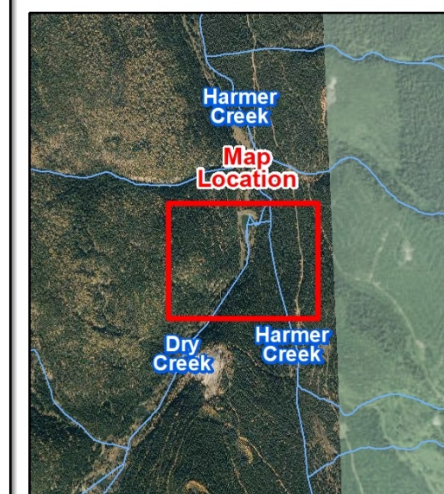
EVO Dry Creek FHAP and Redd Survey

Legend

- Number of Redds Observed (2020)

FHAP Habitat Type

- Cascade
- Falls
- Glide
- Pool
- Riffle
- Run



MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 10 20 40 60 80 100 m

Scale: 1:1,800

NO.	DATE	REVISION	BY
1	2021-01-14	1229_EVODRY_FHAPRedds_4054_20210114	CGA
2			
3			
4			
5			

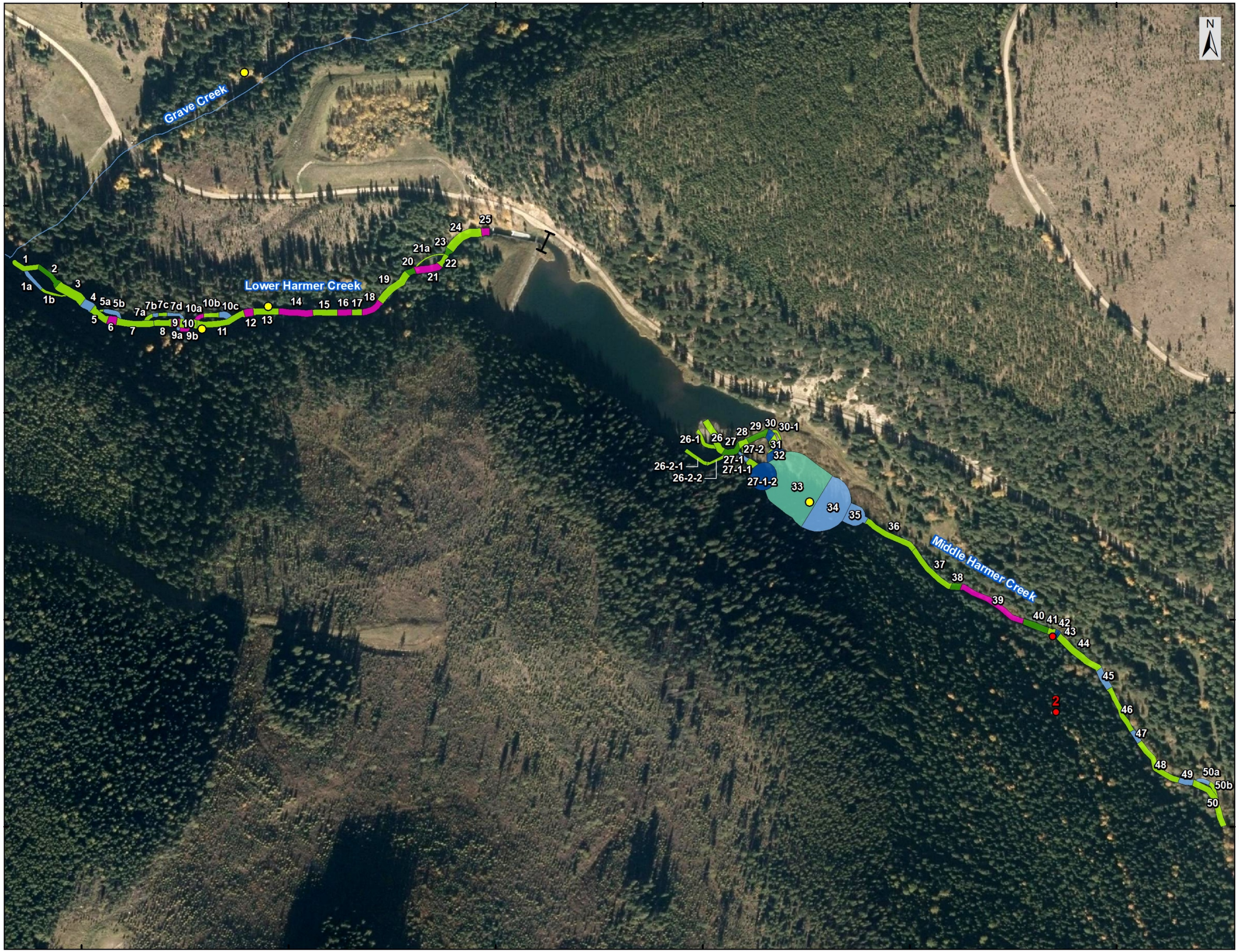
Date Saved: 2021-01-14
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 3

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_EVODRY_FHAPRedds_4054_20210114.mxd

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_GRV_FHAPRedd_4054_20210422.mxd



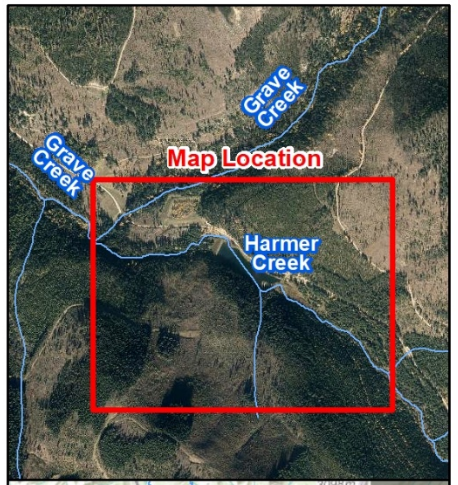
TECK COAL LTD.

Lower and Middle Harmer Creek FHAP and Redd Survey

Legend

Number of Redds Observed
- 2020
- 2019
- Reach Break

FHAP Habitat Type
- Cascade
- Glide
- Pool
- Riffle
- Run
- Wetland



MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 25 50 100 150 200 m

Scale: 1:3,600

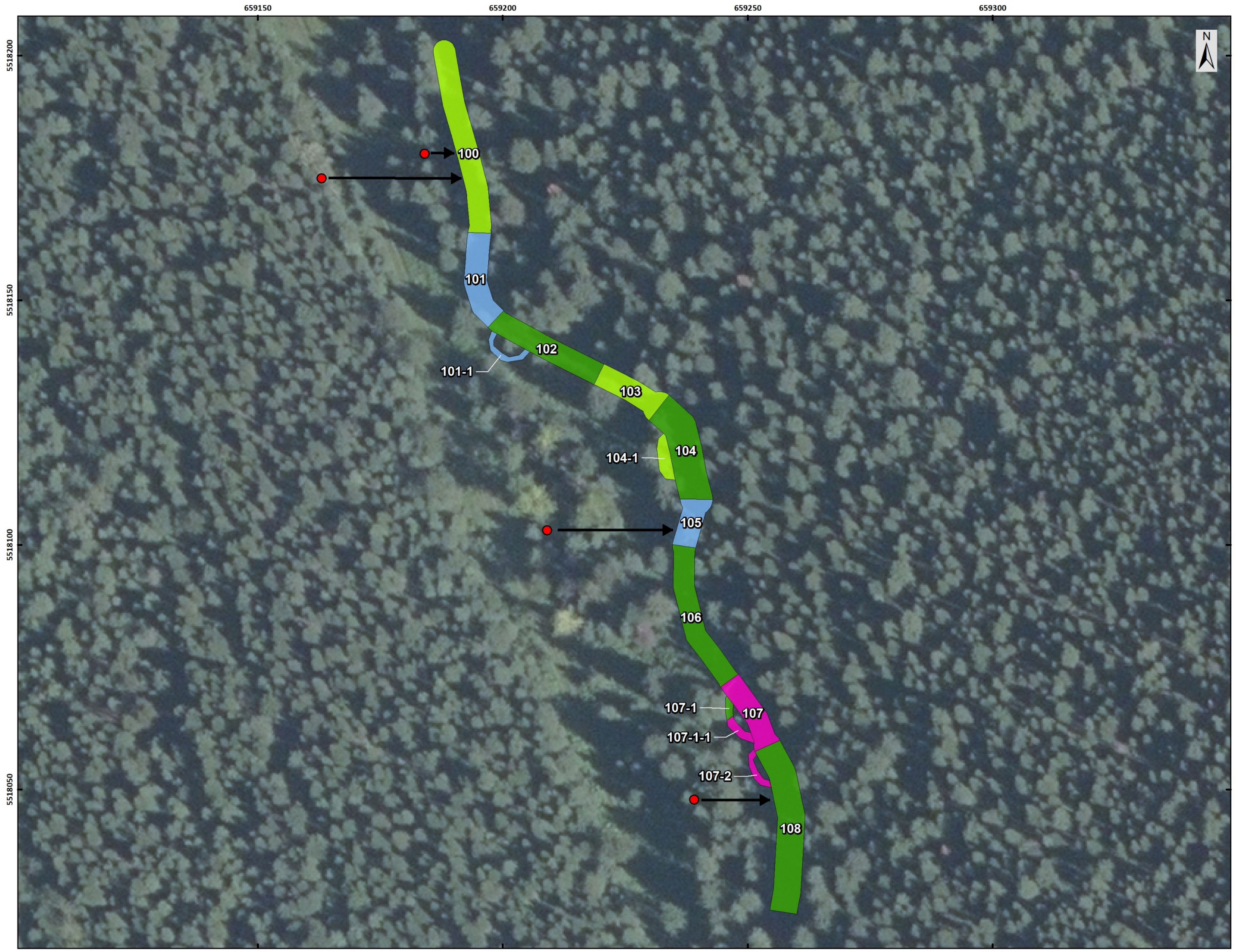
NO.	DATE	REVISION	BY
1	2021-08-30	1229_HMR_FHAP_Lower_4054_20210113	CGA
2			
3			
4			
5			

Date Saved: 2021-08-30
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 5

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_HMR_FHAP_Lower_4054_20210113.mxd



TECK COAL LTD.

Upper Harmer Creek FHAP and Redd Survey

Legend

- Number of Redds Observed (2020)

FHAP Habitat Type

- Cascade
- Falls
- Glide
- Pool
- Riffle
- Run

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 20 40 m

Scale: 1:750

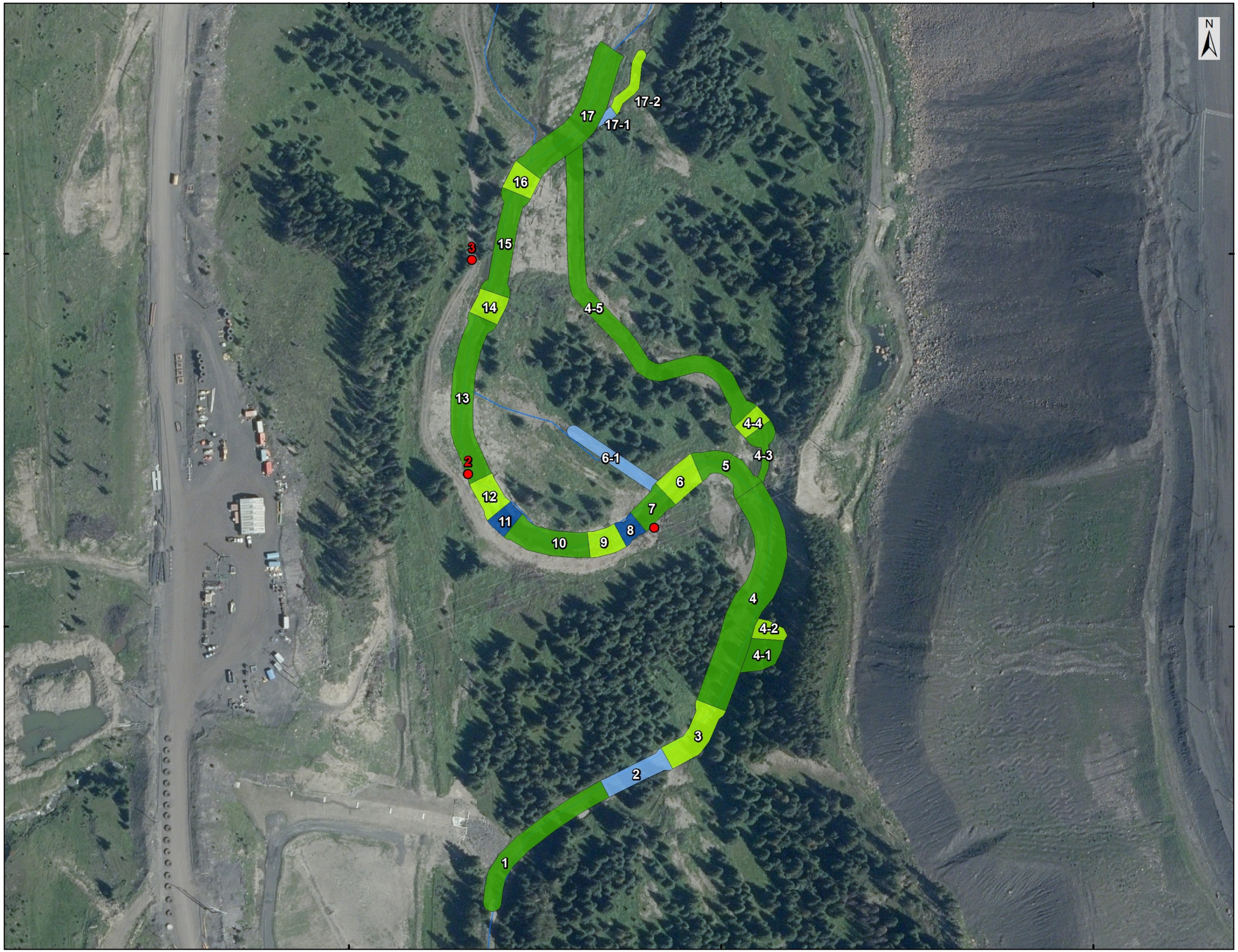
NO.	DATE	REVISION	BY
1	2021-08-30	1229_HMR_FHAP_Upper_4054_20210113	CGA
2			
3			
4			
5			

Date Saved: 2021-08-30
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 6

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_HMR_FHAP_Upper_4054_20210113.mxd



TECK COAL LTD.

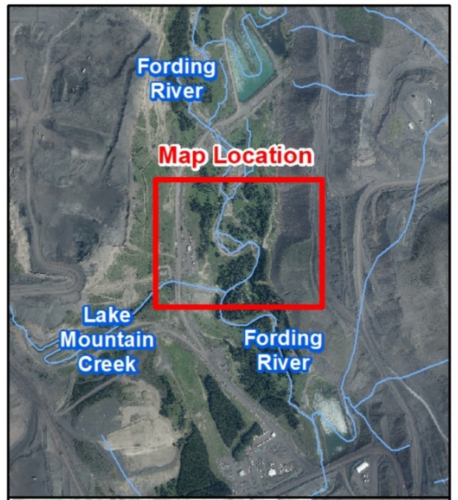
Fording River FHAP and Redd Survey

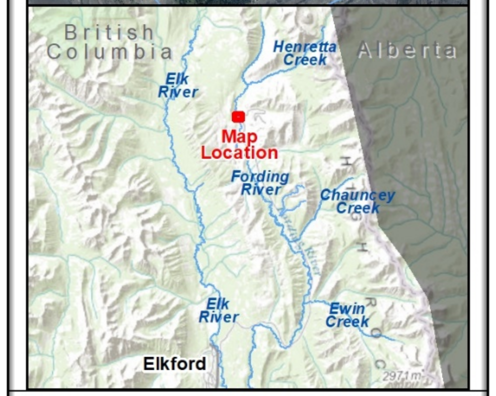
Legend

- Number of Redds Observed (2020)

FHAP Habitat Type

- Glide
- Pool
- Riffle
- Run





MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 10 20 40 60 80 100 m

Scale: 1:2,000

NO.	DATE	REVISION	BY
1	2021-01-14	1407_FRD_FHAPRedds_4054_20210114	CGA
2			
3			
4			
5			

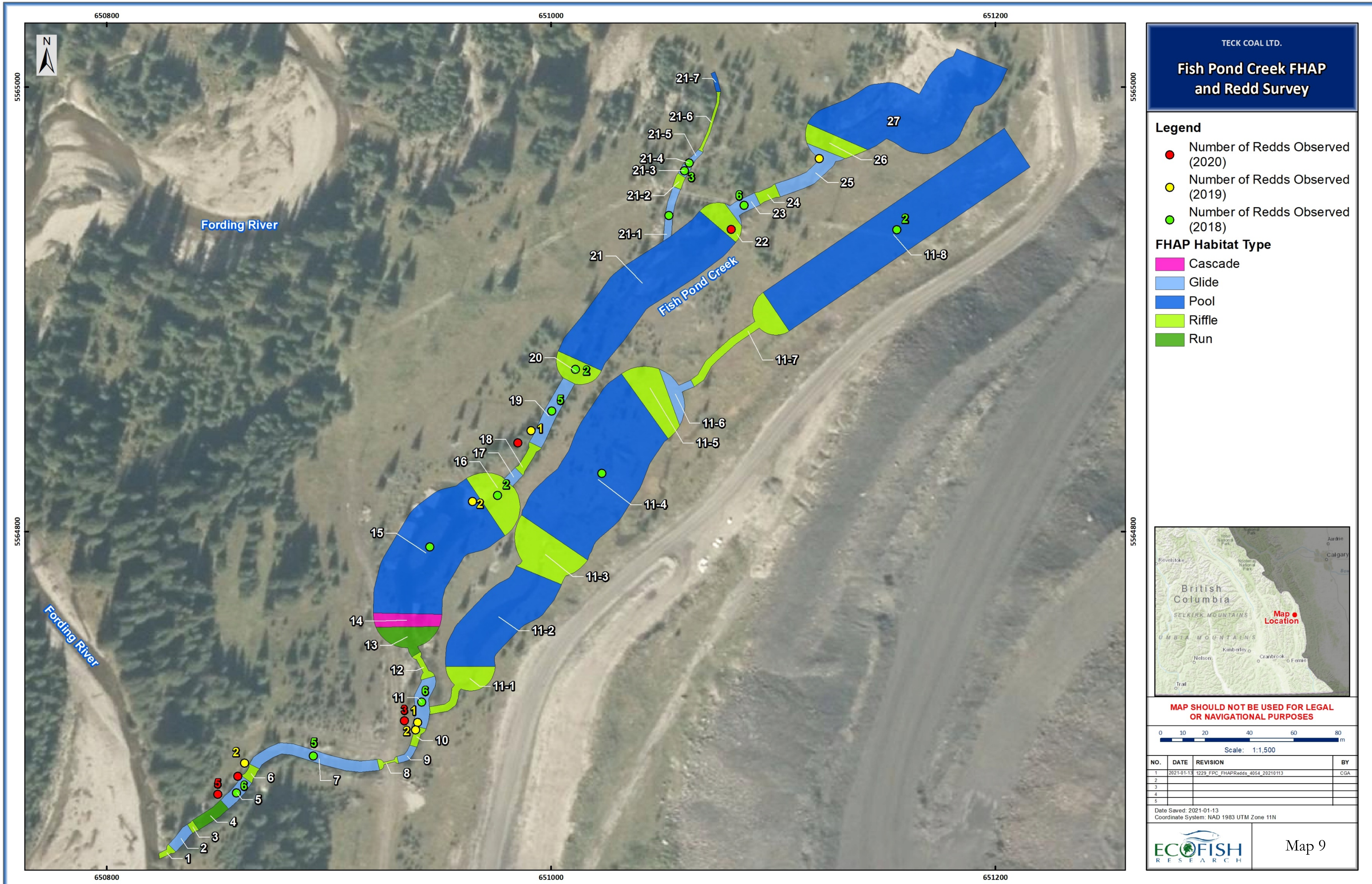
Date Saved: 2021-01-14
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 7

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1407_FRD_FHAPRedds_4054_20210114.mxd

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_CLO_FHAPRedds_4054_20210113.mxd



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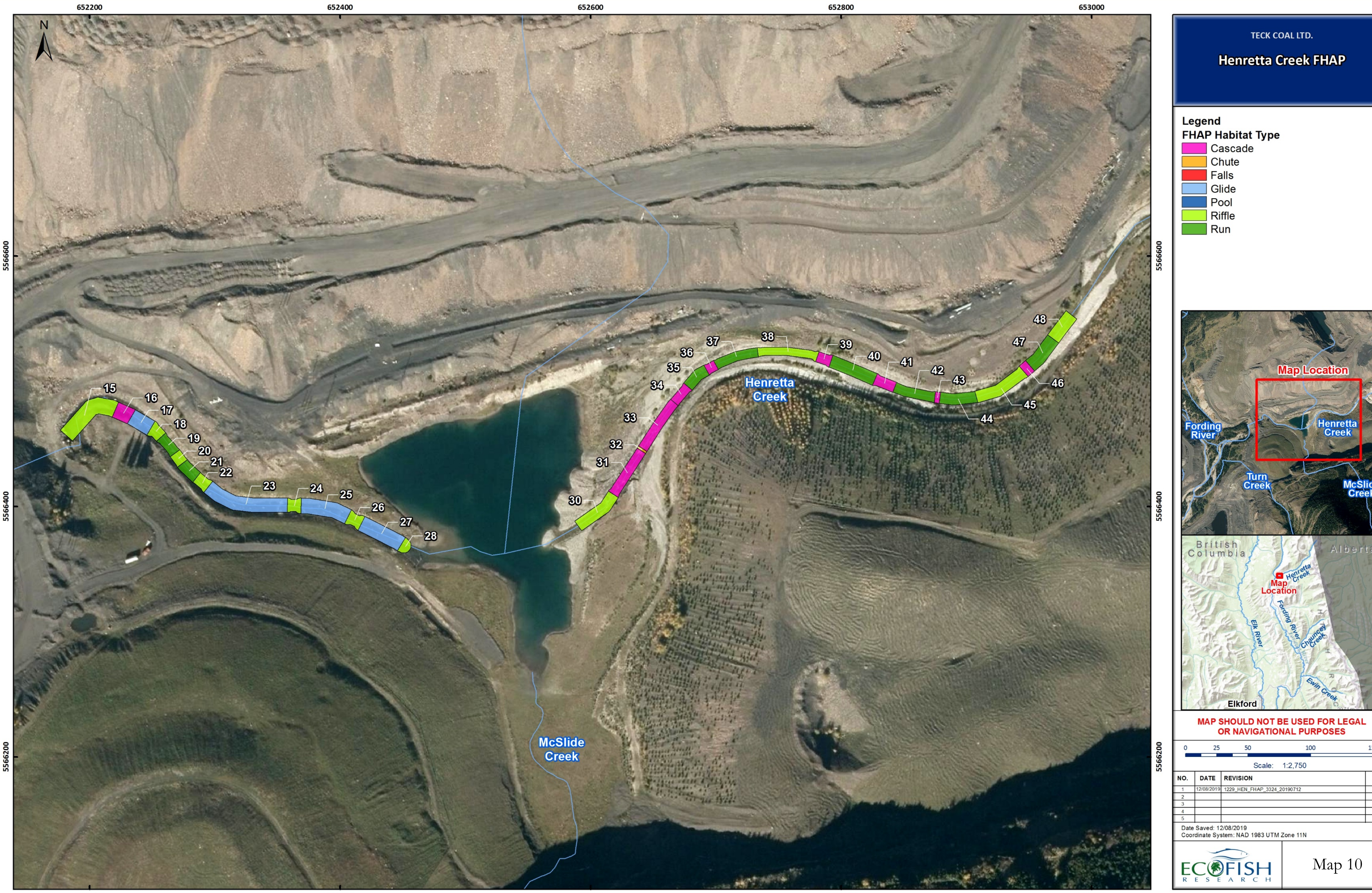


TECK COAL LTD.

Henretta Creek FHAP

Legend

FHAP Habitat Type

- Cascade
- Chute
- Falls
- Glide
- Pool
- Riffle
- Run

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 25 50 100 150 m

Scale: 1:2,750

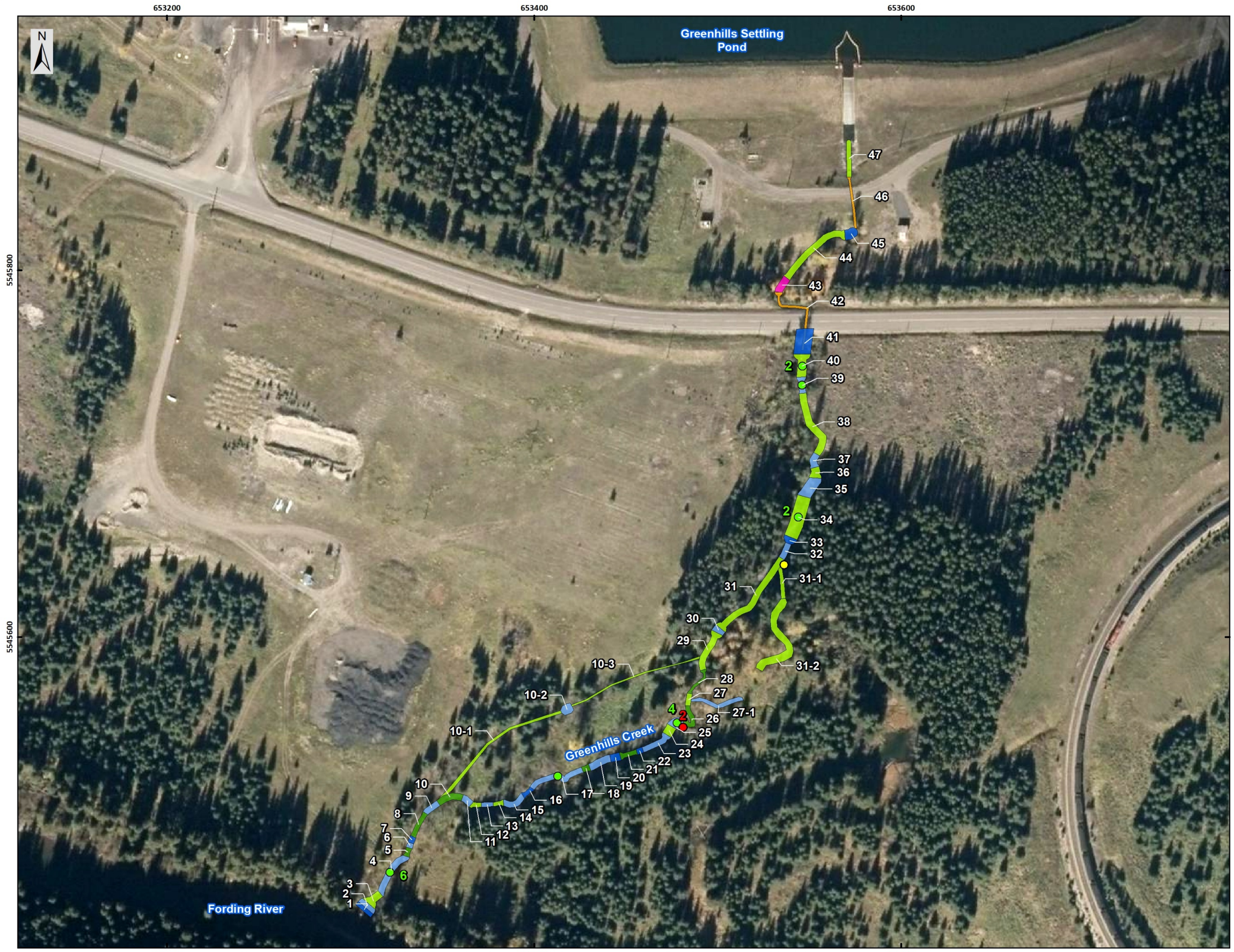
NO.	DATE	REVISION	BY
1	12/08/2019	1229_HEN_FHAP_3324_20190712	CGA
2			
3			
4			
5			

Date Saved: 12/08/2019
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 10

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_HEN_FHAP_3324_20190712.mxd



TECK COAL LTD.

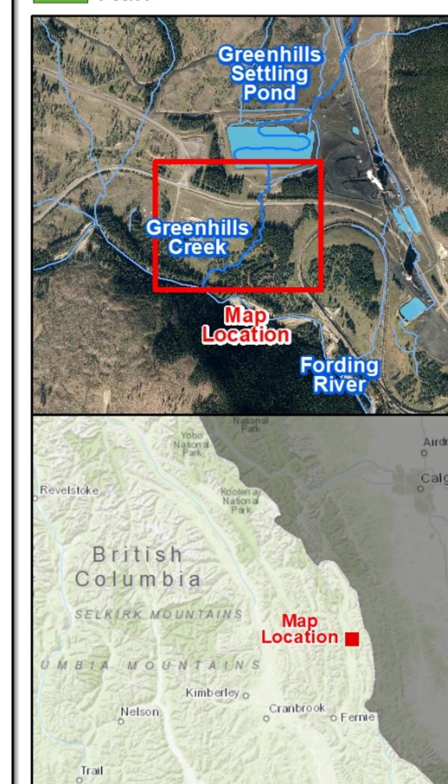
Lower Greenhills Creek FHAP and Redd Survey

Legend

- Number of Redds Observed (2020)
- Number of Redds Observed (2019)
- Number of Redds Observed (2018)

FHAP Habitat Type

- Cascade
- Culvert
- Glide
- Pool
- Riffle
- Run



MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 10 20 40 60 80 100 m

Scale: 1:2,000

NO.	DATE	REVISION	BY
1	2021-01-14	1229_LGRE_FHAPRedds_4054_20210114	CGA
2			
3			
4			
5			

Date Saved: 2021-01-14
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 11

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_LGRE_FHAPRedds_4054_20210114.mxd

TECK COAL LTD.

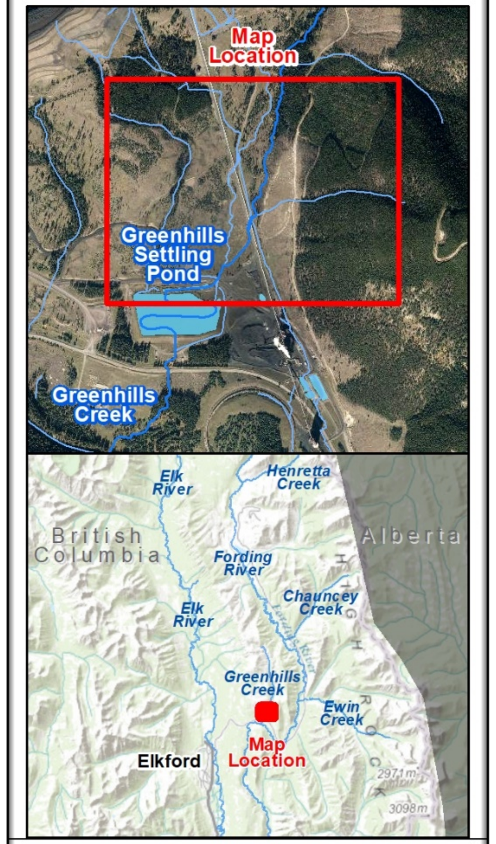
Upper Greenhills Creek FHAP and Redd Survey

Legend

- Number of Redds Observed (2020)
- Number of Redds Observed (2019)

FHAP Habitat Type

- Cascade
- Culvert
- Falls
- Glide
- Pool
- Riffle
- Run



MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 15 30 60 90 120 150 m

Scale: 1:3,500

NO.	DATE	REVISION	BY
1	2021-01-14	1229_UGRE_FHAPRedds_4054_20210114	CGA
2			
3			
4			
5			

Date Saved: 2021-01-14
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 12

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_UGRE_FHAPRedds_4054_20210114.mxd

TECK COAL LTD.

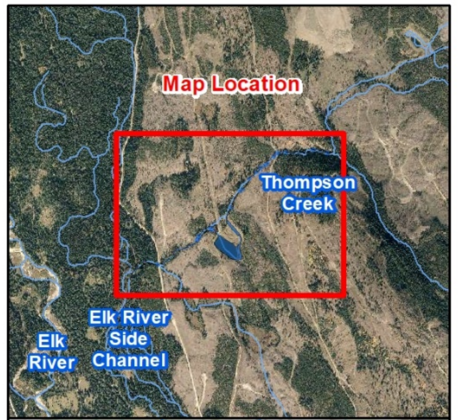
Thompson Creek FHAP and Redd Survey

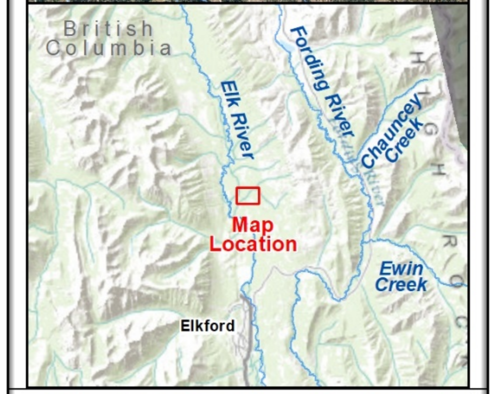
Legend

- Number of Redds Observed (2020)
- Number of Redds Observed (2019)

FHAP Habitat Type

- Cascade
- Chute
- Falls
- Glide
- Pool
- Riffle
- Run





MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 25 50 100 150 200 250 m

Scale: 1:5,000

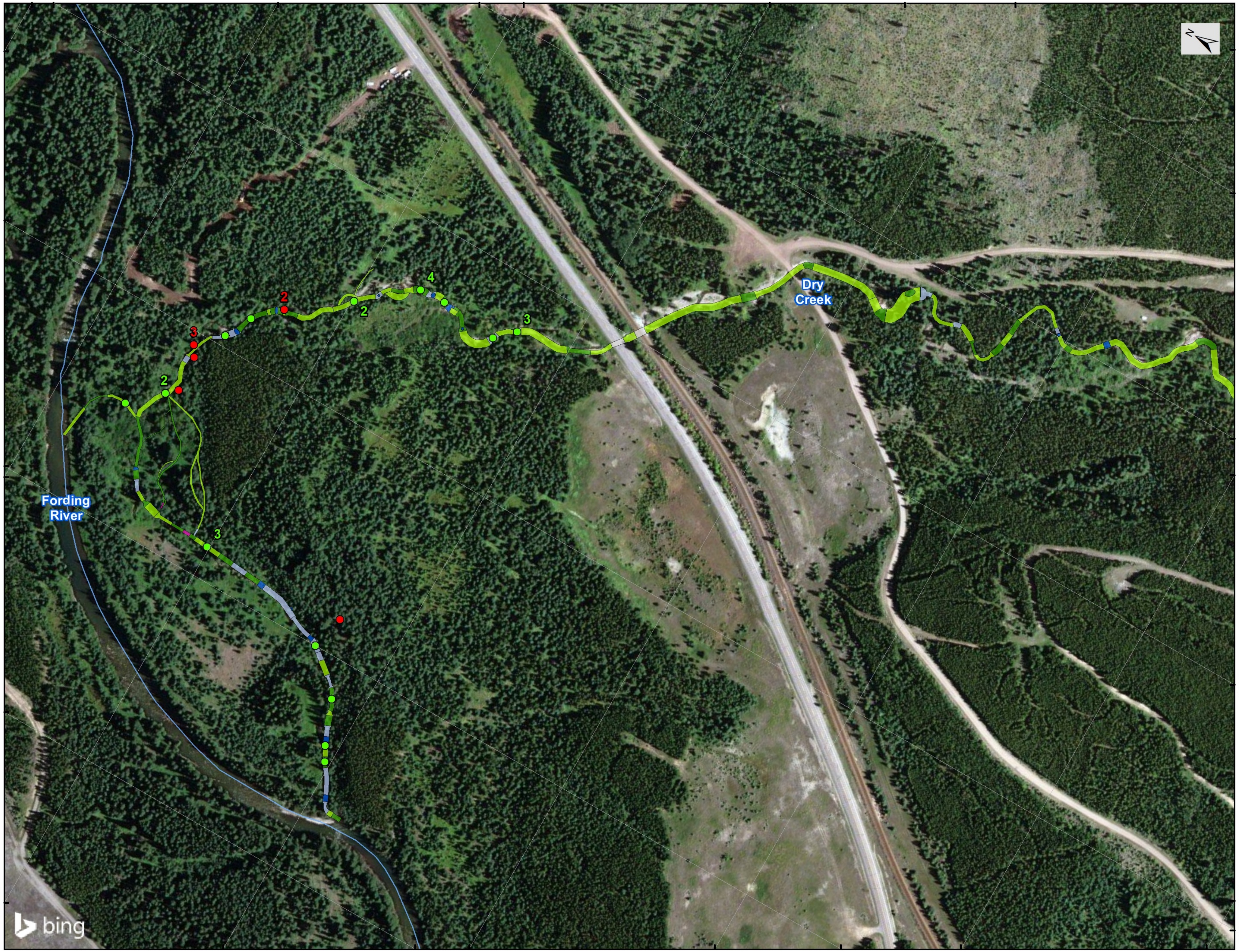
NO.	DATE	REVISION	BY
1	2021-01-14	1229_TMP_FHAPRedds_4054_20210114	
2			
3			
4			
5			

Date Saved: 2021-01-14
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 13

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_TMP_FHAPRedds_4054_20210114.mxd



TECK COAL LTD.

LCO Dry Creek FHAP and Redd Survey

Legend

- Number of Redds Observed (2020)
- Number of Redds Observed (2018)
- Reach Break

FHAP Habitat Type

- Cascade
- Glide
- Pool
- Riffle
- Run
- Unclassified

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 50 100 Meters

Scale: 1:3,500

NO.	DATE	REVISION	BY
1	2021-01-14	1224_DRY_FHAPRedds_4054_20210114	CGA
2			
3			
4			
5			

Date Saved: 2021-01-14
Coordinate System: NAD 1983 UTM Zone 11N

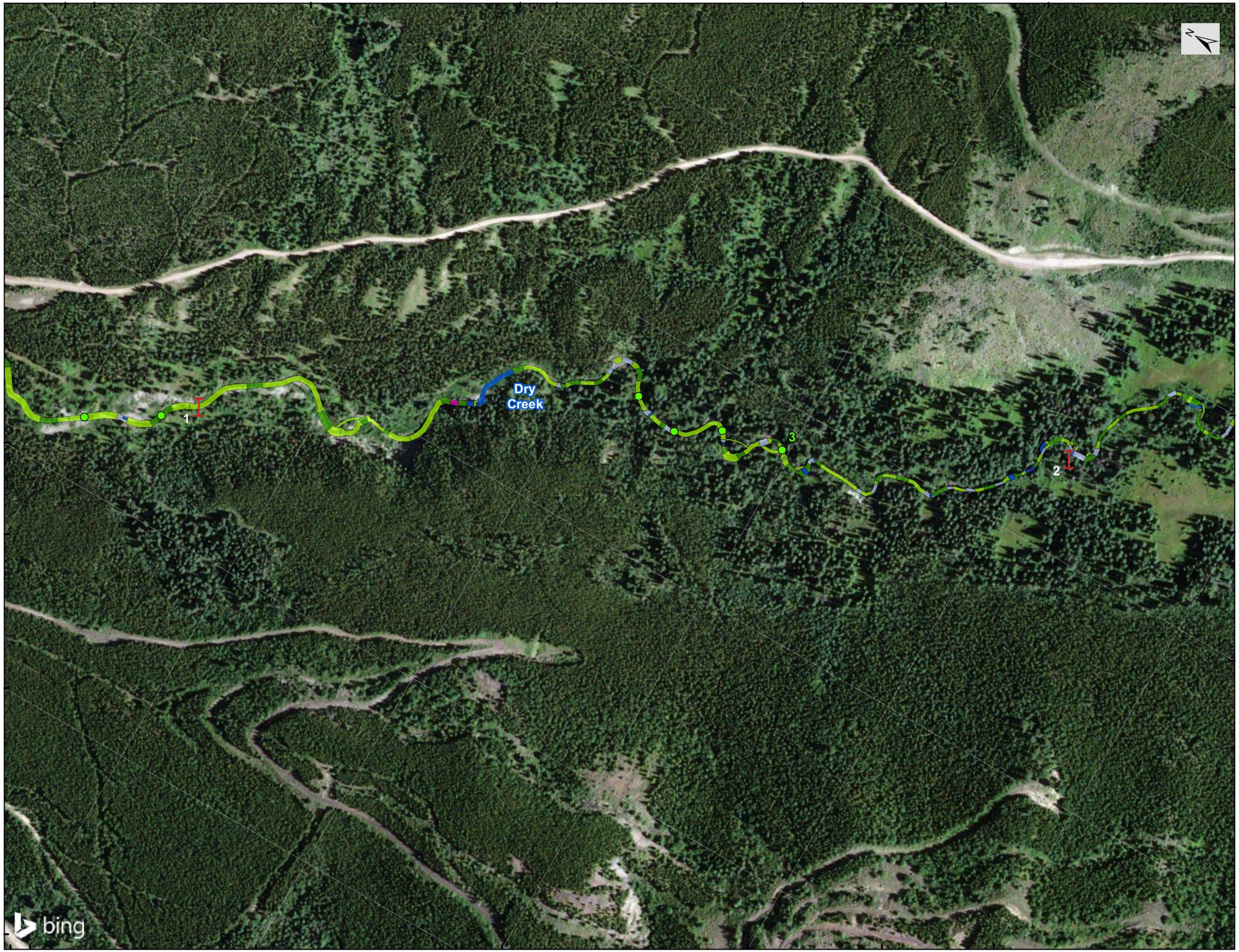
ECOFISH RESEARCH

Map 14

Path: M:\Projects-Active\1224_DryCreek\MXD\Fisheries\1224_DRY_FHAPRedds_4054_20210114.mxd

TECK COAL LTD.

LCO Dry Creek FHAP and Redd Survey



Legend

- Number of Redds Observed (2020)
- Number of Redds Observed (2018)
- Reach Break

FHAP Habitat Type

- Cascade
- Glide
- Pool
- Riffle
- Run
- Unclassified

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 50 100 Meters

Scale: 1:3,500

NO.	DATE	REVISION	BY
1	2021-01-14	1224_DRY_FHAPRedds_4054_20210114	CGA
2			
3			
4			
5			

Date Saved: 2021-01-14
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 15

Path: M:\Projects-Active\1224_DryCreek\MXD\Fisheries\1224_DRY_FHAPRedds_4054_20210114.mxd

TECK COAL LTD.

LCO Dry Creek FHAP and Redd Survey

Legend

- Number of Redds Observed (2020)
- Number of Redds Observed (2018)
- Reach Break

FHAP Habitat Type

- Cascade
- Glide
- Pool
- Riffle
- Run
- Unclassified

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 50 100 Meters

Scale: 1:3,500

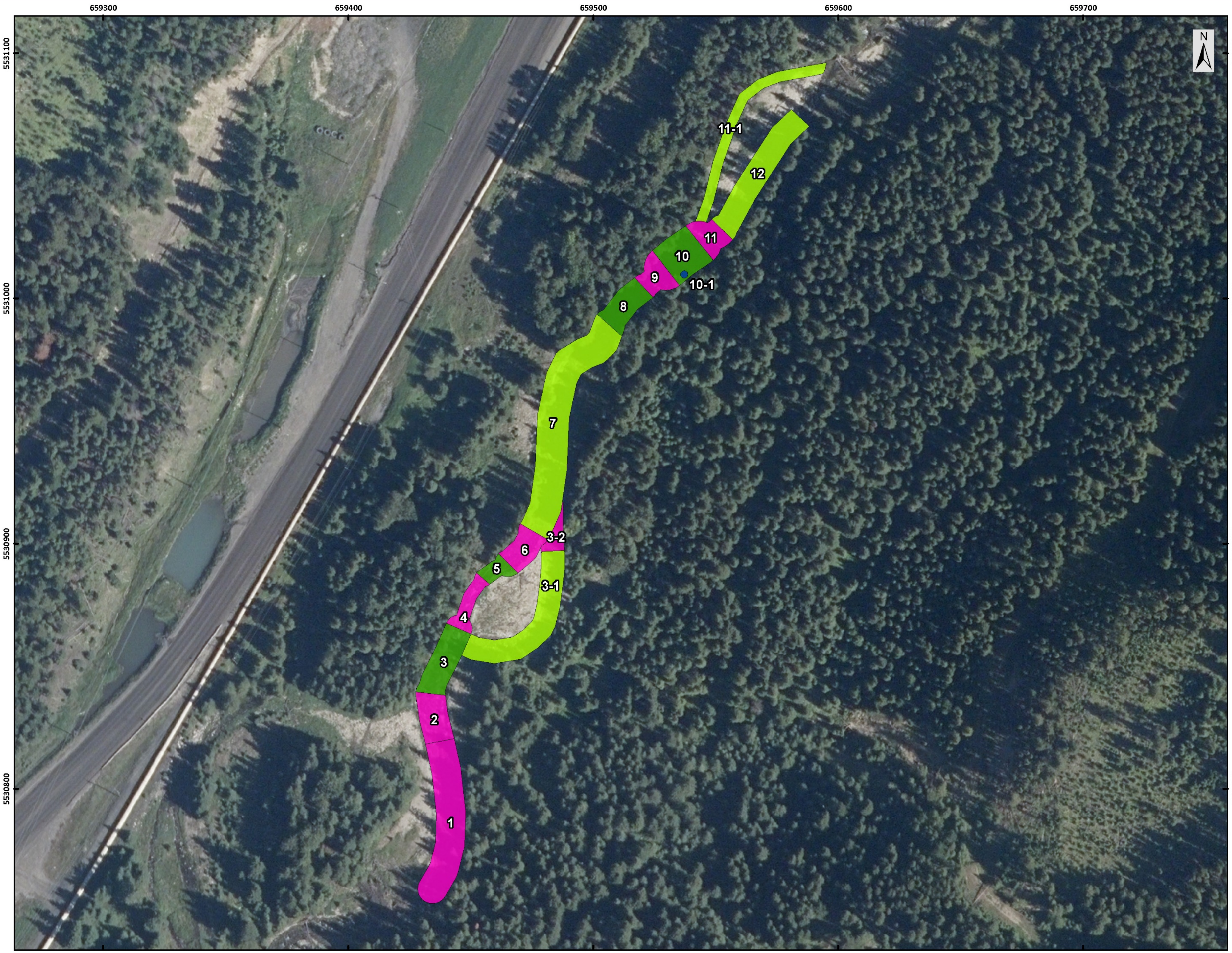
NO.	DATE	REVISION	BY
1	2021-01-14	1224_DRY_FHAPRedds_4054_20210114	CGA
2			
3			
4			
5			

Date Saved: 2021-01-14
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 16

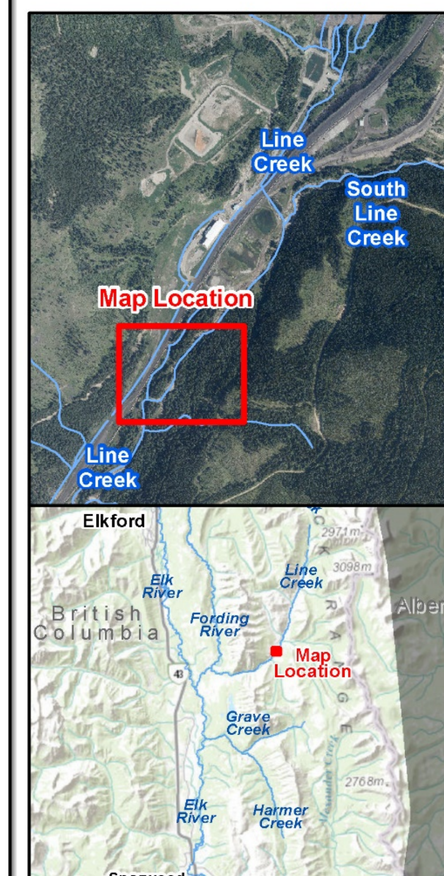
Path: M:\Projects-Active\1224_DryCreek\MXD\Fisheries\1224_DRY_FHAPRedds_4054_20210114.mxd



TECK COAL LTD.

Line Creek FHAP

Legend
FHAP_224
FHAP Habitat Type
- Cascade
- Pool
- Riffle
- Run



MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 5 10 20 30 40 50 m

Scale: 1:1,500

NO.	DATE	REVISION	BY
1	2020-10-14	1229_LNE_FHAP_3919_20201014	CGA
2			
3			
4			
5			

Date Saved: 2020-10-14
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 17

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_LNE_FHAP_3919_20201014.mxd

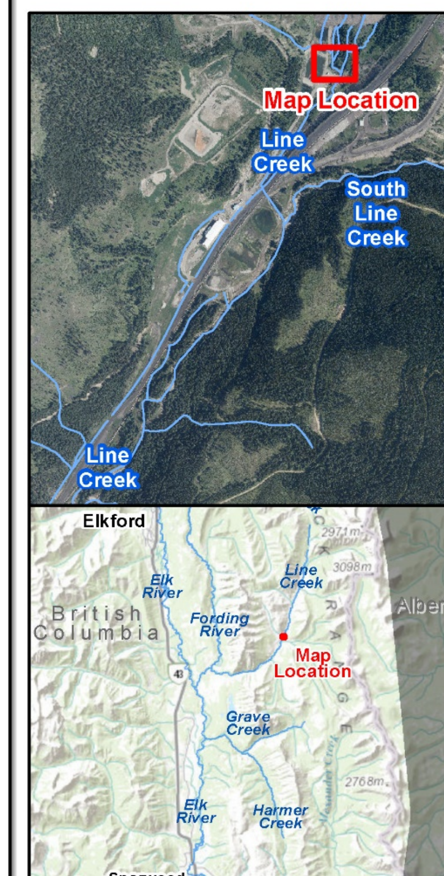
TECK COAL LTD.

Line Creek FHAP

Legend

FHAP Habitat Type

- Cascade
- Riffle
- Run



MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 5 10 20 m

Scale: 1:500

NO.	DATE	REVISION	BY
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2			
3			
4			
5			

Date Saved: 2020-10-14
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 18

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_LNE_FHAP_3919_20201014.mxd

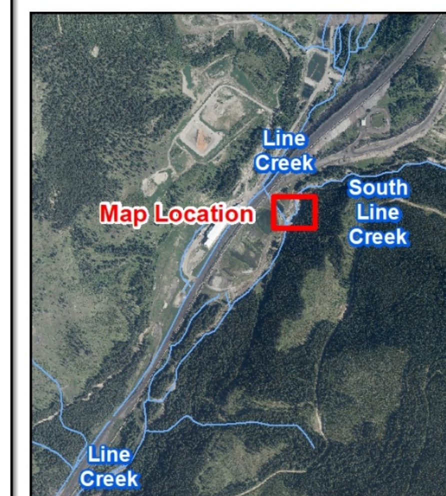
TECK COAL LTD.

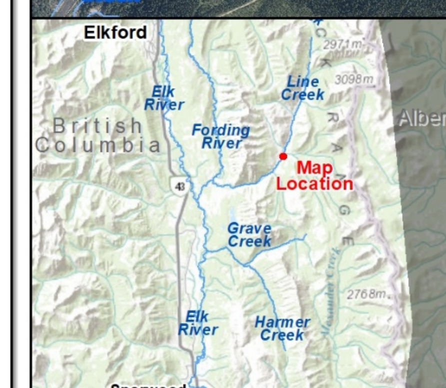
South Line Creek FHAP

Legend

FHAP Habitat Type

- Cascade
- Riffle
- Run





MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 5 10 20 m

Scale: 1:500

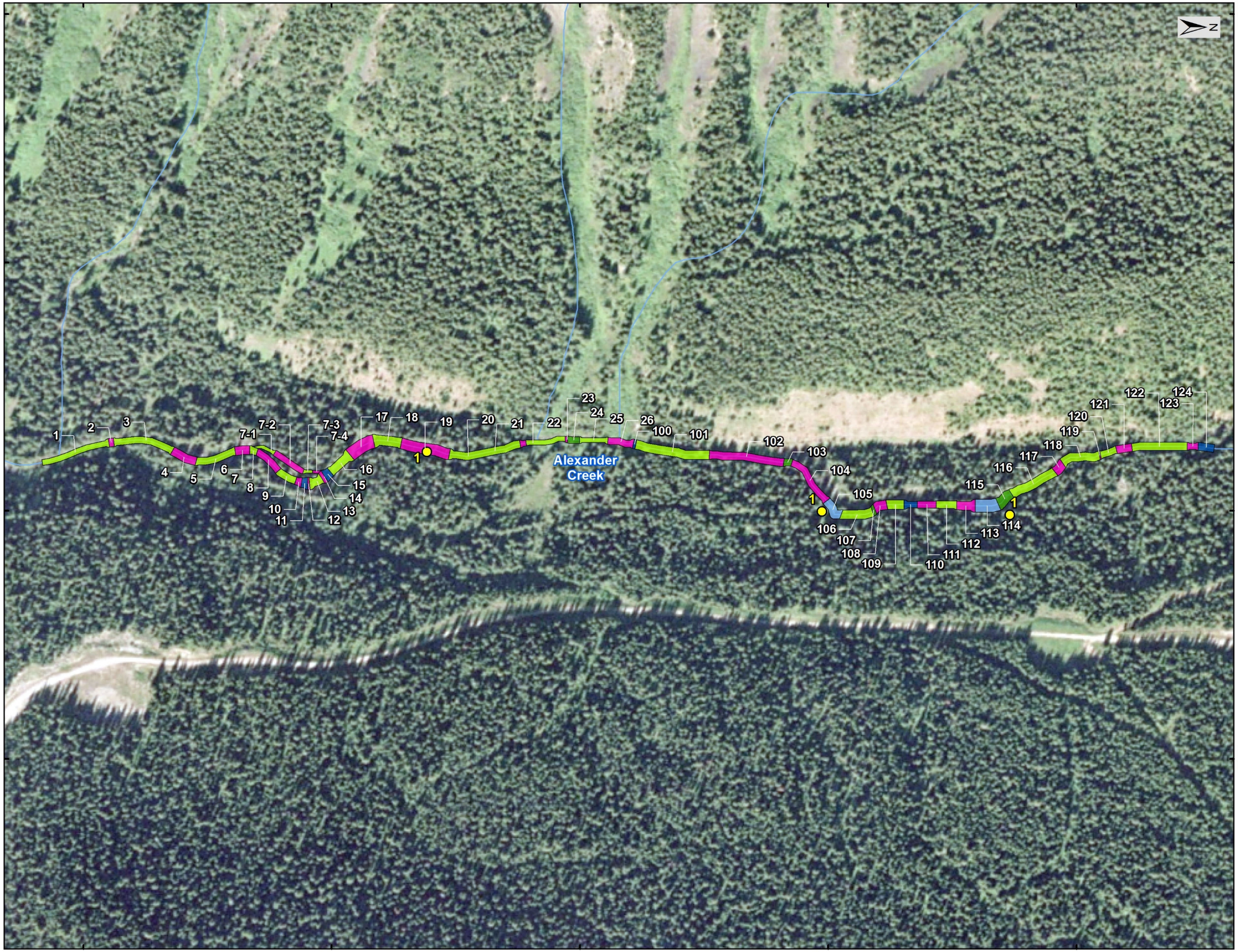
NO.	DATE	REVISION	BY
1	2021-04-22	1229_LNE_FHAP_3919_20201014	CGA
2			
3			
4			
5			

Date Saved: 2021-04-22
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 19

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_LNE_FHAP_3919_20201014.mxd



TECK COAL LTD.

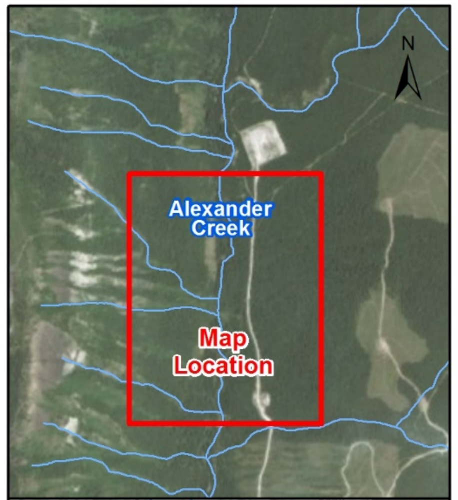
Alexander Creek FHAP and Redd Survey

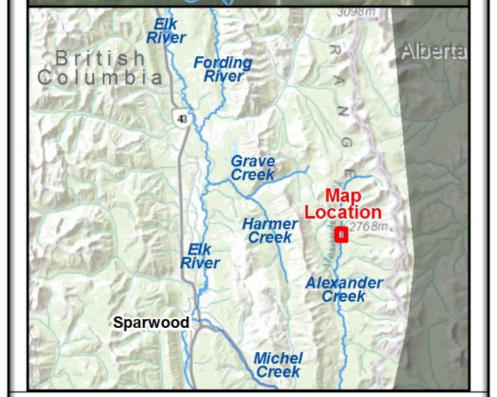
Legend

- Number of Redds Observed (2019)

FHAP Habitat Type

- Cascade
- Glide
- Pool
- Riffle
- Run





MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 25 50 100 150 m

Scale: 1:3,000

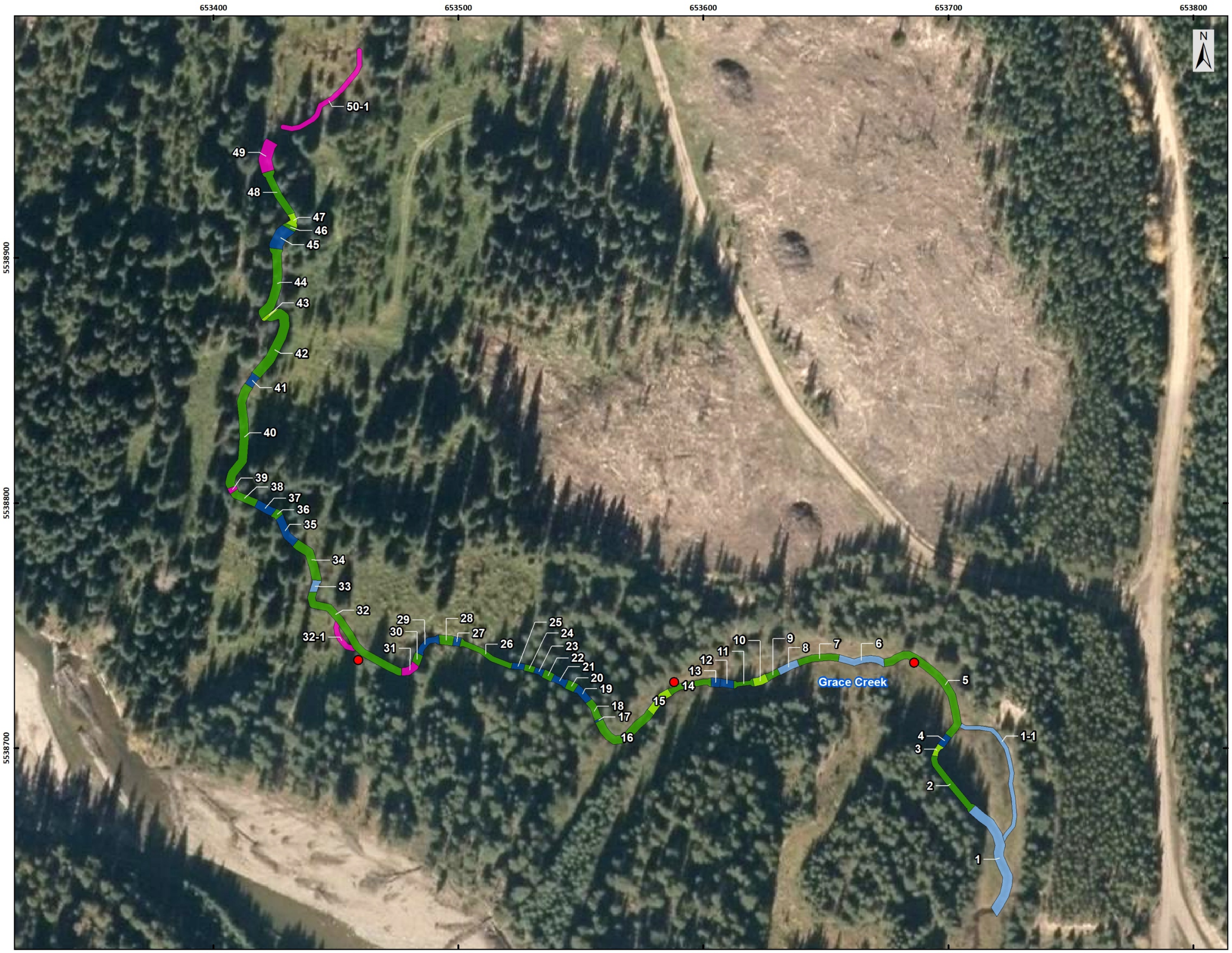
NO.	DATE	REVISION	BY
1	18/11/2019	1229_ALX_FHAP_3348_20190725	CGA
2			
3			
4			
5			

Date Saved: 18/11/2019
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 20

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_ALX_FHAP_3348_20190725.mxd



TECK COAL LTD.

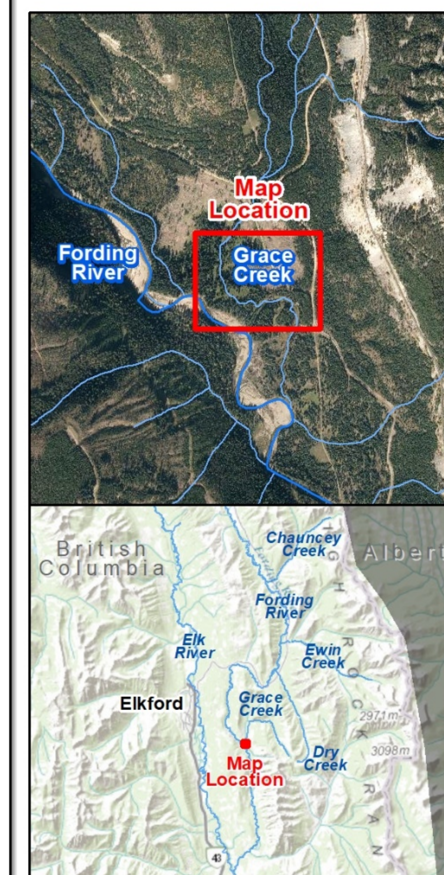
Grace Creek FHAP and Redd Survey

Legend

● Number of Redds Observed (2020)

FHAP Habitat Type

- Cascade
- Glide
- Pool
- Riffle
- Run



MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 10 20 40 60 80 m

Scale: 1:1,500

NO.	DATE	REVISION	BY
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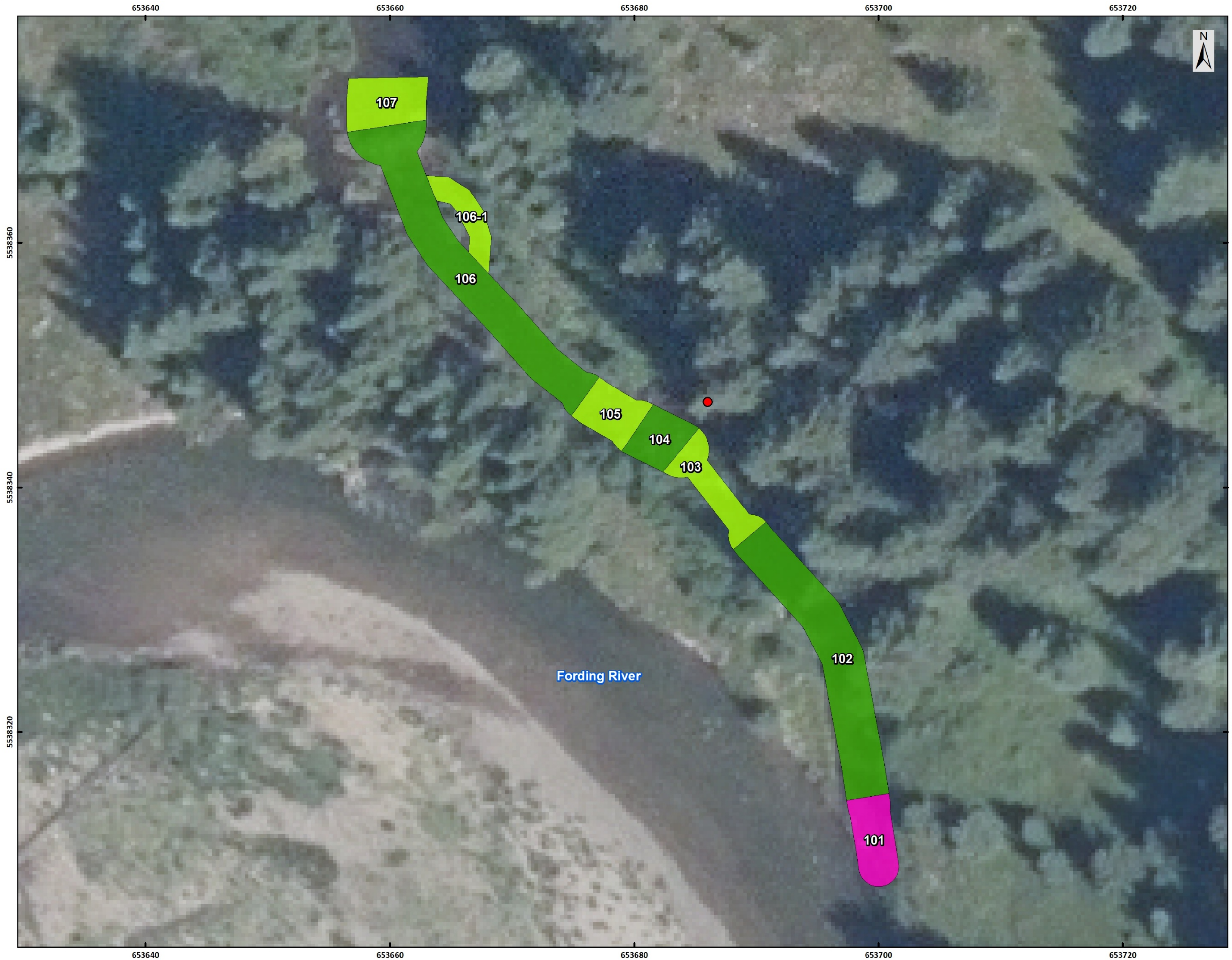
2			
3			
4			
5			

Date Saved: 2021-01-13
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 21

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_GRC_FHAP_4054_20210113.mxd



TECK COAL LTD.

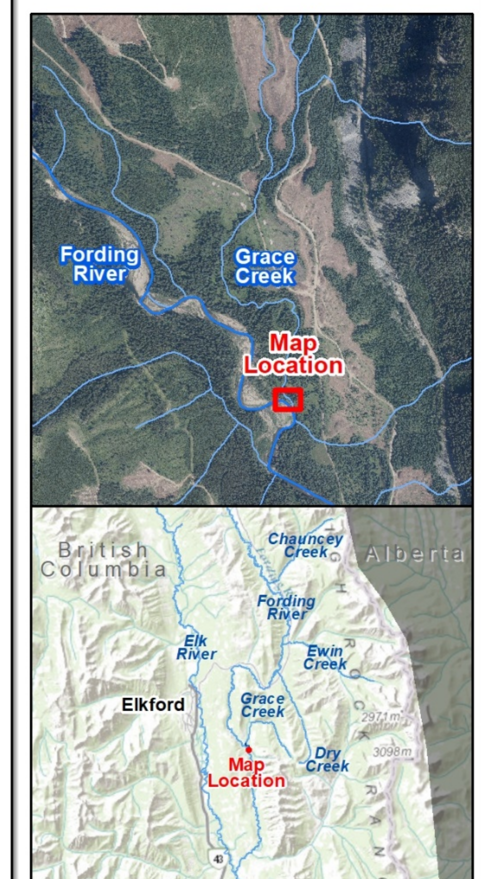
Grace Creek FHAP and Redd Survey

Legend

- Number of Redds Observed (2020)

FHAP Habitat Type

- Cascade
- Riffle
- Run



MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 2.5 5 10 15 m

Scale: 1:300

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4			
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Date Saved: 2021-01-14
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 22

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_GRC_FHAP_South_4054_20210114.mxd

TECK COAL LTD.

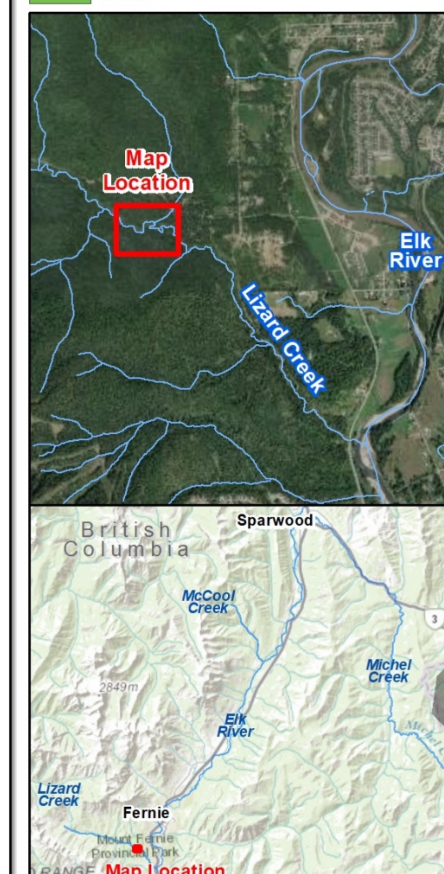
Lizard Creek FHAP and Redd Survey

Legend

- Number of Redds Observed (2020)
- Number of Redds Observed (2019)

FHAP Habitat Type

- Cascade
- Falls
- Glide
- Pool
- Riffle
- Run



MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

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Scale: 1:1,500

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3			
4			
5			

Date Saved: 2021-01-13
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 23

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_LZD_FHAPRedds_4054_20210113_v2.mxd

TECK COAL LTD.

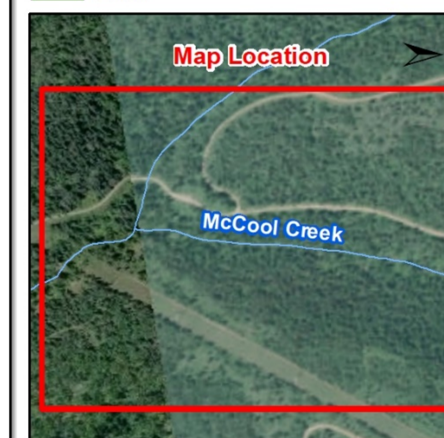
McCool Creek FHAP and Redd Survey

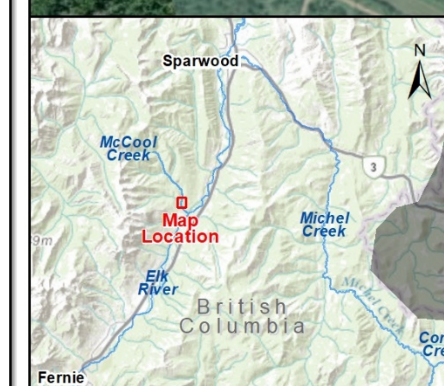
Legend

- Number of Redds Observed (2020)
- Number of Redds Observed (2019)

FHAP Habitat Type

- Cascade
- Falls
- Glide
- Pool
- Riffle
- Run





MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

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Date Saved: 2021-01-14
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 24

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_MCC_FHAPRedds_4054_20210114.mxd

Appendix C. Summary of Habitat, Water Quality, and Spawning Data Collected in Tributaries of the Fording and Elk Rivers, 2020

LIST OF TABLES

Table 1. Fish habitat data of mesohabitat units sampled during calcite study, 2020.

Waterbody	Habitat Type	Number of Units	% of Total Habitat	Total Wetted Area (m^2)	Total Bankfull Area (m^2)	Mean Wetted Area (m^2)	Wetted Width (m)		Bankfull Width (m)		Wetted Depth (m)		Bankfull Depth (m)		Total Length (m)	Individual Length (m)		Gradient (%)		Weighted Gradient (%)
							Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]		Mean	SD[1]	Mean	SD[1]	
Alexander Creek	Pool	5	5%	260	305	52	5.8	1.0	7.0	1.3	0.5	0.1	1.0	0.2	45	9.0	4.0	0.6	0.2	0.6
	Glide	2	3%	164	184	82	7.9	1.6	8.9	2.3	0.3	0.1	0.6	0.2	21	10.5	0.7	1.3	1.1	1.2
	Run	4	5%	309	327	77	6.2	1.3	6.6	1.4	0.4	0.1	0.7	0.3	51	12.8	3.8	1.5	1.0	1.5
	Riffle	21	50%	2,839	3,348	135	4.9	1.5	6.0	1.5	0.3	0.1	0.6	0.3	547	26.0	16.1	2.4	0.7	2.6
	Cascade	23	38%	2,152	2,653	94	5.4	2.0	6.6	2.1	0.2	0.1	0.7	0.2	395	17.2	15.9	7.6	2.3	6.2
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	**55**	**100%**	**5,723**	**6,818**	**104**	**5.4**	**1.7**	**6.5**	**1.8**	**0.3**	**0.1**	**0.7**	**0.3**	**1,059**	**19.3**	**15.3**	**4.3**	**3.3**	**3.8**
Clode Creek	Pool	1	30%	198	220	198	9.0	-	10.0	-	0.6	-	1.5	-	22	22.0	-	0.0	-	0.0
	Glide	4	56%	369	446	92	3.4	1.6	4.1	2.0	0.2	0.1	0.4	0.2	97	24.3	15.3	0.2	0.1	0.2
	Run	1	10%	67	84	67	1.6	-	2.0	-	0.3	-	0.7	-	42	42.0	-	1.5	-	1.5
	Riffle	2	4%	27	48	14	3.2	2.1	4.7	0.9	0.2	0.1	0.6	0.5	11	5.5	3.5	2.0	1.4	1.5
	Cascade	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	**8**	**100%**	**662**	**798**	**83**	**3.8**	**2.5**	**4.7**	**2.7**	**0.3**	**0.2**	**0.6**	**0.4**	**172**	**21.5**	**15.5**	**0.8**	**1.0**	**0.6**
Corbin Creek	Pool	3	3%	152	195	51	5.9	3.8	9.4	4.5	0.6	0.1	1.5	0.2	19	6.4	5.9	0.0	0.0	0.0
	Glide	1	8%	494	770	494	26.0	-	40.5	-	0.4	-	1.0	-	19	19.0	-	0.5	-	0.5
	Run	6	6%	347	849	58	4.5	0.8	11.7	5.0	0.4	0.1	1.0	0.1	76	12.7	3.0	0.5	0.1	0.5
	Riffle	17	81%	4,701	13,201	277	4.6	5.8	15.4	9.9	0.2	0.1	0.9	0.1	970	57.1	58.2	2.4	0.9	2.6
	Cascade	2	2%	130	167	65	4.2	0.0	5.3	0.5	0.3	0.1	1.1	0.1	31	15.5	10.0	5.3	1.1	4.9
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	1	0%	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2	1.5	-	70.0	-	70.0
	Total	**30**	**100%**	**5,823**	**15,182**	**194**	**5.5**	**6.0**	**14.2**	**9.9**	**0.3**	**0.2**	**1.0**	**0.2**	**1,117**	**37.2**	**49.2**	**4.1**	**12.5**	**2.6**
Dry Creek (EVO)	Pool	2	32%	2,163	2,277	1,082	22.5	21.9	23.7	23.1	0.6	0.2	1.0	0.3	61	30.5	36.1	0.3	0.4	0.0
	Glide	17	23%	1,516	1,760	89	6.4	2.7	7.2	3.1	0.3	0.1	0.5	0.2	230	13.5	8.4	0.9	0.6	1.1
	Run	5	6%	400	461	80	6.0	2.2	6.9	2.3	0.3	0.1	0.5	0.2	76	15.2	9.7	1.3	0.8	1.5
	Riffle	8	14%	944	1,080	118	4.1	2.9	4.6	3.1	0.3	0.2	0.4	0.2	275	34.4	34.8	3.3	1.6	3.4
	Cascade	23	25%	1,696	1,888	74	5.3	2.6	5.9	2.6	0.2	0.1	0.4	0.2	339	14.7	13.8	22.6	31.9	9.6
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	1	0%	5	5	5	4.5	-	5.0	-	0.1	-	0.2	-	1	1.0	-	150.0	-	150.0
	Total	**56**	**100%**	**6,723**	**7,471**	**120**	**6.1**	**5.1**	**6.8**	**5.3**	**0.3**	**0.1**	**0.4**	**0.2**	**982**	**17.5**	**18.5**	**12.8**	**29.4**	**4.8**

[1]There are no standard deviations when habitat data was collected for only one unit or that unit was not present within the site.

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Table 1. Continued (2 of 5).

Waterbody	Habitat Type	Number of Units	% of Total Habitat	Total Wetted Area (m^2)	Total Bankfull Area (m^2)	Mean Wetted Area (m^2)	Wetted Width (m)		Bankfull Width (m)		Wetted Depth (m)		Bankfull Depth (m)		Total Length (m)	Individual Length (m)		Gradient (%)		Weighted Gradient (%)
							Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]		Mean	SD[1]	Mean	SD[1]	
Dry Creek (LCO)	Pool	8	4%	109	145	14	3.0	1.3	4.3	2.0	0.7	0.1	0.9	0.2	36	4.5	1.6	0.1	0.3	0.1
	Glide	14	28%	752	874	54	3.9	0.9	4.6	1.0	0.4	0.1	0.6	0.2	186	13.3	8.6	0.9	0.4	0.8
	Run	12	26%	693	890	58	3.8	0.9	4.9	1.1	0.3	0.1	0.5	0.1	181	15.1	8.4	1.4	0.2	1.4
	Riffle	17	42%	1,130	1,465	66	3.3	1.2	4.4	1.3	0.3	0.1	0.4	0.1	355	20.9	17.8	2.6	0.6	2.6
	Cascade	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	**51**	**100%**	**2,684**	**3,374**	**53**	**3.6**	**1.1**	**4.6**	**1.3**	**0.4**	**0.2**	**0.6**	**0.2**	**758**	**14.9**	**12.9**	**1.5**	**1.0**	**1.8**
Fish Pond Creek	Pool	7	87%	13,082	13,559	1,869	23.1	10.6	24.0	11.1	1.4	0.9	2.3	1.4	491	70.1	35.5	0.0	0.0	0.0
	Glide	13	8%	1,158	1,276	89	4.3	1.4	4.7	1.3	0.4	0.2	0.8	0.3	251	19.3	16.5	0.2	0.1	0.1
	Run	2	1%	135	142	67	4.6	0.6	4.9	0.5	0.3	0.1	0.8	0.1	29	14.5	2.1	0.8	0.4	0.8
	Riffle	19	4%	651	741	34	2.9	1.2	3.3	1.2	0.2	0.1	0.5	0.2	238	12.5	10.8	2.0	0.5	2.1
	Cascade	1	0%	21	23	21	3.5	-	3.8	-	0.2	-	0.5	-	6	6.0	-	3.5	-	3.5
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	**42**	**100%**	**15,047**	**15,741**	**358**	**6.8**	**8.5**	**7.3**	**8.8**	**0.5**	**0.6**	**0.9**	**0.9**	**1,015**	**24.2**	**27.6**	**1.1**	**1.1**	**0.6**
Fording River (S8)	Pool	2	2%	165	281	83	7.9	0.5	13.3	3.9	0.7	0.1	1.3	-	21	10.5	0.7	0.0	0.0	0.0
	Glide	3	8%	761	780	254	7.4	1.9	7.5	2.2	0.5	0.1	0.7	0.1	99	33.0	24.2	0.8	1.0	0.8
	Run	11	71%	7,025	9,547	639	8.5	2.7	12.2	3.8	0.4	0.1	0.7	0.1	789	71.7	53.6	2.0	0.6	2.2
	Riffle	9	19%	1,878	2,307	209	11.3	4.3	14.4	3.7	0.2	0.1	0.5	0.2	179	19.9	11.4	2.9	0.7	2.7
	Cascade	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	**25**	**100%**	**9,829**	**12,915**	**393**	**9.3**	**3.5**	**12.5**	**4.0**	**0.4**	**0.2**	**0.6**	**0.2**	**1,088**	**43.5**	**44.4**	**2.0**	**1.1**	**2.1**
Grace Creek	Pool	14	10%	255	256	18	3.3	0.8	3.3	0.8	0.4	0.1	0.8	0.1	76	5.4	1.9	1.0	0.3	1.0
	Glide	5	9%	249	292	50	2.6	0.8	2.9	0.8	0.2	0.1	0.4	0.1	112	22.4	21.3	1.2	0.3	1.1
	Run	28	71%	1,872	1,957	67	3.1	0.7	3.2	0.7	0.2	0.1	0.5	0.1	615	22.0	15.9	1.9	0.5	1.9
	Riffle	9	8%	203	205	23	3.2	1.5	3.2	1.4	0.1	0.0	0.4	0.1	70	7.8	4.1	2.2	0.5	2.1
	Cascade	4	3%	72	74	18	3.8	1.0	3.9	0.9	0.3	0.1	0.6	0.1	19	4.8	0.5	8.8	8.8	8.1
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	**61**	**100%**	**2,651**	**2,785**	**43**	**3.2**	**0.9**	**3.3**	**0.9**	**0.2**	**0.1**	**0.5**	**0.2**	**892**	**14.9**	**14.6**	**2.1**	**2.7**	**1.9**

[1]There are no standard deviations when habitat data was collected for only one unit or that unit was not present within the site.

Table 1. Continued (3 of 5).

Waterbody	Habitat Type	Number of Units	% of Total Habitat	Total Wetted Area (m^2)	Total Bankfull Area (m^2)	Mean Wetted Area (m^2)	Wetted Width (m)		Bankfull Width (m)		Wetted Depth (m)		Bankfull Depth (m)		Total Length (m)	Individual Length (m)		Gradient (%)		Weighted Gradient (%)
							Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]		Mean	SD[1]	Mean	SD[1]	
Grave Creek	Pool	3	1%	45	66	15	5.3	1.6	7.7	1.5	0.3	0.2	0.7	0.3	9	2.8	0.8	0.3	0.3	0.4
	Glide	5	2%	138	228	28	3.3	0.9	5.3	1.4	0.3	0.1	0.7	0.1	40	8.0	3.0	0.9	0.2	0.9
	Run	5	5%	274	352	55	4.5	1.1	5.9	1.0	0.2	0.1	0.6	0.2	58	11.6	5.7	2.1	0.8	2.4
	Riffle	24	42%	2,521	4,016	105	4.1	1.5	6.5	1.9	0.2	0.1	0.6	0.2	611	26.6	18.7	2.8	0.6	2.9
	Cascade	24	50%	3,035	4,234	126	3.9	1.9	5.4	2.2	0.2	0.1	0.6	0.2	768	32.0	20.2	5.8	1.3	5.4
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	3	0%	20	27	7	4.0	3.8	5.8	3.2	0.2	0.1	0.5	0.2	4	1.3	0.6	116.7	57.7	100.0
	Total	**64**	**100%**	**6,034**	**8,922**	**94**	**4.1**	**1.7**	**6.0**	**2.0**	**0.2**	**0.1**	**0.6**	**0.2**	**1,490**	**23.6**	**19.6**	**9.0**	**26.3**	**4.4**
Harmer Creek (Middle)	Pool	5	18%	798	842	160	9.8	9.9	10.9	10.0	0.6	0.3	0.8	0.3	52	10.4	9.4	0.2	0.3	0.1
	Glide	7	14%	618	2,451	88	4.4	1.6	12.3	19.3	0.3	0.1	0.5	0.1	132	18.9	8.0	0.8	0.5	0.4
	Run	4	9%	413	445	103	5.4	0.5	5.9	0.5	0.3	0.0	0.5	0.1	76	19.0	4.5	2.3	1.0	0.7
	Riffle	17	44%	1,985	2,384	117	4.0	1.8	4.9	1.9	0.3	0.1	0.4	0.1	454	26.7	18.5	2.8	0.6	1.4
	Cascade	1	7%	326	346	326	5.1	-	5.4	-	0.3	-	0.5	-	64	64.0	-	5.0	-	1.4
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	**35**	**100%**	**4,498**	**10,108**	**129**	**5.2**	**4.2**	**8.8**	**12.5**	**0.3**	**0.2**	**0.5**	**0.2**	**843**	**24.1**	**17.9**	**1.9**	**1.3**	**1.1**
Harmer Creek (Upper)	Pool	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Glide	3	7%	69	81	23	2.9	1.9	3.5	2.2	0.2	0.1	0.4	0.2	21	7.0	2.6	1.2	0.8	0.1
	Run	5	58%	551	621	110	4.0	1.8	4.5	2.0	0.1	0.0	0.3	0.1	121	24.2	11.5	2.2	1.0	1.2
	Riffle	3	26%	249	290	83	3.1	1.4	3.8	1.4	0.1	0.1	0.2	0.1	68	22.7	18.2	2.8	1.3	0.2
	Cascade	3	9%	90	99	30	2.1	1.9	2.4	1.8	0.1	0.1	0.2	0.1	32	10.7	7.0	5.8	1.3	0.8
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	**14**	**100%**	**958**	**1,091**	**68**	**3.1**	**1.7**	**3.7**	**1.8**	**0.1**	**0.1**	**0.3**	**0.1**	**242**	**17.3**	**12.6**	**2.9**	**1.9**	**0.4**
Henretta Creek	Pool	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Glide	4	24%	1,853	1,942	463	11.8	0.5	12.4	0.6	0.7	0.1	1.1	0.3	160	40.0	20.2	0.3	0.2	0.2
	Run	8	22%	1,739	1,742	217	9.1	1.4	9.1	1.2	0.8	0.2	1.0	0.4	190	23.8	7.2	1.3	0.8	1.3
	Riffle	11	31%	2,440	2,618	222	9.4	1.7	10.0	1.7	0.4	0.1	0.6	0.2	266	24.2	18.5	2.8	0.8	2.5
	Cascade	9	22%	1,716	1,806	191	8.7	1.7	9.1	1.8	0.5	0.1	0.6	0.1	207	23.0	15.9	5.0	1.0	4.7
	Chute	1	0%	14	15	14	7.0	-	7.5	-	0.3	-	0.4	-	2	2.0	-	7.5	-	7.5
	Falls	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	**34**	**100%**	**7,762**	**8,123**	**228**	**9.3**	**1.8**	**9.7**	**1.8**	**0.6**	**0.2**	**0.8**	**0.3**	**825**	**25.0**	**16.3**	**2.9**	**2.0**	**2.4**

[1]There are no standard deviations when habitat data was collected for only one unit or that unit was not present within the site.

Table 1. Continued (4 of 5).

Waterbody	Habitat Type	Number of Units	% of Total Habitat	Total Wetted Area (m^2)	Total Bankfull Area (m^2)	Mean Wetted Area (m^2)	Wetted Width (m)		Bankfull Width (m)		Wetted Depth (m)		Bankfull Depth (m)		Total Length (m)	Individual Length (m)		Gradient (%)		Weighted Gradient (%)
							Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]		Mean	SD[1]	Mean	SD[1]	
Line Creek	Pool	1	0%	8	0	8	2.5	-	0.0	0.0	0.7	-	0.0	0.0	3	3.0	-	0.0	-	0.0
	Glide	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Run	6	17%	843	1,273	141	8.4	2.1	12.4	3.8	0.4	0.1	0.4	0.1	102	17.0	4.7	2.3	0.9	2.4
	Riffle	6	52%	2,538	2,876	423	9.0	3.9	10.5	5.1	0.3	0.1	0.5	0.0	320	53.3	24.3	3.3	0.4	3.4
	Cascade	8	30%	1,469	1,726	184	8.9	2.3	10.3	2.2	0.3	0.1	0.5	-	164	20.5	17.7	6.2	2.2	5.7
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	**21**	**100%**	**4,857**	**5,874**	**231**	**8.5**	**3.0**	**11.0**	**3.6**	**0.4**	**0.1**	**0.5**	**0.1**	**589**	**28.0**	**23.4**	**4.0**	**2.4**	**3.8**
Lizard Creek	Pool	9	6%	297	360	33	4.3	1.8	5.2	2.5	0.7	0.2	1.4	0.4	63	7.0	2.8	0.5	0.0	0.5
	Glide	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Run	20	44%	2,250	3,504	113	5.8	1.8	9.1	3.2	0.3	0.1	0.7	0.2	394	19.7	6.1	1.3	0.4	1.2
	Riffle	15	44%	2,261	3,769	151	5.7	2.0	9.2	2.9	0.2	0.1	0.5	0.2	392	26.1	21.1	2.1	1.0	2.0
	Cascade	3	5%	280	339	93	7.3	2.2	8.6	1.4	0.2	0.1	0.5	0.1	41	13.7	9.7	5.2	0.8	4.9
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	1	0%	4	5	4	3.5	-	4.5	-	0.0	0.0	0.0	0.0	1	1.0	-	125.0	-	125.0
	Total	**48**	**100%**	**5,091**	**7,976**	**106**	**5.5**	**2.0**	**8.3**	**3.2**	**0.4**	**0.2**	**0.8**	**0.4**	**891**	**18.6**	**14.3**	**4.2**	**17.8**	**1.8**
Lower Greenhills Creek	Pool	8	12%	210	264	26	3.3	2.5	5.2	3.2	0.5	0.2	1.0	0.4	46	5.7	3.6	0.1	0.2	0.1
	Glide	18	28%	497	760	28	2.4	1.1	4.2	1.6	0.2	0.1	0.6	0.1	212	11.8	9.1	0.7	0.6	0.7
	Run	7	8%	141	206	20	1.9	0.5	2.7	0.7	0.2	0.1	0.7	0.2	80	11.4	5.3	1.6	0.7	1.8
	Riffle	17	49%	869	1,416	51	2.2	0.9	3.6	1.7	0.1	0.0	0.4	0.2	460	27.1	23.2	2.9	1.1	2.6
	Cascade	4	4%	66	88	16	1.9	1.6	2.4	1.6	0.1	0.0	0.4	0.0	44	22.0	18.4	5.8	4.8	3.4
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	**54**	**100%**	**1,783**	**2,733**	**33**	**2.4**	**1.3**	**3.8**	**2.0**	**0.2**	**0.2**	**0.6**	**0.3**	**841**	**16.2**	**16.6**	**1.7**	**1.9**	**2.0**
McCool Creek	Pool	9	3%	90	96	10	3.3	0.8	3.5	0.9	0.5	0.1	0.7	0.2	28	3.1	0.9	0.1	0.2	0.1
	Glide	1	1%	21	22	21	3.0	-	3.1	-	0.5	-	0.6	-	7	7.0	-	0.5	-	0.5
	Run	12	15%	470	497	39	3.8	0.6	4.0	0.6	0.3	0.1	0.4	0.1	130	10.8	11.9	2.0	0.9	2.8
	Riffle	15	43%	1,325	1,534	88	3.5	1.2	3.9	1.3	0.2	0.0	0.3	0.1	344	22.9	18.8	3.4	0.4	3.4
	Cascade	10	38%	1,164	1,273	116	3.7	0.9	4.1	1.1	0.3	0.0	0.4	0.1	328	32.8	25.0	5.6	1.2	5.4
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	**47**	**100%**	**3,069**	**3,422**	**65**	**3.6**	**0.9**	**3.9**	**1.0**	**0.3**	**0.1**	**0.4**	**0.2**	**837**	**17.8**	**19.5**	**2.8**	**2.0**	**3.9**

[1]There are no standard deviations when habitat data was collected for only one unit or that unit was not present within the site.

Table 1. Continued (5 of 5).

Waterbody	Habitat Type	Number of Units	% of Total Habitat	Total Wetted Area (m^2)	Total Bankfull Area (m^2)	Mean Wetted Area (m^2)	Wetted Width (m) Mean	Wetted Width (m) SD[1]	Bankfull Width (m) Mean	Bankfull Width (m) SD[1]	Wetted Depth (m) Mean	Wetted Depth (m) SD[1]	Bankfull Depth (m) Mean	Bankfull Depth (m) SD[1]	Total Length (m)	Individual Length (m) Mean	Individual Length (m) SD[1]	Gradient (%) Mean	Gradient (%) SD[1]	Weighted Gradient (%)
Michel Creek	Pool	6	2%	157	167	26	4.1	1.7	4.4	1.6	0.8	0.1	1.7	0.5	35	5.8	2.7	0.5	0.0	0.5
	Glide	2	7%	536	592	268	11.5	0.7	12.8	1.0	0.4	0.1	0.8	0.2	48	24.0	22.6	0.8	0.4	0.6
	Run	16	48%	3,457	5,946	216	5.7	1.9	9.3	3.2	0.4	0.1	1.0	0.3	579	36.2	20.8	1.3	0.4	1.5
	Riffle	11	36%	2,543	3,778	231	7.1	2.6	10.8	2.8	0.3	0.1	0.6	0.1	361	32.8	17.1	2.3	0.8	2.3
	Cascade	6	6%	460	527	77	7.0	3.7	8.4	4.5	0.3	0.1	0.6	0.1	79	13.2	7.4	5.3	1.4	5.4
	Chute	1	0%	2	6	2	1.0	-	2.3	-	0.1	-	0.3	-	2	2.4	-	30.0	-	30.0
	Falls	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	**42**	**100%**	**7,155**	**11,015**	**170**	**6.2**	**2.9**	**8.9**	**3.8**	**0.4**	**0.2**	**0.9**	**0.5**	**1,104**	**26.3**	**20.0**	**2.7**	**4.6**	**2.0**
Thompson Creek	Pool	7	4%	83	120	12	3.0	0.8	4.6	0.6	0.4	0.2	1.0	0.2	27	3.8	2.0	0.0	0.0	0.0
	Glide	3	9%	193	8,100	64	2.1	1.2	100.0	0.0	0.2	0.1	1.2	0.1	81	27.0	8.2	0.4	0.5	0.4
	Run	2	1%	17	126	9	1.7	0.2	9.5	10.6	0.2	0.0	0.5	0.4	11	5.4	2.3	1.1	1.2	0.9
	Riffle	7	48%	1,014	22,591	145	1.5	0.7	31.5	46.8	0.2	0.1	0.8	0.1	595	85.0	47.9	2.1	1.1	2.0
	Cascade	13	37%	772	1,366	59	2.1	0.7	5.1	4.7	0.2	0.1	0.6	0.2	373	28.7	27.5	9.6	4.6	10.1
	Chute	2	1%	16	19	8	1.7	0.7	2.1	-	0.2	0.1	0.7	-	11	5.6	4.8	32.5	10.6	27.9
	Falls	6	0%	5	4	1	1.7	0.3	3.3	1.8	0.0	0.0	0.0	0.0	6	0.9	0.5	114.2	49.9	124.9
	Total	**40**	**100%**	**2,099**	**32,327**	**52**	**2.1**	**0.9**	**18.5**	**34.0**	**0.2**	**0.1**	**0.8**	**0.3**	**1,103**	**27.6**	**38.0**	**22.3**	**43.7**	**5.5**
Upper Greenhills Creek	Pool	2	1%	39	43	19	4.0	1.5	4.4	1.6	0.5	0.0	0.9	0.0	9	4.5	2.1	0.0	0.0	0.0
	Glide	6	6%	158	176	26	3.0	1.5	3.4	1.6	0.2	0.1	0.5	0.1	50	8.3	4.9	1.3	0.8	1.6
	Run	12	15%	432	490	36	2.9	1.2	3.3	1.4	0.2	0.0	0.4	0.0	142	11.8	7.9	1.7	0.6	1.9
	Riffle	7	16%	467	533	67	3.1	0.5	3.5	0.5	0.2	0.0	0.4	0.1	148	21.1	21.4	3.1	0.2	3.0
	Cascade	23	60%	1,710	1,985	74	3.1	1.2	3.6	1.3	0.2	0.0	0.4	0.1	587	25.5	22.2	7.5	2.4	6.8
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	1	0%	5	5	5	4.7	-	5.1	-	0.0	0.0	0.0	0.0	1	1.0	-	150.0	-	150.0
	Total	**53**	**100%**	**2,858**	**3,302**	**54**	**3.0**	**1.2**	**3.4**	**1.3**	**0.2**	**0.1**	**0.4**	**0.1**	**1,006**	**19.0**	**18.8**	**7.2**	**20.3**	**5.2**
South Line Creek	Pool	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Glide	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Run	2	31%	493	1,541	247	7.0	2.8	18.5	17.7	0.2	0.1	0.5	0.1	61	30.5	23.3	2.8	1.1	3.2
	Riffle	3	26%	425	1,559	142	5.5	0.5	12.7	16.9	0.2	0.1	0.6	0.2	80	26.7	16.1	3.0	0.5	3.0
	Cascade	6	43%	695	1,503	116	6.0	2.5	15.5	11.3	0.1	0.1	0.4	0.2	101	16.8	8.0	6.1	1.4	5.6
	Chute	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	**11**	**100%**	**1,613**	**4,603**	**147**	**6.0**	**2.1**	**15.2**	**12.8**	**0.2**	**0.1**	**0.5**	**0.2**	**242**	**22.0**	**13.2**	**4.6**	**2.0**	**4.1**

[1]There are no standard deviations when habitat data was collected for only one unit or that unit was not present within the site.

Table 2. Water quality, calcite, gravel, and spawning data collected during 2020 calcite study by habitat type.

Waterbody	Habitat Type	Mean Velocity (m/s)		Mean Flow (cms)		Calcite Measures CI		Calcite Measures CC		Calcite Measures CP		Mean Pebble Size (mm)		Gravel Prop. (%)		Water Temp. (°C)		DO (mg/L)		Spec. Cond/ (µS/cm)		pH		Total Redds
		Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	
Alexander Creek	Pool	0.30	0.15	0.98	0.29	0.15	0.14	0.00	0.00	0.15	0.14	90.5	49.5	1.42	1.99	5.1	1.0	10.4	0.3	231.9	31.1	8.3	0.0	0
	Glide	0.49	0.02	1.26	0.35	0.32	0.07	0.00	0.00	0.32	0.07	98.9	33.1	0.24	0.12	6.2	0.2	10.6	0.0	254.7	0.0	8.2	0.0	0
	Run	0.65	0.18	1.33	0.42	0.18	0.11	0.00	0.00	0.18	0.11	134.6	21.5	2.36	2.42	5.9	0.4	10.6	0.0	254.7	0.0	8.2	0.0	0
	Riffle	0.48	0.09	1.05	0.34	0.17	0.10	0.00	0.00	0.17	0.10	111.7	25.5	1.81	2.09	4.9	1.2	10.6	0.0	258.2	16.1	8.2	0.0	0
	Cascade	0.68	0.17	1.31	0.54	0.19	0.14	0.00	0.00	0.19	0.14	133.0	43.8	0.30	0.71	4.9	1.2	10.6	0.2	256.4	8.4	8.2	0.0	0
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	*0.56*	*0.18*	*1.18*	*0.44*	*0.18*	*0.12*	*0.00*	*0.00*	*0.18*	*0.12*	*119.7*	*38.3*	*1.13*	*1.73*	*5.0*	*1.2*	*10.6*	*0.2*	*254.7*	*15.7*	*8.2*	*0.0*	*0*
Clode Creek	Pool	0.00	-	0.00	-	0.57	-	0.00	-	0.57	-	49.1	-	0.00	-	6.0	-	7.3	-	297.1	-	8.0	-	0
	Glide	0.04	0.04	0.09	0.09	0.68	0.70	0.24	0.34	0.43	0.41	42.2	15.1	4.54	8.19	10.3	3.3	7.8	0.6	832.2	617.9	8.0	0.1	3
	Run	0.27	-	0.34	-	1.77	-	1.00	-	0.77	-	78.2	-	0.00	-	13.9	-	8.4	-	1538.7	-	7.9	-	0
	Riffle	0.49	0.04	0.41	0.20	2.35	0.82	1.37	0.80	0.98	0.02	69.4	4.5	0.63	0.89	13.2	1.1	8.2	0.1	1281.7	121.2	8.1	0.3	0
	Cascade	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	*0.18*	*0.21*	*0.19*	*0.19*	*1.22*	*0.97*	*0.59*	*0.67*	*0.63*	*0.36*	*54.4*	*18.3*	*2.43*	*5.83*	*10.9*	*3.4*	*7.9*	*0.5*	*966.0*	*561.4*	*8.0*	*0.2*	*3*
Corbin Creek	Pool	0.55	0.04	1.11	0.10	1.97	0.61	1.03	0.57	0.93	0.05	56.7	4.0	0.00	0.00	7.4	0.2	9.5	0.2	1539.5	89.9	8.0	0.1	0
	Glide	0.25	-	1.27	-	2.20	-	1.23	-	0.97	-	25.5	-	0.53	-	7.2	-	9.6	-	1579.7	-	8.1	-	0
	Run	0.68	0.06	1.30	0.24	2.11	0.37	1.15	0.33	0.96	0.04	62.9	21.2	0.81	2.15	7.6	0.4	9.6	0.1	1580.3	1.5	7.9	0.3	2
	Riffle	0.65	0.26	0.91	0.63	2.16	0.60	1.20	0.55	0.96	0.08	80.6	25.8	1.04	2.99	7.9	0.6	9.6	0.2	1567.3	30.4	7.9	0.3	1
	Cascade	0.79	0.64	1.32	0.33	2.67	0.38	1.67	0.38	1.00	0.00	103.0	11.3	0.05	0.06	7.6	0.8	9.6	0.0	1579.7	0.0	8.1	0.0	0
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	1.10	-	0.88	-	3.00	-	2.00	-	1.00	-	0.0	0.0	0.00	-	7.2	-	9.6	-	1579.7	-	8.1	-	0
	Total	*0.66*	*0.26*	*1.04*	*0.52*	*2.20*	*0.54*	*1.24*	*0.50*	*0.96*	*0.06*	*74.7*	*26.6*	*0.73*	*2.38*	*7.7*	*0.6*	*9.6*	*0.3*	*1579.7*	*84.9*	*7.9*	*0.2*	*3*
Dry Creek (EVO)	Pool	0.14	0.15	0.37	0.28	2.63	0.47	1.63	0.47	1.00	0.00	98.3	33.5	4.58	6.47	9.9	0.9	8.5	0.0	1662.2	0.0	8.2	0.0	0
	Glide	0.07	0.06	0.13	0.13	2.25	0.37	1.39	0.32	0.86	0.16	23.7	18.9	0.43	1.30	10.3	1.1	8.4	0.3	1658.7	21.1	8.2	0.0	0
	Run	0.13	0.10	0.15	0.09	2.21	0.33	1.27	0.34	0.93	0.09	45.0	26.1	1.07	2.39	9.6	1.2	8.7	0.4	1673.9	16.2	8.2	0.1	1
	Riffle	0.32	0.18	0.29	0.22	2.31	0.27	1.46	0.25	0.85	0.10	31.3	19.1	0.00	0.00	10.1	1.2	8.5	0.0	1662.2	0.0	8.2	0.1	0
	Cascade	0.17	0.14	0.22	0.22	2.61	0.31	1.66	0.29	0.95	0.09	35.7	24.9	0.06	0.20	10.2	1.0	8.5	0.0	1662.2	0.0	8.2	0.0	1
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0.36	-	0.12	-	3.00	-	2.00	-	1.00	-	0.0	0.0	0.00	-	9.2	-	8.5	-	1662.2	-	8.2	-	0
	Total	*0.16*	*0.15*	*0.20*	*0.19*	*2.43*	*0.37*	*1.52*	*0.33*	*0.91*	*0.12*	*35.3*	*27.0*	*0.42*	*1.56*	*10.1*	*1.1*	*8.5*	*0.2*	*1662.2*	*12.8*	*8.2*	*0.0*	*2*

Table 2. Continued (2 of 5).

Waterbody	Habitat Type	Mean Velocity (m/s)		Mean Flow (cms)		Calcite Measures CI		Calcite Measures CC		Calcite Measures CP		Mean Pebble Size (mm)		Gravel Prop. (%)		Water Temp. (°C)		DO (mg/L)		Spec. Cond/ (µS/cm)		pH		Total Redds
		Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	
Dry Creek (LCO)	Pool	0.05	0.02	0.07	0.06	0.26	0.30	0.00	0.00	0.26	0.30	25.2	27.2	0.05	0.12	6.8	2.1	10.6	0.0	421.5	0.0	8.2	0.1	0
	Glide	0.25	0.20	0.28	0.37	0.38	0.25	0.01	0.04	0.37	0.23	37.3	18.3	3.13	3.63	6.5	1.9	10.6	0.1	421.4	0.4	8.2	0.1	4
	Run	0.37	0.21	0.30	0.22	0.42	0.27	0.00	0.00	0.42	0.27	48.7	23.6	6.53	5.88	7.6	2.0	10.6	0.1	421.5	0.3	8.3	0.1	2
	Riffle	0.49	0.18	0.28	0.13	0.46	0.25	0.00	0.01	0.46	0.24	61.0	21.3	5.18	7.11	8.0	2.0	10.6	0.1	421.7	1.1	8.3	0.1	2
	Cascade	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	*0.32*	*0.23*	*0.25*	*0.25*	*0.41*	*0.26*	*0.00*	*0.03*	*0.40*	*0.25*	*46.9*	*23.9*	*4.00*	*5.71*	*7.3*	*2.0*	*10.6*	*0.1*	*421.5*	*0.7*	*8.3*	*0.1*	*8*
Fish Pond Creek	Pool	0.05	0.06	0.44	0.50	0.65	0.37	0.00	0.00	0.65	0.37	46.5	8.6	5.56	6.56	6.6	0.6	7.8	0.3	284.9	18.2	7.8	0.1	0
	Glide	0.11	0.05	0.19	0.13	0.59	0.29	0.00	0.01	0.59	0.28	54.0	15.2	8.72	9.54	6.3	0.4	8.2	0.4	290.2	20.0	7.8	0.0	12
	Run	0.20	0.04	0.22	0.05	0.93	0.05	0.00	0.00	0.93	0.05	77.5	16.4	7.52	7.36	6.8	0.4	8.1	0.8	303.2	12.4	7.8	0.0	0
	Riffle	0.34	0.18	0.20	0.13	0.68	0.31	0.00	0.00	0.68	0.31	77.9	26.2	3.48	5.28	6.3	0.4	8.1	0.4	291.1	18.9	7.8	0.1	0
	Cascade	0.58	-	0.46	-	0.63	-	0.00	-	0.63	-	60.2	-	0.00	-	6.9	-	7.6	-	291.9	-	7.8	-	0
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	*0.22*	*0.18*	*0.24*	*0.24*	*0.66*	*0.30*	*0.00*	*0.01*	*0.66*	*0.30*	*64.5*	*23.7*	*5.56*	*7.25*	*6.4*	*0.5*	*8.1*	*0.4*	*290.4*	*18.4*	*7.8*	*0.1*	*12*
Fording River	Pool	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Glide	0.27	0.45	0.82	1.36	0.33	0.34	0.00	0.00	0.33	0.34	63.8	21.6	0.00	0.00	8.6	1.7	9.1	0.0	525.8	0.0	8.0	0.3	0
	Run	0.67	0.20	2.23	0.96	0.20	0.12	0.00	0.01	0.20	0.12	66.0	9.4	31.91	52.14	8.6	1.0	9.1	0.1	525.8	1.5	8.2	0.0	6
	Riffle	0.81	0.25	2.48	1.44	0.23	0.31	0.00	0.00	0.23	0.31	65.5	7.7	1.37	3.26	8.8	1.1	9.1	0.0	525.8	0.0	8.2	0.0	0
	Cascade	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	*0.65*	*0.30*	*2.14*	*1.22*	*0.22*	*0.23*	*0.00*	*0.01*	*0.21*	*0.23*	*65.0*	*10.2*	*15.29*	*37.06*	*8.7*	*1.0*	*9.1*	*0.1*	*525.8*	*1.0*	*8.2*	*0.1*	*6*
Grace Creek	Pool	0.38	0.08	0.31	0.14	0.17	0.19	0.00	0.00	0.17	0.19	19.4	7.1	3.42	3.68	7.9	0.4	10.7	0.0	417.1	0.0	8.3	0.0	0
	Glide	0.37	0.23	0.23	0.15	0.14	0.11	0.00	0.00	0.14	0.11	13.3	6.9	3.80	4.81	7.8	0.4	10.6	0.1	432.4	34.3	8.0	0.4	0
	Run	0.45	0.13	0.25	0.07	0.27	0.26	0.00	0.01	0.27	0.26	27.3	12.0	18.44	15.03	8.0	0.5	10.7	0.1	416.6	1.3	8.3	0.3	3
	Riffle	0.58	0.10	0.25	0.02	0.67	0.36	0.01	0.02	0.65	0.34	47.8	12.9	5.65	9.26	8.0	0.7	10.7	0.0	417.1	0.0	8.3	0.0	1
	Cascade	0.47	0.14	0.34	0.09	0.47	0.56	0.04	0.08	0.43	0.49	43.2	31.3	3.12	3.42	8.6	0.3	10.7	0.0	417.1	0.0	8.3	0.0	0
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	*0.44*	*0.13*	*0.27*	*0.10*	*0.31*	*0.32*	*0.01*	*0.02*	*0.30*	*0.31*	*28.2*	*16.2*	*11.46*	*14.11*	*8.0*	*0.5*	*10.7*	*0.1*	*417.1*	*13.0*	*8.3*	*0.2*	*4*

Table 2. Continued (3 of 5).

Waterbody	Habitat Type	Mean Velocity (m/s)		Mean Flow (cms)		Calcite Measures: CI		Calcite Measures: CC		Calcite Measures: CP		Mean Pebble Size (mm)		Gravel Prop. (%)		Water Temp. (°C)		DO (mg/L)		Spec. Cond/ (µS/cm)		pH		Total Redds
		Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	
Grave Creek	Pool	0.51	0.37	0.90	0.42	0.00	0.00	0.00	0.00	0.00	0.00	39.0	23.0	0.60	0.90	6.5	0.2	10.0	0.0	302.7	0.0	8.3	0.0	0
	Glide	0.84	0.17	1.82	0.76	0.06	0.10	0.00	0.00	0.06	0.10	126.8	24.3	0.60	0.79	5.9	0.4	10.0	0.0	302.7	0.0	8.3	0.0	0
	Run	0.89	0.08	1.94	0.35	0.01	0.01	0.00	0.00	0.01	0.01	87.5	27.0	1.95	2.64	6.6	0.2	10.0	0.1	302.3	0.8	8.3	0.0	0
	Riffle	0.93	0.15	1.65	0.74	0.02	0.06	0.00	0.00	0.02	0.06	91.8	42.1	1.19	1.75	6.3	0.5	10.0	0.1	302.8	0.9	8.3	0.0	1
	Cascade	0.87	0.40	1.46	0.87	0.01	0.01	0.00	0.00	0.01	0.01	101.3	31.7	1.30	1.37	6.5	0.5	10.0	0.0	302.5	0.6	8.3	0.1	1
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0.92	0.05	1.46	2.02	0.00	0.00	0.00	0.00	0.00	0.00	126.1	76.2	0.00	0.00	6.0	0.5	10.0	0.0	302.7	0.0	8.3	0.0	0
	Total	***0.88***	***0.27***	***1.58***	***0.80***	***0.01***	***0.05***	***0.00***	***0.00***	***0.01***	***0.05***	***97.4***	***38.4***	***1.16***	***1.57***	***6.3***	***0.5***	***10.0***	***0.1***	***302.7***	***0.7***	***8.3***	***0.1***	***2***
Harmer Creek	Pool	0.35	0.26	0.81	0.67	0.33	0.29	0.00	0.00	0.33	0.29	44.6	22.5	1.81	3.37	7.5	0.6	10.1	0.0	634.7	0.0	8.3	0.1	1
	Glide	0.37	0.30	0.58	0.54	0.66	0.32	0.02	0.05	0.64	0.29	59.6	28.9	0.29	0.52	7.3	1.4	10.1	0.1	633.6	4.5	8.3	0.1	1
	Run	0.49	0.19	0.60	0.42	0.74	0.15	0.02	0.06	0.72	0.16	64.5	16.1	3.48	7.36	6.5	1.1	10.1	0.1	638.1	11.7	8.3	0.1	1
	Riffle	0.55	0.30	0.64	0.49	0.59	0.35	0.01	0.03	0.58	0.34	57.8	26.0	4.51	16.19	7.1	1.2	10.1	0.1	635.0	8.7	8.3	0.1	4
	Cascade	0.56	0.29	0.59	0.64	0.44	0.10	0.00	0.00	0.44	0.10	51.3	14.9	0.81	1.95	6.7	1.2	10.1	0.1	632.4	8.8	8.2	0.1	0
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	***0.47***	***0.28***	***0.64***	***0.50***	***0.58***	***0.31***	***0.01***	***0.04***	***0.57***	***0.30***	***56.5***	***24.5***	***2.76***	***11.22***	***7.0***	***1.1***	***10.1***	***0.1***	***634.7***	***8.3***	***8.3***	***0.1***	***7***
Henretta Creek	Pool	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Glide	0.61	0.12	2.25	0.33	0.00	0.00	0.00	0.00	0.00	0.00	60.9	7.0	4.62	4.91	5.5	0.0	9.7	0.0	310.9	0.0	8.1	0.0	0
	Run	0.65	0.11	2.54	0.47	0.00	0.00	0.00	0.00	0.00	0.00	72.7	19.8	5.07	7.30	6.4	0.6	9.7	0.0	310.9	0.0	8.2	0.1	0
	Riffle	0.95	0.27	3.49	1.13	0.00	0.00	0.00	0.00	0.00	0.00	80.7	25.2	9.95	22.80	5.9	0.6	9.7	0.1	310.9	15.4	8.1	0.1	0
	Cascade	1.10	0.14	3.91	0.80	0.00	0.00	0.00	0.00	0.00	0.00	117.3	16.7	0.41	0.87	6.5	0.4	9.7	0.0	310.9	0.0	8.2	0.1	0
	Chute	0.00	0.00	0.00	0.00	0.00	-	0.00	-	0.00	-	246.2	-	0.00	-	0.0	0.0	9.7	-	310.9	-	0.0	0.0	0
	Falls	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	***0.87***	***0.27***	***3.22***	***1.02***	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***91.3***	***39.2***	***5.07***	***13.66***	***6.2***	***0.6***	***9.7***	***0.1***	***310.9***	***8.5***	***8.1***	***0.1***	***0***
Line Creek	Pool	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Glide	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Run	0.87	0.21	2.92	1.40	0.67	0.30	0.00	0.00	0.67	0.30	85.6	15.7	0.62	0.99	6.5	0.8	10.2	0.1	658.4	122.8	8.0	0.3	0
	Riffle	0.78	0.31	2.28	1.38	0.65	0.40	0.00	0.00	0.65	0.40	84.1	18.0	1.74	2.77	6.5	0.8	10.3	0.0	608.3	0.0	8.0	0.3	1
	Cascade	1.16	0.16	3.21	0.97	0.58	0.26	0.00	0.00	0.58	0.26	106.1	28.6	0.40	0.78	6.9	0.6	10.3	0.0	608.3	0.0	8.2	0.2	0
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	***0.92***	***0.32***	***2.72***	***1.33***	***0.60***	***0.31***	***0.00***	***0.00***	***0.60***	***0.31***	***90.8***	***25.9***	***0.83***	***1.61***	***6.5***	***0.8***	***10.3***	***0.1***	***608.3***	***87.9***	***8.1***	***0.3***	***1***

Table 2. Continued (4 of 5).

Waterbody	Habitat Type	Mean Velocity (m/s)		Mean Flow (cms)		Calcite Measures CI		Calcite Measures CC		Calcite Measures CP		Mean Pebble Size (mm)		Gravel Prop. (%)		Water Temp. (°C)		DO (mg/L)		Spec. Cond/ (µS/cm)		pH		Total Redds
		Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	
Lizard Creek	Pool	0.23	0.20	0.90	0.88	0.15	0.16	0.00	0.00	0.15	0.16	38.3	15.4	0.55	0.98	9.1	0.9	12.1	0.7	360.6	2.2	8.3	0.1	0
	Glide	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Run	0.54	0.18	4.00	12.45	0.32	0.20	0.01	0.03	0.31	0.19	61.7	13.0	19.28	15.87	9.1	0.8	12.2	0.6	361.1	1.2	8.3	0.0	23
	Riffle	0.62	0.19	1.28	0.73	0.41	0.16	0.00	0.00	0.41	0.16	73.2	16.9	11.19	16.57	9.1	0.7	12.8	3.4	362.2	2.2	8.3	0.0	8
	Cascade	0.85	0.23	1.24	0.62	0.47	0.13	0.00	0.00	0.47	0.13	92.3	10.1	1.43	2.48	9.2	0.5	12.3	0.0	361.4	0.0	8.4	0.0	0
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.00	-	0.0	0.0	12.3	-	361.4	-	0.0	0.0	0
	Total	*0.53*	*0.25*	*2.36*	*8.15*	*0.32*	*0.20*	*0.00*	*0.02*	*0.32*	*0.20*	*62.8*	*20.3*	*11.72*	*15.56*	*9.1*	*0.8*	*12.3*	*1.9*	*361.4*	*1.8*	*8.3*	*0.0*	*31*
Lower Greenhills Creek	Pool	0.19	0.17	0.20	0.11	0.74	0.77	0.23	0.39	0.51	0.44	44.2	41.2	0.26	0.42	15.0	1.2	9.5	0.0	1181.4	1.2	8.4	0.0	0
	Glide	0.22	0.12	0.17	0.09	0.68	0.55	0.13	0.30	0.56	0.33	37.9	31.1	0.64	0.77	14.4	1.4	9.5	0.0	1181.2	1.0	8.3	0.2	2
	Run	0.23	0.26	0.13	0.04	0.37	0.38	0.00	0.00	0.37	0.38	19.5	14.9	0.51	0.89	14.7	1.0	9.5	0.0	1181.0	0.0	8.4	0.0	0
	Riffle	0.38	0.22	0.17	0.10	1.14	0.87	0.42	0.61	0.72	0.40	62.9	43.6	0.76	1.20	14.8	2.1	9.5	0.0	1180.5	1.9	8.3	0.2	0
	Cascade	0.92	0.24	0.35	0.02	2.89	0.19	1.89	0.19	1.00	0.00	112.2	-	0.00	0.00	16.8	0.4	9.5	0.0	1181.0	0.0	8.4	0.0	0
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	*0.29*	*0.23*	*0.18*	*0.09*	*0.92*	*0.86*	*0.32*	*0.58*	*0.60*	*0.39*	*46.2*	*38.8*	*0.56*	*0.89*	*14.7*	*1.6*	*9.5*	*0.0*	*1181.0*	*1.3*	*8.4*	*0.1*	*2*
McCool Creek	Pool	0.51	0.18	0.66	0.22	0.18	0.16	0.03	0.07	0.16	0.12	66.5	11.3	1.17	1.94	6.9	0.2	10.9	0.2	517.5	38.9	8.4	0.0	0
	Glide	0.41	-	0.52	-	0.27	-	0.00	-	0.27	-	67.3	-	0.00	-	6.9	-	11.0	-	536.4	-	8.5	-	1
	Run	0.74	0.11	0.71	0.15	0.19	0.14	0.00	0.00	0.19	0.14	69.0	10.8	1.16	1.16	6.8	0.2	11.0	0.0	536.4	0.0	8.4	0.0	0
	Riffle	0.81	0.12	0.65	0.19	0.20	0.12	0.00	0.01	0.20	0.12	72.0	15.1	1.01	0.95	6.8	0.1	11.0	0.4	551.8	115.2	8.4	0.0	1
	Cascade	0.78	0.22	0.70	0.21	0.31	0.21	0.06	0.13	0.25	0.11	73.6	9.2	1.64	2.05	6.9	0.2	10.9	0.1	530.2	19.6	8.4	0.0	1
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	*0.72*	*0.19*	*0.68*	*0.19*	*0.22*	*0.16*	*0.02*	*0.07*	*0.20*	*0.12*	*70.4*	*11.9*	*1.19*	*1.47*	*6.9*	*0.2*	*11.0*	*0.3*	*536.4*	*67.3*	*8.4*	*0.0*	*3*
Michel Creek	Pool	0.46	0.08	0.89	0.52	0.27	0.36	0.00	0.00	0.27	0.36	56.0	31.6	1.23	1.74	8.0	0.4	9.8	0.0	532.1	151.3	8.3	0.0	0
	Glide	0.65	0.04	2.39	0.61	0.25	0.02	0.00	0.00	0.25	0.02	47.4	19.1	59.74	76.53	7.9	0.4	9.8	0.0	593.9	0.0	8.3	0.0	2
	Run	0.77	0.27	2.25	1.17	0.30	0.18	0.01	0.03	0.30	0.17	71.4	21.1	29.55	36.02	7.7	0.5	9.8	0.1	431.8	189.9	8.2	0.2	0
	Riffle	0.75	0.21	1.39	0.71	0.25	0.18	0.00	0.00	0.25	0.18	70.7	19.3	9.86	12.12	7.9	0.2	9.8	0.0	425.5	193.6	8.3	0.1	0
	Cascade	0.97	0.24	3.14	1.31	0.42	0.02	0.00	0.00	0.42	0.02	72.7	13.5	7.48	17.54	7.9	0.3	9.8	0.0	532.1	151.3	8.3	0.0	0
	Chute	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.00	-	0.0	0.0	9.8	-	593.9	-	0.0	0.0	0
	Falls	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	*0.75*	*0.25*	*1.98*	*1.17*	*0.29*	*0.19*	*0.00*	*0.02*	*0.29*	*0.19*	*68.4*	*21.1*	*17.93*	*30.19*	*7.8*	*0.4*	*9.8*	*0.1*	*470.4*	*176.8*	*8.2*	*0.1*	*2*

Table 2. Continued (5 of 5).

Waterbody	Habitat Type	Mean Velocity (m/s)		Mean Flow (cms)		Calcite Measures CI		Calcite Measures CC		Calcite Measures CP		Mean Pebble Size (mm)		Gravel Prop. (%)		Water Temp. (°C)		DO (mg/L)		Spec. Cond/ (µS/cm)		pH		Total Redds
		Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	Mean	SD[1]	
Thompson Creek	Pool	0.21	0.10	0.13	0.08	0.72	0.28	0.00	0.00	0.72	0.28	65.8	18.6	0.60	0.50	13.9	0.9	9.6	0.5	1498.3	12.8	8.4	0.0	0
	Glide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.0	0.0	0.35	0.61	0.0	0.0	9.8	0.0	1493.5	0.0	0.0	0.0	0
	Run	0.34	0.05	0.14	0.03	0.58	0.35	0.00	0.00	0.58	0.35	39.8	27.1	2.18	0.11	13.4	1.3	9.8	0.0	1493.5	0.0	8.4	0.0	0
	Riffle	0.39	0.08	0.13	0.04	0.76	0.20	0.00	0.00	0.76	0.20	48.4	19.1	8.93	7.76	13.1	1.3	9.8	1.7	1483.6	57.3	8.4	0.0	0
	Cascade	0.47	0.16	0.15	0.06	0.88	0.13	0.00	0.00	0.88	0.13	66.3	12.2	0.72	0.92	14.1	0.8	9.8	0.0	1493.5	0.0	8.4	0.0	1
	Chute	1.09	0.22	0.38	0.24	0.97	0.05	0.00	0.00	0.97	0.05	71.5	23.3	0.00	0.00	14.8	0.1	9.8	0.0	1493.5	0.0	8.4	0.0	0
	Falls	0.63	0.48	0.11	0.02	0.86	0.24	0.00	0.00	0.86	0.24	74.3	29.9	0.00	0.00	14.2	1.0	9.8	0.0	1493.5	0.0	8.4	0.0	0
	Total	*0.46*	*0.28*	*0.15*	*0.09*	*0.74*	*0.30*	*0.00*	*0.00*	*0.74*	*0.30*	*55.4*	*24.8*	*2.40*	*4.98*	*13.8*	*1.0*	*9.8*	*0.8*	*1493.5*	*28.0*	*8.4*	*0.0*	*1*
Upper Greenhills Creek	Pool	0.20	0.04	0.27	0.09	2.50	0.09	1.50	0.09	1.00	0.00	92.2	5.2	0.24	0.33	8.0	0.1	11.1	0.0	1370.9	0.0	8.5	0.0	0
	Glide	0.20	0.14	0.15	0.08	1.99	0.20	1.11	0.15	0.88	0.09	55.7	19.7	1.34	1.83	9.7	0.6	11.1	0.0	1370.9	0.0	8.4	0.1	0
	Run	0.34	0.09	0.21	0.08	2.49	0.23	1.57	0.19	0.92	0.08	47.9	26.6	1.31	2.54	9.1	0.9	11.1	0.3	1370.6	4.4	8.5	0.0	1
	Riffle	0.53	0.11	0.21	0.04	2.60	0.15	1.62	0.17	0.97	0.04	61.1	33.7	1.32	1.43	8.8	0.8	11.1	0.0	1370.6	0.9	8.5	0.0	0
	Cascade	0.48	0.19	0.24	0.10	2.50	0.23	1.57	0.22	0.93	0.04	62.6	37.8	1.52	1.66	9.2	0.8	11.1	0.0	1371.2	1.2	8.5	0.0	0
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	0.47	-	0.25	-	2.77	-	1.77	-	1.00	-	125.0	-	0.00	-	9.4	-	11.1	-	1370.9	-	8.5	-	0
	Total	*0.44*	*0.28*	*0.22*	*0.09*	*2.47*	*0.29*	*1.54*	*0.26*	*0.93*	*0.06*	*60.5*	*33.6*	*1.29*	*1.81*	*9.1*	*0.8*	*11.1*	*0.1*	*1370.9*	*2.2*	*8.5*	*0.0*	*1*
South Line Creek	Pool	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Glide	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Run	0.40	0.33	0.90	1.11	0.08	0.12	0.00	0.00	0.08	0.12	72.5	8.8	0.42	0.28	5.8	1.3	10.7	0.1	242.3	8.7	8.5	0.1	0
	Riffle	0.43	0.18	0.63	0.63	0.06	0.07	0.00	0.00	0.06	0.07	67.7	9.5	1.33	1.79	5.8	0.9	10.6	0.0	252.6	7.1	8.4	0.1	0
	Cascade	0.47	0.24	0.50	0.52	0.07	0.13	0.00	0.00	0.07	0.13	69.0	8.5	0.10	0.24	5.8	0.8	10.7	0.0	248.5	0.0	8.5	0.1	0
	Chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Falls	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	*0.45*	*0.22*	*0.61*	*0.60*	*0.07*	*0.10*	*0.00*	*0.00*	*0.07*	*0.10*	*69.3*	*8.0*	*0.49*	*0.99*	*5.8*	*0.8*	*10.7*	*0.0*	*248.5*	*5.5*	*8.5*	*0.1*	*0*

Appendix D. Summary of 2020 Calcite Coverage Data Analysis

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1. CALCITE PRESENCE VERSUS CALCITE COVERAGE ANALYSIS

1.1. Methods

The calcite sampling protocol was revised in 2020 to include an additional trial measure of calcite presence based on the percent coverage of calcite on each pebble (hereafter referred as calcite coverage or $CI_{Coverage}$) (see Section 2.3.2 of main report). As a first step we contrasted calcite presence with calcite coverage collected in the same streams in 2020.

As a second step, a model was designed to hindcast calcite coverage for years 2018 and 2019 based on the observed relationship between the current calcite presence metric and the new metric of calcite coverage from 2020 field data collection. To define the relationship between calcite coverage and calcite presence, we designed a univariate logistic mixed effects model, where we modeled calcite presence at the mesohabitat level as a function of calcite coverage, while including a stream random effect. This random effect allowed for the relationship between calcite variables to vary between streams (i.e., random slope). To hindcast the calcite coverage for 2018 and 2019, we estimated inverse predictions based on calcite presence from 2018 and 2019 and stream identity. Note that only Erickson Creek was sampled in 2019. As a result, stream level specific predictions are not available, but rather the marginal predictions. This analysis was conducted using the "lme4" package in the R Statistical Language (Bates *et al.* 2015; R Core Team 2018).

1.2. Results

The calcite sampling protocol was altered in 2020 to include an additional measure of calcite presence based on the percent coverage of calcite on each pebble ($CI_{Coverage}$). The two metrics for calcite presence are contrasted by stream in Figure 1. Overall, we observed a non-linear relationship between calcite coverage and calcite presence (binary) (Figure 2). Observed values for both calcite metrics were similar when both were at low (~ 0.1) and high levels (~ 0.9) of calcite presence. However, at intermediate levels of calcite presence, average calcite coverage by mesohabitat unit tended to be lower than calcite presence estimated using the binary yes/no method (Figure 1).

A logistic mixed effects model was developed to hindcast calcite coverage for years 2018 and 2019 based on the observed relationship between calcite coverage and calcite presence from the 2020 field survey. Based on data collected in 2020 and analysis performed herein, calcite coverage and calcite presence were inferred to have a significant, nonlinear positive relationship (*p-value* < 0.001; Figure 2). Calcite presence tended to increase sharply with calcite coverage, reaching mean presence scores of 0.75 around a calcite coverage score of 0.25. Additionally, stream-level random slopes showed considerable deviations from the marginal mean prediction, in particular streams such as LCO Dry Creek where a steeper relationship was more evident (Figure 2). These results reinforce the model structure to account for stream-level specific variability when hindcasting calcite coverage.

To estimate calcite coverage for 2018 and 2019, we estimated the inverse prediction from the above model based on calcite presence observed values. Overall, the predicted calcite coverage values in

2020 matched with the observed values in 2020 (Figure 3). Note that Erickson Creek was not sampled in 2020, thus calcite coverage estimates were based on marginal predictions (i.e., no random slope).

Based on the calcite coverage collected in 2020, and analysis performed above, we estimated CI across years by summing predicted calcite coverage with measured calcite concretion and compared its effects on the average counts of redds to those of the current CI (binary) used in this study. The objective of this preliminary approach was to investigate potential differences in the effects of binary and coverage CI on WCT spawning suitability. This comparison was based on similar univariate GAMs as in Section 3.4.1.1 of the main report. In both metrics, the predicted average redd counts was higher between CI scores ranging between 0 and 1 and quickly decreasing to values close to zero at scores of two (Figure 4); however, the maximum predicted average redd count was lower for CI coverage model and associated with lower CI coverage levels (Figure 4). Similar to Section 3.3.1.1, we observed a significant non-linear relationship between redd counts and CI coverage (*p-value* < 0.001; Figure 4b). These preliminary results suggest CI levels for optimal WCT spawning are dependent on the calcite presence metric used, and thus calcite presence coverage and calcite presence binary are not interchangeable. In other words, peak spawning suitability is predicted to be closer to CI = 0.5 using calcite coverage as the calcite presence metric versus CI ~ 0.7 using calcite presence binary.

Figure 1. Average calcite presence and calcite coverage (± 1 SD) for each mesohabitat unit by stream in 19 tributaries of the Elk River, B.C. from 2020 field surveys. CMO: Coal Mountain Operations, EVO: Elkview Operations, FRO: Fording River Operations, GHO: Greenhills Operations, LCO: Line Creek Operations.

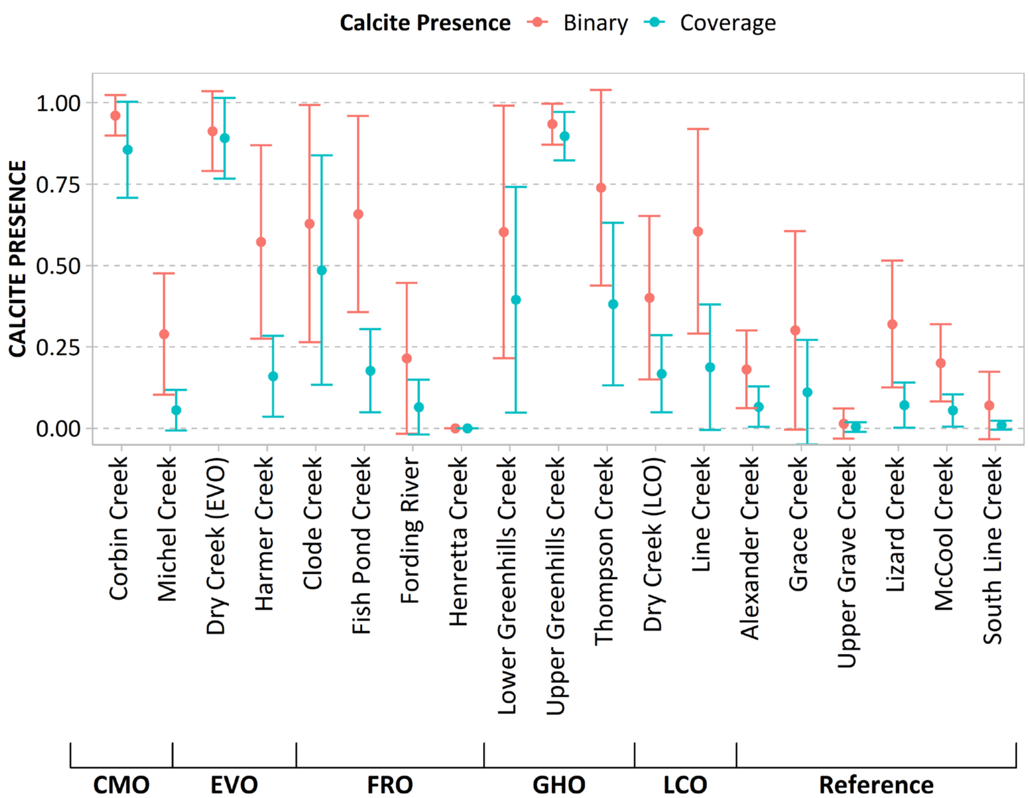


Figure 2. Distribution of calcite presence by mesohabitat unit in function of calcite coverage (raw points) in tributaries of the Elk River, BC from 2020 field surveys. Black line depicts the predicted average calcite presence based on a logistic mixed effect model, while colored lines depict individual stream relationships estimated by the random slope.

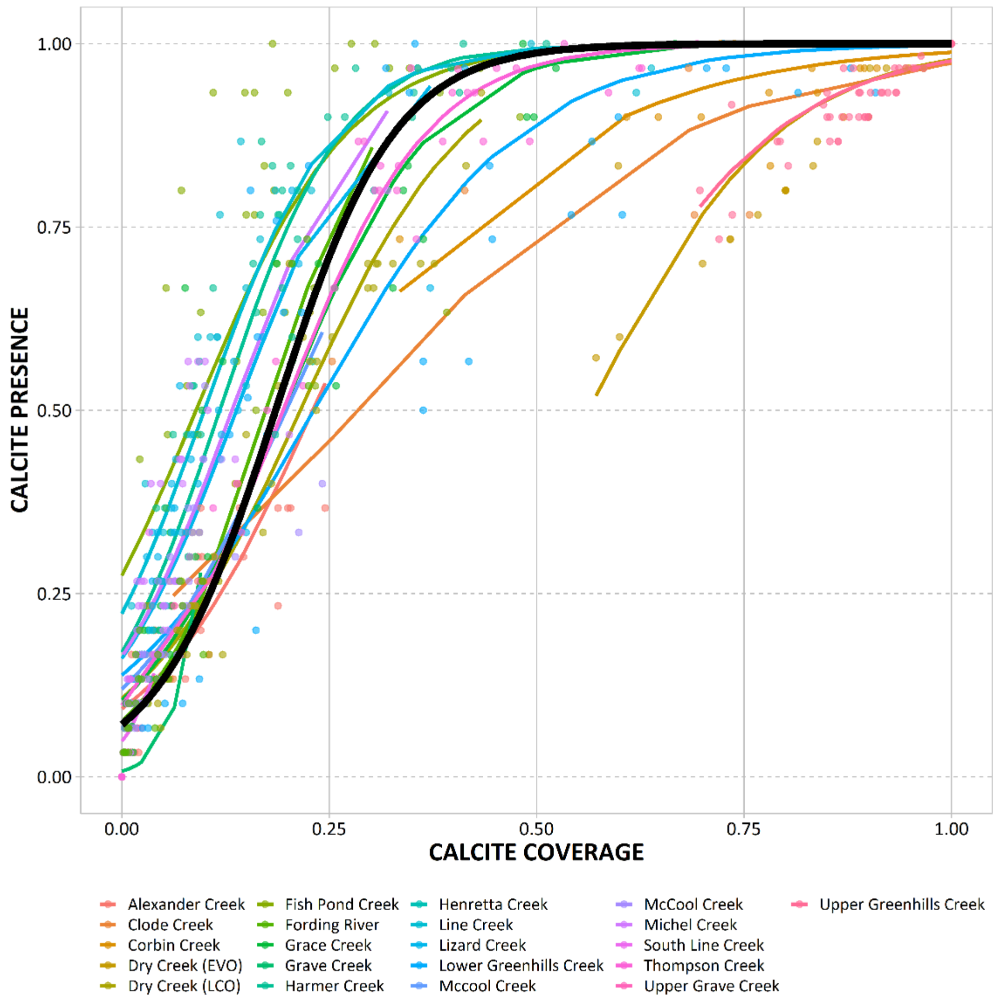


Figure 3. Predicted *versus* observed calcite coverage in function of calcite presence in tributaries of the Elk River, BC. Observed values (red) are based on 2020 field surveys. Predictions (blue) are based on the model in Figure 2.

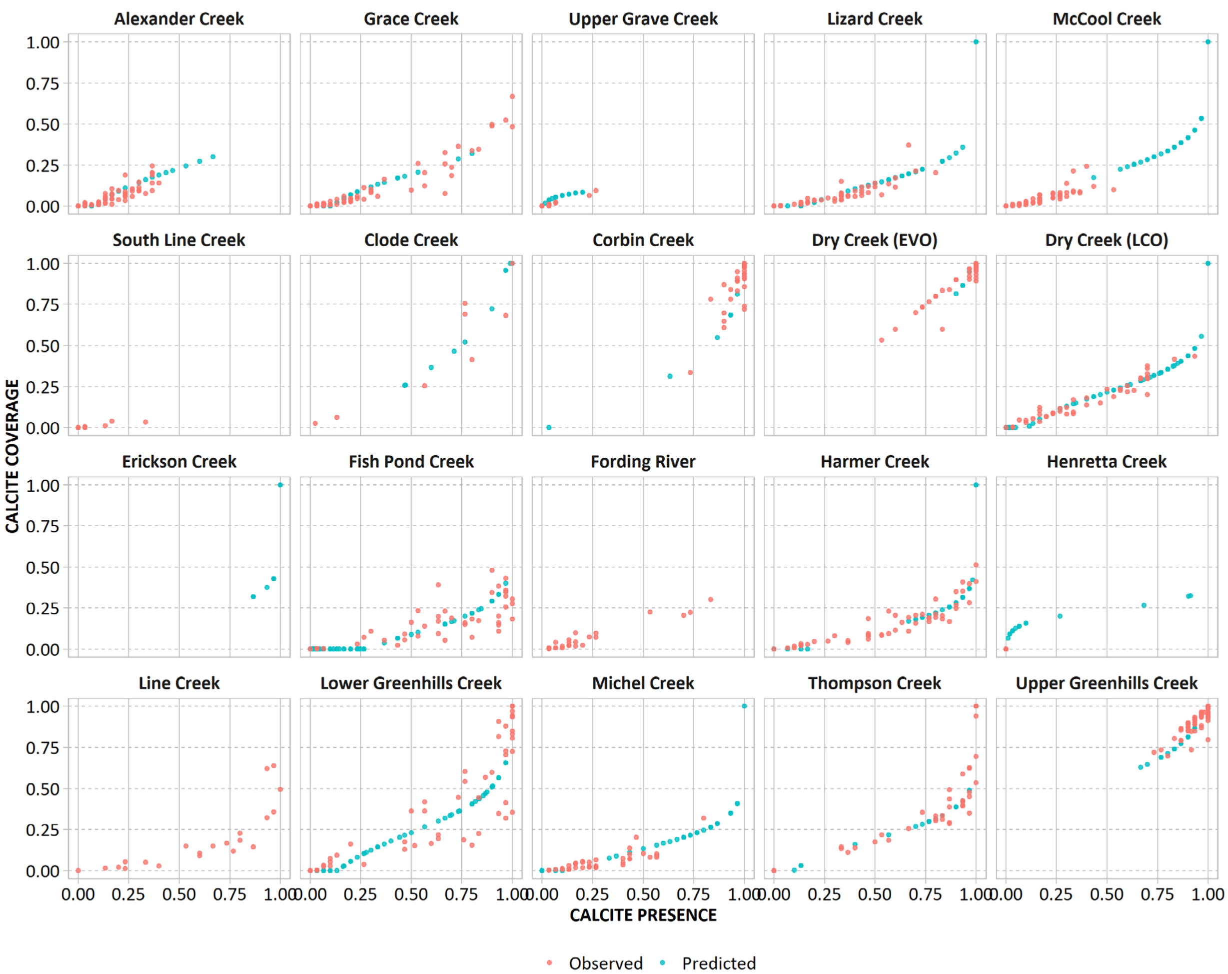
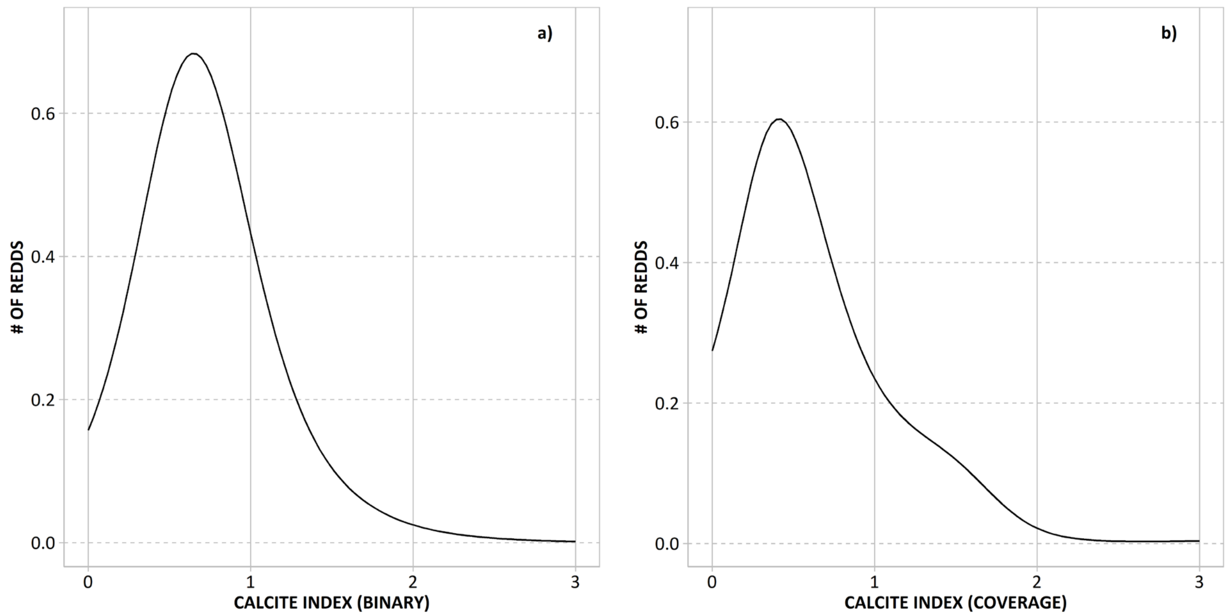


Figure 4. Predicted average count of redds as a function of CI based on a) calcite presence and based on b) hind-casted calcite coverage in 20 tributaries of the Elk River, BC. The solid line depicts the predicted average count of redds as a smoother function of CI, estimated from a univariate generalized additive model.



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Appendix E. Summary of 2020 Calcite Biological Model Validation of Redd Presence and Redd Count GLMMs and GAMMs

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1 MODEL VALIDATION ANALYSES

1.1 Methods

1.1.1 Stratified Cross-Validation

Stratified cross-validation (CV) techniques were applied to the "all-streams" average models from Sections 2.5.2 and 2.5.3 of the main report to better understand the repeatability of the model estimates for calcite concretion and other top predictors of WCT redd presence and counts. Model CV assesses the predictive performance of a given model, by estimating predictions error from respective observations. For that purpose, CV relies on data splits referred as the training and validation sets. Stratified CV ensures that nested structure of data is maintained and accounted for when splitting the data and fitting the validation models. The training set is used to fit the statistical model and estimate its coefficients, while the validation set is used to predict and estimate the deviation from observed values. To estimate the prediction error, CV techniques compute the error between observed and predicted values as root mean squared error and mean absolute error. In both cases, the lower the error, the better the model can predict the observed value.

In here, we performed a repeated stratified K-fold cross-validation. This technique subsets data into equally sized sets of data and fits the model on k – 1 folds (sets of data), and uses the remainder fold as the validation sets. This technique iteratively ran through all folds to account for all possible data combinations, and in each fold, all streams were proportionally represented. We used a 4-fold CV and additionally repeated the validation ten times (i.e., applied the 4-fold CV ten times) to ensure more data combinations were included. Because the "all-streams" average models (Sections 2.5.2 and 2.5.3) are composed by multiple models, all top models were re-fitted using training set, then model averaged. We then predicted new redd presence (Section 2.5.2) or new redd counts (Section 2.5.3) values based on validation set. Area under the curve was estimated for each redd presence "all-stream" validation model. Area under the curve provided a performance metric to our model redd presence predictions, as it assessed the ability of the models to correctly classifying a redd being present or absent from any given mesohabitat. To estimate the area under the curve we used "pROC*"* package (Robin *et al.* 2011) in the R Statistical Language (R Core Team 2018). To provide context to these values, we estimated the AUC for all top models that predict redd presence, and for their respective null models. We defined a null model as model fitted only with the redd presence mean, and stream and year (not included in reference stream analyses) random effects.

Additionally, we estimated the mean absolute error (MAE) for redd count models. The MAE is a measure of error of any given model calculated as the average absolute difference between an observed value and the corresponding predicted value by that model. This process was repeated for all CV iterations for redd counts (Section 2.5.3 of the main report), and the MAE for each iteration was then averaged into a single MAE value.

1.1.2 Variance Partitioning

Variance partitioning methods were applied to estimate the coefficient of determination of redd presence and redd counts models. The coefficient of determination (R^2) is defined as the proportion of the variance explained by a linear model. In the case of generalized linear mixed effect models (models with random effects; GLMM), the variance can be decomposed in three major components: variance explained by fixed-effects, variance explained by random effects, and variance not explained by the models (residual variance). Two different R^2 statistics are usually reported for GLMMs, the Marginal R^2 and Conditional R^2. Marginal R^2 is the proportion of variance explained exclusively by fixed effects, whereas Conditional R^2 combines portions of variance explained from predictors and random effects (i.e., the total amount of variance explained by the model).

The associated R^2 statistics have been developed mostly for linear models and applying such statistics to any (generalized) linear mixed models (or any other types of statistical models) is not standard in the literature, leading to method dependent results. The estimates of the residual variance component for non-gaussian response variables (e.g., logistic regressions) are highly affected by "shape" of the response (link function) and multiple methods have been proposed for each link function. Each method estimates a pseudo-R^2, and these should not be directly interpreted as proportion of variance explained by a model, but rather a relative measure to be compared between similar models to indicate how well a model "explains" the response variable. In here, we used the R^2_{GLMM} proposed by Nakagawa and Schielzeth (2013). We estimated the marginal and conditional variance components of each top model (only for "all streams" GLMM) using the delta method of residual variance estimation (Nakagawa *et al.* 2017) present in function *r.squaredGLMM* within "MuMIn" R package (Barton 2018). In addition, two additional R^2 metrics were estimated, an adjusted R^2 for "all streams" non-linear models (GAMM) using the *summary.gam* function in "mgcv" R package, and the pseudo-R^2 for the 95th Quantile Regression using the method proposed by Koenker and Machado (1999).

We further partitioned the variance explained by a model into the amount of variance explained by each predictor variable to identify which predictor explained most of the variance of a model, and to rank variables based on variance explained. For that purpose, we estimated Semi-Partial R^2 (Jaeger *et al.* 2017), which estimates the proportion of the variance of the response variable explained by a predictor while accounting for covariance between the other predictors in the model. However, this is method currently available only for on logistic regressions (logit link functions) and Poisson regressions (log link functions), and no R package to our knowledge estimates Semi-Partial R^2 for negative binomial distributions or to generalized additive mixed models. Thus, we only present Semi-Partial R^2 results for Redd Presence top models. In addition, we compare the ranking of variables based on their variance explained on models with (GLMM) and without (GLM) random effects. Because no package can estimate Semi-Partial R^2 for both GLM and GLMM, two R packages were used: "partR2" (Stoffel *et al.* 2021) for GLMMs and "r2glmm" (Jaeger *et al.* 2017) for GLMs. Because different packages use different methods of variance estimation, Semi-partial R^2 and other R^2 values should be compared among models of the same type.

1.2 Results

1.2.1 Stratified Cross-Validation

1.2.1.1 Redd Presence Models.

We performed a repeated stratified k-fold cross validation to assess the predictive performance of the all-stream GLMM redd presence model. Data was subdivided into four folds, while imposing that each fold contained similar proportion of zeros, and that all streams were represented in each fold. We repeated the CV validation procedure ten times to fit a total of 40 validation models. Additionally, we assessed the ability of the model to correctly classifying a redd being present or absent from any given mesohabitat by estimating the area under curve (AUC).

Across all 40 validation models, coefficient estimates were consistent and centered around the coefficients obtained in Section 3.3.2.1. (depicted in red in Figure 1). The AUC of the all-stream GLMM redd presence model was 0.84. In comparison, the all-stream null model AUC was 0.81 (Table 1). This suggested that the all-streams model was able to correctly predict the presence or absence of redds but that a significant amount of the variation is explained by differences in redd presence across different streams and years. In addition, we compared the AIC and AUC scores between redd presence top models and their respective null models (Table 1, Table 2). All redd presence top models showed lower AIC scores than their null models, suggesting a better fit of these models. Similarly, all redd presence top models showed higher AUC scores than their null models, suggesting better performance and predictive ability of these models to explain redd presence across the studied streams.

Figure 1. Distribution of coefficient estimates from cross-validation models. In total, 40 validation models were considered. Red dots depict model coefficients from all-stream GLMM model from Section Error! Reference source not found..

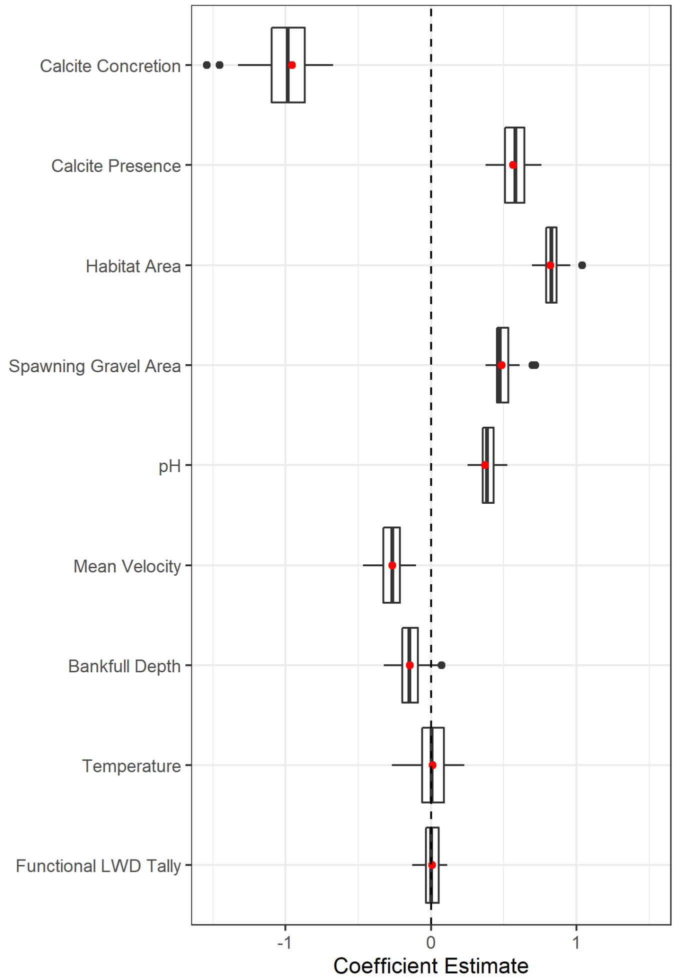


Table 1. Area under the curve (AUC) comparison between top models and their respective null models across all subsets of streams considered. Null models were fitted using the overall mean and year (except reference streams) and stream random effects.

WCT Metric	Model Type	Stream subset	Top Model AUC	Null Model AUC
Redd Presence	Logistic Mixed Effect Model	All Streams	0.84	0.81
	Logistic Mixed Effect Model	Mine-Influenced Streams	0.76	0.73
	Logistic Mixed Effect Model	Reference Streams	0.89	0.83
	Generalized Additive Mixed Model	All Streams	0.86	0.80

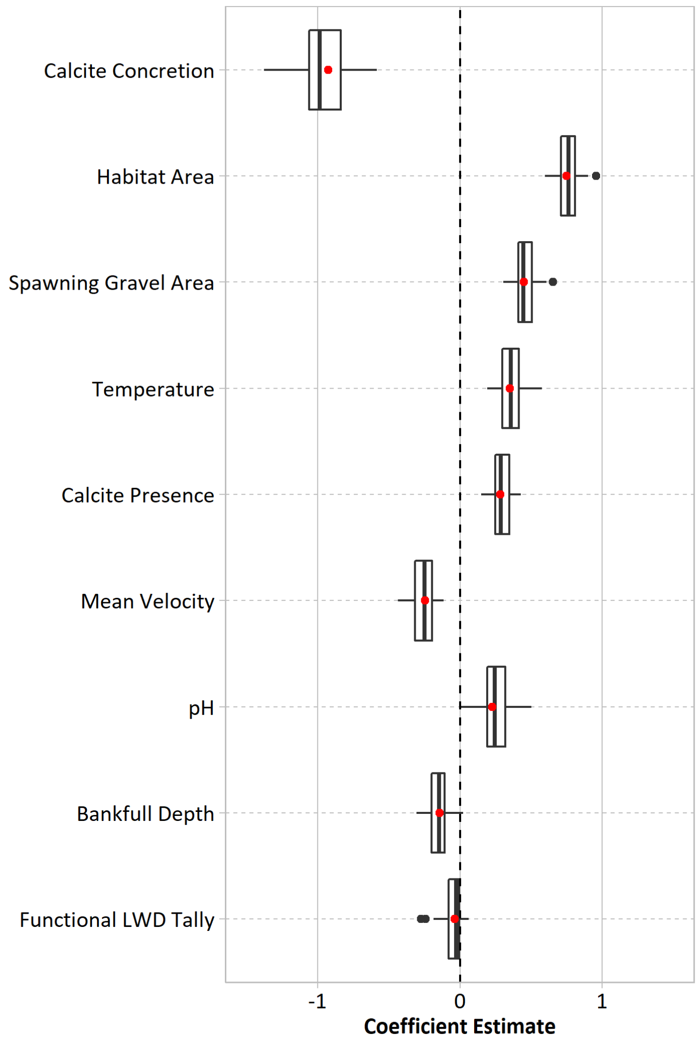
Table 2. Akaike Information Criterion (AIC) comparison between top models and their respective null models across all subsets of streams considered. Null models were fitted using the overall mean and year (except reference streams) and stream random effects.

WCT Metric	Model Type	Stream subset	Top Model AIC	Null Model AIC	ΔAIC
Redd Presence	Logistic Mixed Effect Model	All Streams	646	722	75.15
	Logistic Mixed Effect Model	Mine-Influenced Streams	379	414	35.22
	Logistic Mixed Effect Model	Reference Streams	267	314	47.44
	Generalized Additive Mixed Model	All Streams	601	684	82.35
Redd Counts	Generalized Linear Mixed Effect Model (Negative Binomial)	All Streams	1,261	1,328	66.66
	Generalized Linear Mixed Effect Model (Negative Binomial)	Mine Influenced Streams	740	771	30.88
	Generalized Linear Mixed Effect Model (Negative Binomial)	Reference Streams	499	568	69.13
	Generalized Additive Mixed Model	All Streams	1,286	1,569	283.54
	95th Quantile Regression	All Streams	7,266	7,794	528.05

1.2.1.2 Redd Count Models

We applied the same stratified k-fold cross validation to assess the predictive performance of the all-stream mean redd counts GLMM. Across all 40 validation models, coefficient estimates were again consistent and centered around the coefficients obtained in Section 3.4.2.1 (depicted in red in Figure 2). Moreover, the estimated mean absolute error around predictions was 0.42. This suggests that the all-streams model was able to predict the mean number of redds with low deviations from observed redd counts. In addition, we compared the AIC between redd count top models and their respective null models (Table 2). Redd count top models showed lower AIC scores than their respective null models, suggesting a better performance of these top models to explain redd counts across the studied streams compared to a model with only year and stream.

Figure 2. Distribution of coefficient estimates from cross-validation models. In total, 40 validation models were considered. Red dots depict model coefficients from all-stream generalized mixed effects model from Section 3.4.2.1.



1.2.2 Variance Partitioning

1.2.2.1 Redd Presence Models

Overall, the redd presence "all stream" models had low to intermediate pseudo-R^2 values (Table 3). Nevertheless, the largest component of variance explained by the logistic mixed effects model was attributed to its fixed effects (the marginal R^2), suggesting that the current set of predictors explain part of the variability of redd presence in the Elk Valley (see Section 3.3.2.1 for model details). Note that these pseudo-R^2 only reflect the top model of each model type, whereas the above results (Section 3.3.2.1) were based on an average of top models (except GAMM), thus these pseudo-R^2 may not reflect the total amount of variance explained by the averaged models.

We further partitioned the variance explained by each redd presence GLMM and GLM for each predictor variable (Table 4 and Table 5). Variance partitioning confirmed the relative variable importance (RVI) results obtained in Section 3.3.2, i.e., calcite concretion was among the most important predictors to explain the variability in presence of WCT redds in either "all streams" or "mine influenced" streams. This was observed on both generalized linear mixed effect models (Table 4) and generalized linear models (Table 5). Note that the pseudo-R^2 in Table 4 only reflect the top model of each model type, whereas in Section 3.3.2, results were based on an average of the top models. Thus, these semi-partial R^2 may not reflect the total amount of variance explained by those predictors.

Table 3. Pseudo-R^2 for "All Stream" top Logistic Mixed Effect Model and Generalized Additive Mixed Model that predict redd presence in tributaries of the Elk River, B.C.

WCT metric	Model Type[1]	Marginal R^2_{GLMM}	Conditional R^2_{GLMM}	R^{2*}
Redd Presence	Logistic Mixed Effect Model	0.11	0.15	-
	Generalized Additive Mixed Model	-	-	0.28

[1] Values are based on the top model only.

[*] Based on adjusted R^2 present in "mgcv" R package (Wood, 2011).

Table 4. Semi-partial R^2, marginal and conditional R^2_{GLMM}, and AIC for top logistic mixed effect models that predict redd presence in tributaries of the Elk River, B.C. within "all streams", "mine-influenced streams", and "reference streams" only.

Streams subset	Predictor	Semi-Partial R^2	Marginal R^2_{GLMM}	Conditional R^2_{GLMM}	AIC
All Streams	Calcite Concretion	0.04	0.12	0.15	646.43
	Calcite Presence	0.01			
	Habitat Area	0.04			
	Spawning Gravel	0.02			
	Mean Velocity	0.00			
	pH	0.01			
Mine Streams	Calcite Concretion	0.04	0.08	0.08	379.26
	Calcite Presence	0.01			
	Habitat Area	0.02			
	Spawning Gravel	0.01			
Reference Streams	Conductivity	0.18	0.30	0.37	266.99
	Habitat Area	0.03			
	Spawning Gravel	0.06			
	Mean Velocity	0.00			

Table 5. Semi-partial R^2, R^2, and AIC for top logistic regression models that predict redd presence in tributaries of the Elk River, B.C. within "all streams", "mine streams", and "reference streams" only.

Streams subset	Predictor	Semi-Partial R^2	R^2	AIC
All Streams	Calcite Concretion	0.02	0.04	668.69
	Habitat Area	0.01		
	Calcite Presence	0.01		
	pH	0.00		
	Mean Velocity	0.00		
	Spawning Gravel	0.00		
Mine Streams	Calcite Concretion	0.01	0.02	375.26
	Habitat Area	0.01		
	Calcite Presence	0.00		
	Spawning Gravel	0.00		
Reference Streams	Habitat Area	0.04	0.11	272.61
	Calcite Index	0.03		
	pH	0.01		
	Spawning Gravel	0.00		

1.2.2.2 Redd Count Models

Overall, the redd counts "all stream" model had low to intermediate pseudo-R^2 values (Table 6). Contrary to the redd presence models presented above, the variance decomposition showed that both fixed-effects and random-effects explain similar amounts of variance. This suggests that the variability in number of redds is also linked to stream spatial variability (i.e., some streams have high numbers of redds, while others have no redds) and sampled year. Note that the pseudo-R^2 in Table 6 only reflects the top model of each model type (except GAMM and 95th Quantile regression), whereas in Section 3.4.2.1 of the main report, the results were based on an average of the top models. Thus, pseudo-R^2 may not reflect the total amount of variance explained by those average models.

Table 6. Pseudo-R^2 for "All Stream" top Generalized Linear Mixed Effect Model, Generalized Additive Mixed Model, and 95th Quantile Regression Model that predict the number of WCT redds within the tributaries of the Elk River, B.C.

WCT metric	Model Type[1]	Marginal R^2_{GLMM}	Conditional R^2_{GLMM}	R^{2*}	Pseudo - $R^{2\dagger}$
Redd Counts	Generalized Linear Mixed Effect Model (Negative Binomial)	0.19	0.43	-	-
	Generalized Additive Mixed Model	-	-	0.58	-
	95th Quantile Regression	-	-	-	0.17

[1] Values are based on the top model only.
[*] Based on adjusted R^2 present "mgcv" R package (Wood, 2011).
† Based on Koenker & Machado, 1999.

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Appendix F. Westslope Cutthroat Trout Spawning Suitability: Boosted Regression Tree Data Analysis of Calcite within Streams. Technical Memo submitted to Teck Coal Ltd. and Ecofish Research Ltd. by Jeff Row and Jennifer Ings, Minnow Environmental Inc.

Technical Memo

Date: August 31, 2021

To: Allie Ferguson, Mariah Arnold, Jason Ammerlaan, and Morgan Hocking

From: Jeff Row and Jennifer Ings, Minnow Environmental Inc.

Cc:

RE: Westslope Cutthroat Trout Spawning Suitability: Boosted Regression Tree Data Analysis of Calcite within Streams

Background and Objectives

An accurate characterization of the natural and anthropogenic factors influencing suitable spawning habitat for westslope cutthroat trout (WCT) in the Elk River watershed is essential to developing cogent management strategies. However, the selection of locations for redds (i.e., a spawning nest) by female WCT is a product of a complex and hierarchical selection process making this characterization challenging. At landscape scales, stream morphology and landcover characteristics can influence spawning locations within tributaries for some trout species (Baxter and Hauer 2000; Steel et al. 2004), whereas substrate and water (e.g., temperature, flow) characteristics are often important in the selection of individual spawning locations (Hall and Wissmar 2004). At these local scales, however, some evidence suggests that selection patterns can vary among tributaries (Hall and Wissmar 2004), suggesting potential for interactions between the landscape scale selection factors (e.g., stream morphology) and site-specific selection (e.g., substrate).

Teck operates four steelmaking coal mines and manages one closed mine in care and maintenance in the Elk River watershed offering the potential to introduce stressors into the environment that can influence suitable spawning habitat for WCT. One such stressor with the potential to influence redd presence and/or density is calcite formation[1]. To assess the effects of calcite on spawning suitability, data on redd locations and counts and associated field data,

[1] Calcite results from the precipitation of dissolved calcium and carbonate ions under conditions of saturated carbonate and/or increasing water pH or calcium concentrations. Although these conditions occur naturally, they are enhanced when water passes over mine waste rock surfaces, which elevates both aqueous calcium and carbonate concentrations.

including calcite presence and concretion, were collected at multiple streams from 2018 to 2020 (Hocking *et al*. 2019; 2020; In prep). Because of non-linear relationships identified with generalized additive mixed models (GAMM) and the potential for interactive effects of habitat and stressor variables, the effects of calcite and other natural and anthropogenic variables on WCT redd presence and counts were quantified using boosted regression trees (BRT). BRT analysis is a modelling approach that relies on first developing a series of simple decision trees that split a response variable with a set of predictors and then using boosting to combine these trees into a predictive model. Similar to generalized linear mixed models (GLMM), the analysis was conducted at the within-stream scale with data collected for individual mesohabitat units (i.e., individual pools, riffles, run habitat units) within a stream. Boosted regression tree analysis does not assume any underlying relationship between response and predictors (i.e., can accommodate non-linearity) and incorporates interactions between predictor variables. The primary objective of the BRT analysis is to support the GLMM model analysis (Hocking *et al*. In prep) and investigate the importance of calcite and other covariates within streams on redd presence and counts. Boosted regression tree analysis incorporates interactions between variables (i.e., the importance of one variable can depend on the value of another) and between stream and habitat variables (i.e., allow individual relationships between response and predictor to change within streams) and generally leads to highly predictive models. Thus, a secondary objective of the BRT analysis is to estimate the potential success of calcite remediation on redd presence and counts within individual habitat units in the context of other covariates that may be influencing the suitability of that habitat unit.

Methods

Field Data

The BRT analysis was conducted at the within-stream scale on data collected for individual mesohabitat units (i.e., individual pools, riffles, run habitat units) within 21 streams over three years (2018-2020). Within each habitat until field data was also collected using the Fish Habitat Assessment Procedure (FHAP) and used as predictors in the model. The primary objective of the analysis was to assess the effect of calcite on spawning habitat, but there was a large variability in the level of calcite across streams included in this analysis. To aid in interpretation, some of the analyses and data visualizations were broken down into three calcite categories based on the maximum concretion values observed in the stream. Streams were grouped into no, low (>0 and <=0.1), medium (> 0.1 and >0.5) and high calcite (>0.5) concretion groups (Table 1).

Boosted Regression Tree Analysis

Boosted regression tree analysis (BRT) relies on first developing a series of simple decision trees, which use repeated binary splits of predictor variables to divide the dataset into groups with the objective of partitioning the response variable (e.g., probability of redd presence; redd counts) into homogenous groups to compare with predictor variables (Breiman et al. 1984; De'Ath and Fabricius 2000). Developed trees have a hierarchical structure and the response to one predictor depends on the splits from other predictors higher in the tree; thus interactions are incorporated into the underlying model. Boosting improves model accuracy by using machine learning to combine the series of smaller trees that explain the variance in the response in a stage-wise fashion with each new tree focused on reducing unexplained variation (Schapire 2003; Elith et al. 2008), which differs from approaches that average over multiple trees. The result is a final BRT model which is a combination of many simpler trees and can lead to highly predictive models.

Boosted regression tree models have associated parameters (i.e., learning rate, tree complexity and bag fraction) that need be set and have an impact on overall model performance. Thus, the BRT model needs to be 'tuned' by testing a variety of combinations of each parameter and determining which set leads to the greatest overall performance. The learning rate refers to the contribution of each tree to the growing model with lower values typically resulting in more trees, because the influence of each individual tree is reduced. How many variables are included within each individual tree is controlled by the tree complexity. For example, a tree complexity of one allows only single variable trees, whereas a value of two would allow two-way interactions within individual trees. Lastly, introducing randomness by selecting a subset of the data at each step in the BRT increases computational running time and reduces overfitting (i.e., a model that fits a given dataset well, but is too complex to predict well to new datasets). This is accomplished through a bag fraction, which is the percentage of data drawn randomly for each step within the tree building. Combined, these three parameters determine the optimal number of trees and drive the overall predictive performance of the model (Elith et al. 2008).

Here, models were first parameterized (i.e., determined the best set of parameters) using a cross validation approach with the *gbm.step* function in *dismo* R package. This approach is designed to prevent overfitting. This process was conducted using two different learning rates (0.001 and 0.005), a range of tree complexities (1-4; interactions between parameters within individual trees) and bag fractions (60, 75 and 90%). These initial parameters were chosen through an initial screening process that led to meaningful results and differences among runs and also considered overall computing time. The final set of parameters were selected by comparing model performance for all combinations of each parameter. Model performance was assessed differently for redd presence and redd count models. Because the redd presence models considered a binary (0 or 1) response variable, a Bernoulli distribution (i.e., logistic regression) was utilized for the response variable and the models were assessed using the highest area under the curve (AUC) of the receiving operator characteristic (ROC)[2] for the cross validation. The AUC statistic measures the classification potential by considering the rate of true positives to false negatives for different thresholds and models with an AUC of > 0.7 are generally considered to be good classifiers and results in a higher ratio of true positives to false negatives (Hosmer and Lemeshow 2000). Model parameters that gave the highest AUC values for the cross validation were used in the model comparison and final models. The redd count models utilized a Poisson distribution and model performance was assessed using the mean absolute error (MAE) for the difference between observed and predicted redd counts. Parameters that led to the lowest MAE were chosen for the final model.

Once the optimal parameters were chosen for both the presence and count data, the models were further validated using a cross validation outside of the *gbm.step* function. In the validation procedure, the data were divided into equal subsets. Each subset of the data contained roughly the same proportion of total mesohabitat units surveyed per stream as the original dataset. In the five-fold cross validation, four of the folds were used as training datasets and the fifth was used as a test dataset and this was repeated for each of the five folds and repeated 10 times. Comparisons between model sets were made with boxplots of performance indices and averages over folds and replicates.

The boosted regression tree analysis was conducted using the *dismo* and *gbm* packages in R (R Core Development Team, 2020).

Model Derivation and Selection

Twelve variables were initially considered for inclusion into the boosted regression tree analysis: calcite concretion, calcite presence, conductivity, FHAP area, mean velocity, proportion of resident gravel, pH, temperature, functional large woody debris (LWD) tally, pebble size, bankfull depth, and bankfull width. Bankfull depth and width and FHAP area were all highly skewed and thus were $\log_{10}$ transformed. Further, because the proportion of resident gravel varied between 0 and 1, it was logit transformed. The variables to include in the final models were chosen through a model selection process with the overall goal of developing a final model that had the highest model performance with the lowest number of variables to aid in interpretation. To this end, the influence of individual variables were first measured by using an add variable procedure where individual variables were added sequentially to a null model, which only the contained *Year* and

[2] Receiver operating characteristic curve is a diagnostic plot of true positive rate to false positive rate that illustrates the ability of a binary model to distinguish between outcomes for different thresholds

Stream terms. Secondly, variables were dropped sequentially from a global model which included all model variables. Using the results of these model comparisons and alignment with variables uses in the GLMM, where possible, final model sets were compared using two sets of multivariate models (Tables 1 and 2). Final models were selected by comparing the model performance indices (highest AUC for redd presence models and lowest MAE for redd count models) for models with different sets of predictor variables.

Variable Influence and Effect

Breakdown Analysis

The boosted regression tree analysis allows for interactions among variables and between variables and stream. This provides an opportunity for the overall influence of variables to vary by stream and for the influence of predictor variables to depend on the values of other variables. The overall influence and effect of predictor variables was quantified using a breakdown analysis with the *flashlight* package in R (R Core Team 2020). This analysis quantifies the variable importance (i.e., how much influence each variable has on the presence or count prediction for that habitat unit) for each individual data point (i.e., mesohabitat unit) using approximate Shapley Additive Explanations (SHAPs; Lundberg et al. 2017; Gosiewska and Biecek 2019). The importance of each variable is measured by quantifying each variable's contribution to the change from the average prediction in the dataset to the prediction at the individual mesohabitat. Because the statistical design was to measure the influence of variables on presence or counts within a stream, the SHAPs were estimated by stream. For example, if the average stream level prediction is a mean count of 1.5 and the prediction at an individual habitat unit is a count of 1, the breakdown analysis will quantify the contribution of each variable to the difference between the average stream prediction and the prediction at the habitat unit (i.e., how much does each variable contribute to the difference of 0.5).

Variable Influence

The values at individual variables can influence the prediction in either a positive (increase in the counts or probability of presence) or negative (decrease in counts or probability of presence) direction. Measuring the absolute change for each variable can quantify its overall influence for that mesohabitat unit. Because the stream level predictions varied with stream, the contribution was calculated as an absolute change relative to the average stream contribution for each variable within each mesohabitat unit:

$$|\%\ Change\ in\ Predition| = \left|\frac{Change\ in\ Prediction}{Average\ Stream\ Prediction}\right| \times 100\ \%$$

Averaging this measure of influence over streams (or other relevant group) gives an overall estimate of the influence of each variable on the predictions within that group.

Variable Effect

To estimate the effect of variables on the prediction, the direction of the influence and the value of the variable for the individual mesohabitat unit needs to be considered. Thus, the overall relative change was also calculated:

$$\%\ Change\ in\ Predition = \frac{Change\ in\ Prediction}{Average\ Stream\ Prediction} \times 100\ \%$$

Comparing the percent change relative to the stream level predictions for individual variable values can establish the overall effect by highlighting the relationship between their values and the direction (positive or negative) and extant (% change) of the change in prediction for that mesohabitat unit. The overall trend of the relationship for streams and groups of streams was visualized using a local polynomial regression (LOESS), which is a non-parametric approach that fits locally weighted regressions to estimate a smooth curve through the relationship between two variables.

Results

Model Derivation and Selection

Redd Presence

The null model including only *Stream* and *Year* in the model had a high AUC value (mean AUC = 0.807 $\pm$ 0.037 SD; Figure 1) and was likely due to the high proportion of absences within the dataset and large differences in the overall level of presence among streams and years. The addition of single variables to the null model did not lead to large increases in AUC (Figure 1). The parameters with the greatest increases were mean velocity (0.814 $\pm$ 0.043 SD), bankfull width (0.817 $\pm$ 0.033 SD), and FHAP area (0.830 $\pm$ 0.042 SD; Figure 1).

The global model with all variables had a mean AUC much higher than the null model (mean AUC = 0.852 $\pm$ 0.037 SD; Figure 1). Removing calcite concretion (mean AUC = 0.853 $\pm$ 0.033 SD), temperature (mean AUC = 0.855 $\pm$ 0.029 SD), functional LWD tally (mean AUC = 0.855 $\pm$ 0.033 SD), and Bankfull depth (mean AUC = 0.855 $\pm$ 0.035 SD) led to slight increases in AUC, while removing all other variables led to drops in AUC (Figure 1). Removing mean velocity (mean AUC = 0.847 $\pm$ 0.035 SD) and FHAP area (mean AUC = 0.840 $\pm$ 0.032 SD) led to the greatest drops in AUC values.

Because of the higher correlation between calcite variables and conductivity, two sets of multivariate models were developed and compared (Table 2). The first set had a base model set of calcite concretion, calcite presence, FHAP area, mean velocity and proportion of resident gravel. All of these variables were integral to the overall objective of the study (calcite variables) and/or had demonstrated importance in the add/remove model comparison or GLMM models. The remaining variables (pH, temperature, functional LWD tally, pebble size, bankfull depth, bankfull width) were subsequently added to and removed from the base model. The second set of models was set up in the same way but included conductivity instead of the calcite variables (Table 2).

The top calcite and conductivity models had similar AUC values and were similar to the global model (Figure 2; top panel). The top calcite model (Mult12) included all variables with the exception of temperature and had a mean AUC of 0.853 ($\pm$0.030 SD). Preliminary comparisons of variable influence and effect suggested a lack of a clear patten in the relationship with temperature and pH. Thus, a second set of multivariate models that compared base models with and without these variables was developed (Table 2). There was very little variability in the top models in run two, but the models with the highest mean AUC were primarily calcite variable models (Mult2, Mult4, Mult9, and Mult20) all having mean AUC values above 0.85 (Figure 2; bottom panel). The calcite model with the least number of variables included (Mult9) was chosen as the top model and used to determine variable influence and effect. This top model had seven variables: calcite concretion and presence, FHAP area, mean velocity, proportion of resident gravel, mean velocity, functional LWD tally, and bankfull width.

Redd Counts

A similar approach to the process used for the redd presence model selection was used to find the most parsimonious redd count model. The null count model had a mean absolute error (MAE) of 0.36 ($\pm$0.02 SD) (Figure 3). Adding proportion of resident gravel (mean MAE = 0.33 $\pm$ 0.03 SD) and FHAP area (mean MAE = 0.34 $\pm$ 0.03 SD) led to the greatest drops in MAE. The addition of other variables had similar influences on MAE (Figure 3). Including all variables into the model led to a drop in MAE to around 0.31 $\pm$0.04 SD and removing proportion of resident gravel (mean MAE = 0.33 $\pm$ 0.04 SD) led to the highest increase in MAE (Figure 3). Mult9 in multivariate run two had an MAE (mean MAE = 0.30 $\pm$ 0.03 SD) lower than the global model and had one of the lowest overall mean MAEs (Figure 4). The relationship between predicted and observed counts from this model was near a 1:1 relationship for most streams, further suggesting a high predictive potential of redd counts for the top model (Figure 5 and Figure 6).

Variable Influence and Effect

Variable Influence

The absolute influence of individual variables ($|\%\ Change\ in\ Prediction|$) on redd presence varied by stream (Figure 7). Overall, the most influential variables were FHAP area (25 %) and mean velocity (16 %) when averaged across streams (Table 4). Calcite concretion had the lowest overall influence (1.7 %), but was more influential in streams with medium to high levels of levels of calcite concretion (Figure 7, Table 4). Calcite concretion had the highest relative influence in Corbin Creek (8.6 %), Harmer Creek (5.5 %), Upper (3.4 %) and Lower (3.2 %) Greenhills Creek, EVO Dry Creek (3.2 %) and LCO Dry Creek (2.5%; Table 3). Not surprisingly, calcite concretion had the lowest influence in reference streams and streams with very low values of calcite concretion overall (Table 4). Calcite presence had an average influence of 10 % and generally had a higher influence in streams with low to medium levels of calcite concretion. The exception was Corbin Creek where calcite presence had a high influence (26 %; Table 4).

Similar to presence, the absolute influence of individual variables on redd counts varied by stream (Figure 8). For most streams, the most influential variables were FHAP area (47 %), bankfull width (35%), and mean velocity (25%; Table 5). Calcite concretion had a very low overall influence (0.047%) and no influence for the majority of streams (Figure 8, Table 5).

A number of streams had no or very low (maximum concretion <=0.1) levels of concretion (10 of 20 streams; Table 1). This included two streams (Lizard Creek and Michel Creek) with much higher redd presence and counts than the rest of the streams. Thus, reducing residual variation for these streams where concretion could not have had a high influence could lead to an under estimation for its importance in streams with medium to high levels of concretion. To address this, the top model was re-parameterized using only streams with medium and high levels of calcite concretion, only mine exposed streams, and only reference streams. For the medium and high calcite stream model and mine-exposed stream model there was an improvement in the model fit (reduction in MAE) for these streams. For the reference stream model the performance decreased (mean MAE increased) for reference streams. Thus, the influence estimates for the counts of medium and high concretion streams was recalculated using the reduced model. In the medium and high concretion streams, this increased the influence of concretion to an average of a 12% change relative to the stream level predictions (Table 6). The largest change for the other variables was a decrease in the influence of bankfull width from 25 % to 12 % influence. Because of the improvement in model fit, the direction of the variable influence for medium-high concretion streams and exposed streams, was estimated using the reduced models.

\Variable Effect

Because the relative influence of calcite concretion varied by stream and was higher in streams with higher concretion, the effects for all variables were presented for streams broken down by levels of concretion (see Table 1 for breakdown of streams). Within streams with a high level of concretion, there was a negative influence of concretion with the probability of redd presence. Specifically, there was a decrease from a high of 5.92 % positive influence to a low of -3.96 % negative influence (~10 % drop). The decrease began for concretion values greater than 0.5 (Figure 9). Directional plots also pointed to the importance of a number of other variables. Mesohabitats with a mean velocity between 0.1 and 0.7 m/s and bankfull widths between 3.98 and 12.59 m had higher probabilities of redd presence (Figure 9). Proportion of resident spawning gravel, FHAP area, calcite presence and counts of large woody debris all had positive associations with redd presence. This suggested higher probabilities of redds with increasing values for all these variables. Within the medium and low concretion streams there was also a slight negative relationship with calcite concretion, but there was a lack of consistent data above a concretion score of 0 and < 0.5 in medium concretion streams making it difficult to draw any conclusions (Figures 10 and 11). The relationships with other variables was similar to the high concretion streams (Figures 10 and 11).

For comparison with the GLMM models the breakdown analysis was also summarized by reference (Figure 12), mine-exposed streams (Figure 13) and all streams combined (Figure 14). The general patterns for most parameters remained the same in all comparisons. When using the loess smoothing on the full dataset for calcite concretion the overall prediction drop decreased slightly from a high of 4.52% to a low of -3.62% and an overall drop of 8.15 %.

Redd count models that included all streams and reference streams displayed similar patterns to the redd presence models for most variables. There was an apparent non-linear relationship with mean velocity and bankfull width, with higher predicted redd counts within the range of 0.1 and 0.7 m/s for mean velocity and a bankfull width between 3.98 and 12.59 m. This pattern was consistent across all calcite concretion groupings (Figures 15 to 18). Further, there were positive associations with proportion of resident spawning gravel, FHAP area, calcite presence and counts of large woody debris, which was consistent across levels of concretion and similar to the redd presence models. Using the full model with all streams, calcite concretion had almost zero influence on redd count predictions for streams with low, medium and high levels of calcite concretion and reference streams alone (Figures 15 to 18).

The models that were refit with only the medium and high concretion streams, and only mine-exposed streams both showed negative relationships with calcite concretion that were similar the relationship observed with the redd presence (Figures 19 to 21). The decrease for high and medium calcite streams was more extreme than with redd presence, and in the high concretion streams there was a decrease from a high positive influence of 19 % to low influence of -19 % (~38% drop), for concretion values greater than 0.7 (Figure 19). In the medium concretion streams there was a more gradual 7 % decrease from no concretion to a value of 0.3, but there was limited data within this range. Although the shape of the relationship using the mine-exposed stream model was similar to the high concretion streams, the overall drop was much less from a high of 0.79 % to a low of -0.10%. This is likely due to presence of many mine-exposed streams with low levels of calcite concretion.

Discussion

Overall, the boosted regression tree (BRT) analyses led to highly predictive models for spawning habitat across the Elk Valley and suggested strong relationships between redd presence and counts with calcite and several other covariates. The primary objective of this report was to examine the relationship between calcite and spawning habitat suitability for westslope cutthroat trout. Similar to the GLMM analysis, the BRT models found a positive association between calcite presence with redd presence and counts. The influence of calcite presence varied by stream, but there was no clear association between the level of calcite within a stream and its influence, as streams with both medium-to-high calcite (e.g, Corbin Creek, Harmer Creek) and low calcite (e.g., Lizard Creek, Thompson Creek) had strong associations between redds and calcite presence. Although the influence of this relationship varied, the positive direction was consistent (i.e., higher presence = higher probability of presence and counts) when it was present. Although it is likely that presence is correlated with other predictor variables not considered here, these results suggest that any negative association between spawning and calcite will be driven by calcite concretion and that associations with calcite index only should be considered with caution. Any negative influence of concretion at low levels (<0.75) could be masked by this positive association when the concretion and presence scores are summed together.

The BRT models suggested that the influence of calcite concretion on redd presence and counts varied widely by stream. In high calcite streams there was a consistent negative relationship with concretion and a clear drop in probability of redd presence and redd counts above concretion values of 0.5 to 0.7 depending on the stream. Averaged across the habitat units of high concretion streams the breakdown analysis found approximately a 10 % increase in the probability of a redd being present for units with concretion values below 0.5. Although the overall influence compared to other predictors was lower, there also appeared to be a drop in probability of presence in some medium concretion streams with lower levels of calcite. For example, in Harmer, Michel and LCO Dry Creeks there appeared to be an increase in the probability of a redd presence for units with concretion lower than 0.1 than for units equal to and above 0.1. However, overall there were only

8 units (6 of those in Harmer creek) that had concretion above 0.1 and no units with values between 0.05 and 0.1. More data within this range (0.05 – 0.5) for medium concretion streams will likely help better establish the relationship with concretion in streams with moderate levels of calcite.

The redd count models were run with all streams included and also with only the medium and high calcite streams included. When all streams were included in the model, the breakdown analysis suggested very little influence of calcite concretion. However, a few of the low-calcite streams (e.g., lizard Creek, Michel Creek, Fish Pond Creek) had much higher redd counts and due to low levels of calcite concretion within these streams it could not be a strong predictor of counts and thus reduced the influence of concretion for all other streams. When using the model with just medium and high concretion streams the MAE was lower for these streams, suggesting a better model fit and the influence of calcite was greater. The breakdown analysis for the redd count BRT models with only medium and high concretion streams exhibited similar patterns to the redd presence models with a clear drop in predicted redd counts within a similar range (0.5 to 0.7). The overall decrease in redd counts, however, was higher and there was a 38% decrease in predicted redd counts in units with concretion above 0.5 to 0.7.

In addition to calcite several other predictors had strong relationships with redds. Apart from habitat area, the relationship with mean velocity was the strongest observed pattern for both counts and presence. In both cases there was a clear non-linear relationship that suggested a positive influence on predicted presence and counts within the range of 0.1 to 0.7 m/s. This range matched with other studies on closely related species that found a high percentage of redds at locations with mean velocities within very similar ranges (Thurow and King 1994 - 0.25 to 0.6 m/s). In addition to mean velocity, several other covariates had consistent relationships with redd presence and counts with some support for their importance in driving abundance and spawning habitat in similar species and other regions. There was a non-linear relationship with bankfull width and redd presence and counts were higher with values that ranged between 3.98 and 12.59 m and a positive association with large woody debris (LWD). Rosenfeld et al. (2000) similarly found positive associations with both channel bankfull width and LWD with juvenile cutthroat trout densities in British Columbia with the former being one of the strongest predictors.

The BRT model set up here included stream as a predictor variable and in most cases stream had a much higher influence than all other variables. Setting up the models with stream as a predictor variable was done to focus the results on discerning the relationships between the predictors and redds within streams. Thus, the results can be viewed as how the predictors influence the choice of a spawning location for an individual within a stream and not why the individual choose to spawn in one stream versus another. Redd presence and counts varied widely by stream and the influence of calcite and other predictors on these differences is not accounted for in the current model set up. To better understand the influence of these predictors on differences in redd presence and counts among stream this term would need to be removed and other stream level variables would likely need to be included. For example, at the landscape scale, stream morphology and landcover characteristics have been shown to correlate with differences in redd densities among tributaries (Baxter and Hauer 2000; Steel et al. 2004). A next step is to exclude stream from the model to determine the variables driving the stream-level differences in presence and counts.

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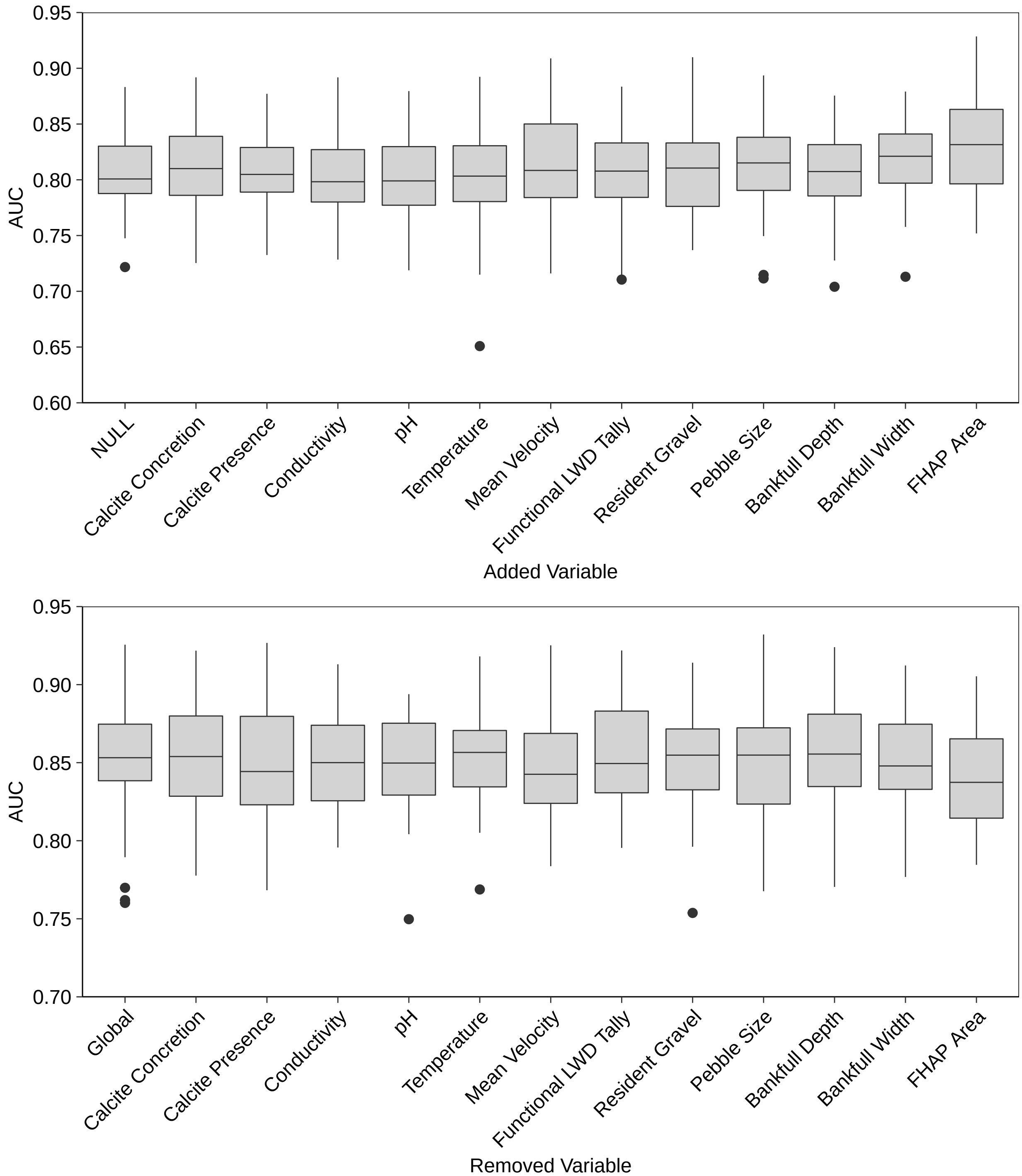


Figure 1: Westslope Cutthroat Trout Redd Presence Model Set Comparison for Boosted Regression Tree Models with Variables Added to a Null Model (Top) or Removed from a Global Model (Bottom) for Streams in the Elk Valley, 2018 to 2020

Notes: AUC = Area under the curve of a receiver operating characteristic curve measured using ten replicates of a five−fold cross validation. Higher AUC values represent greater predictive potential. Null model contained only stream and year and the global model contained stream, year and all twelve habitat variables.

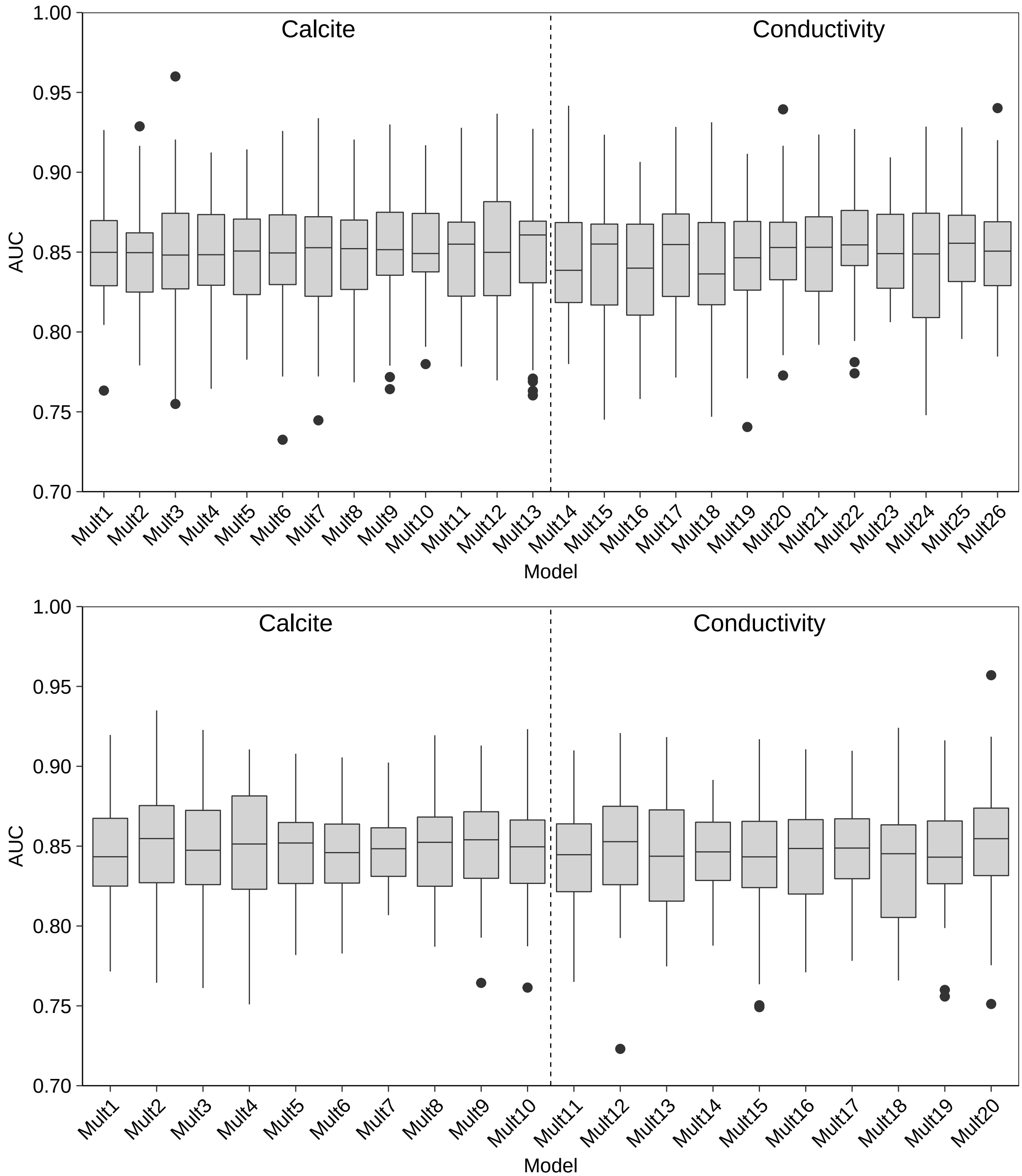


Figure 2: Westslope Cutthroat Trout Redd Presence Multi−Model Set Comparison for Boosted Regression Tree Models with Base Models Containing Calcite (Concretion and Presence) or Conductivity for Streams in the Elk Valley, 2018 to 2020

Notes: AUC − Area under the curve of a receiver operating characteristics curve measured using 10 replicates of a five−fold cross validation. Top model sets contain base models with calcite variables (or conductivity), FHAP area, mean velocity, and proportion of resident gravel area with different combinations of pH, temperature, functional LWD tally, pebble size, bankfull width and bankfull depth added to the model. Bottom model sets have pH and temperature added to, and removed from the base models with different combinations of the remaining parameters added to the models. See Table 1 and Table 2 for a full list of model sets.

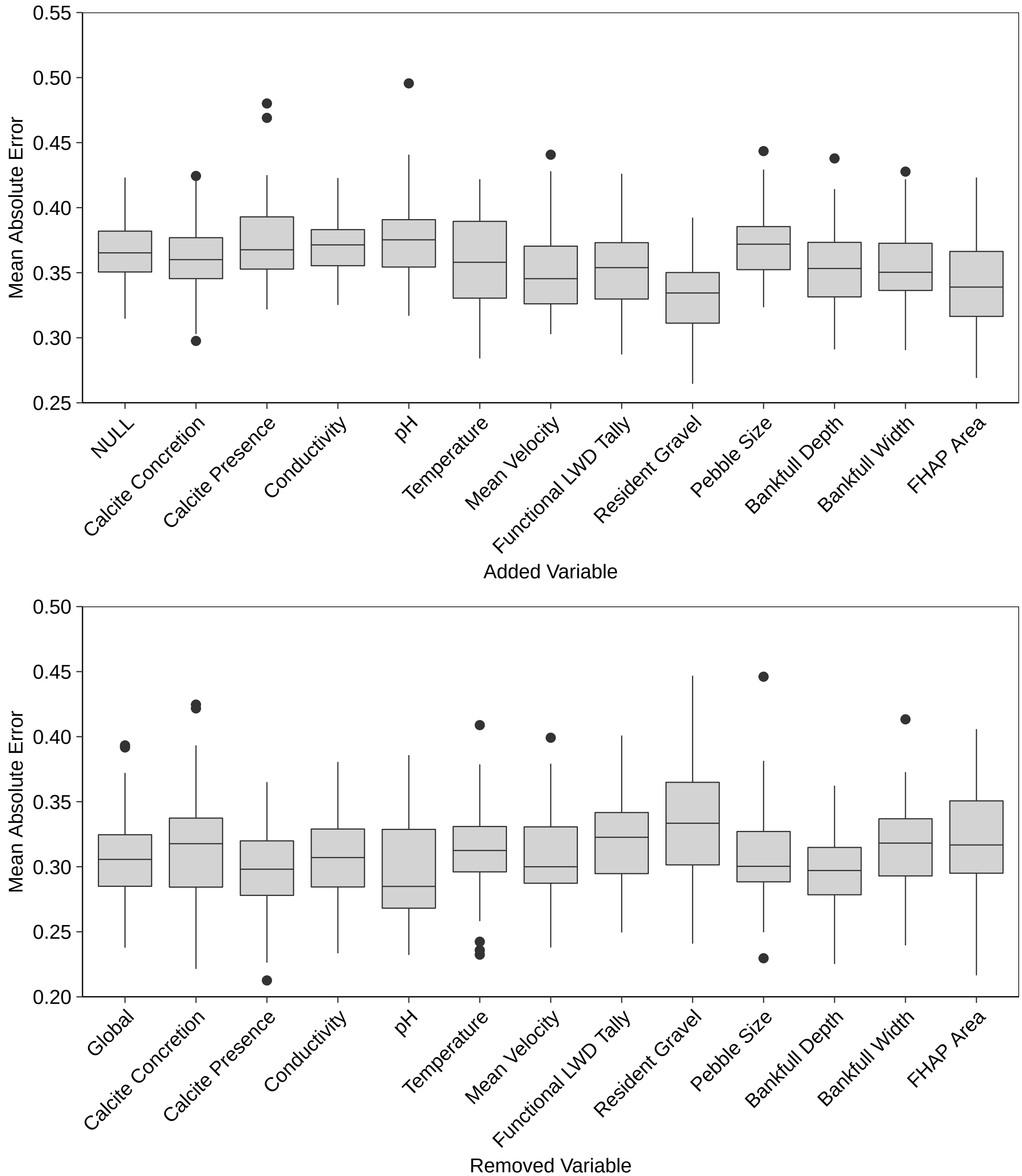
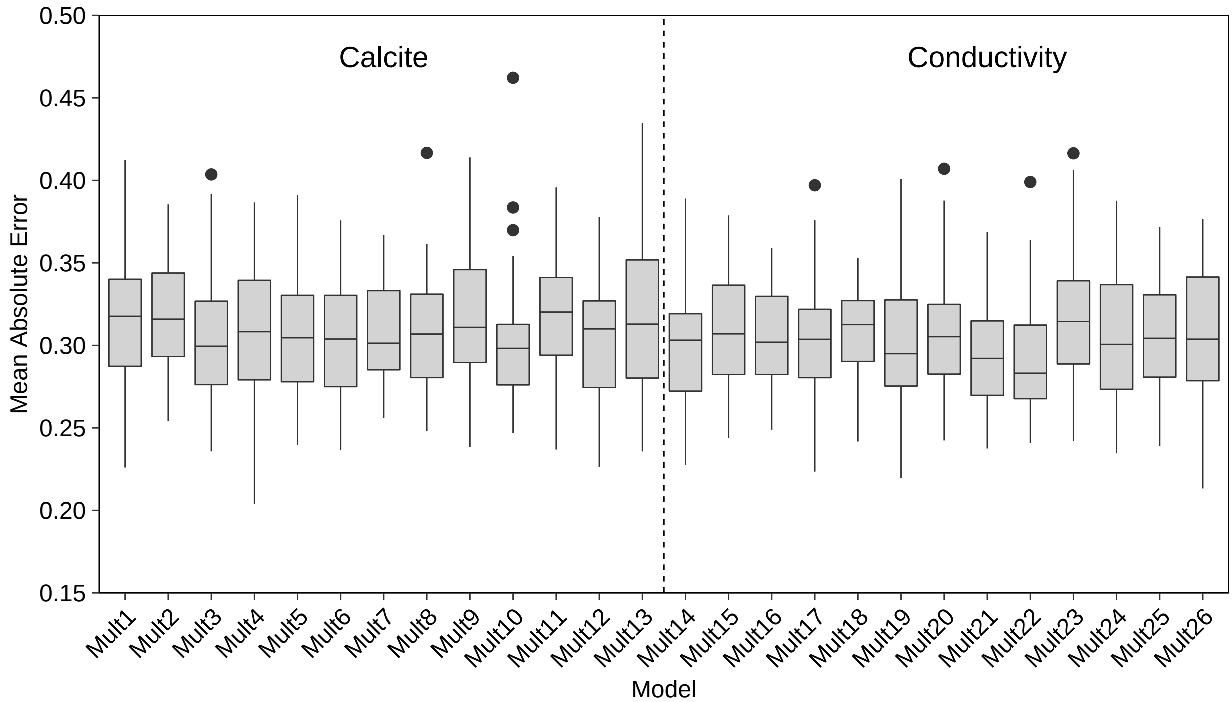


Figure 3: Westslope Cutthroat Trout Redd Count Model Set Comparison for Boosted Regression Tree Models with Variables Added to a Null Model (Top) or Removed from a Global Model (Bottom) for Streams in the Elk Valley, 2018 to 2020

Notes: Mean Absolute Error (MAE) measured using ten replicates of a five−fold cross validation. Lower MAE represent greater predictive potential. Null model contained only stream and year and the global model contained stream, year and all twelve habitat variables.



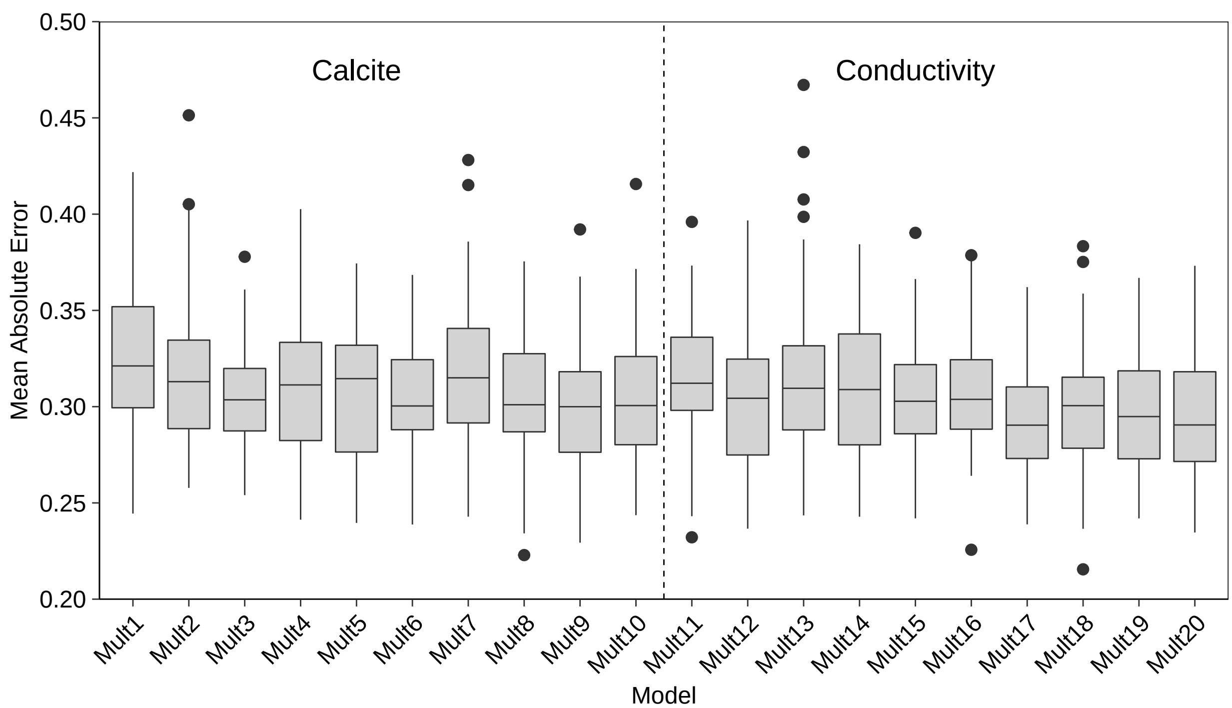


Figure 4: Westslope Cutthroat Trout Redd Count Multi−Model Set Comparison for Boosted Regression Tree Models with Base Models Containing Calcite (Concretion and Presence) or Conductivity for Streams in the Elk Valley, 2018 to 2020

Notes: Mean absolute error (MAE) measured using ten replicates of a five−fold cross validation. Top model sets contain base models with calcite variables (or conductivity), FHAP area, mean velocity, and proportion of resident gravel area with different combinations of pH, temperature, functional LWD tally, pebble size, bankfull width and bankfull depth added to the model. Bottom model sets have pH and temperature added to, and removed from the base models with different combinations of the remaining parameters added to the models. See Table 1 and Table 2 for a full list of model sets.

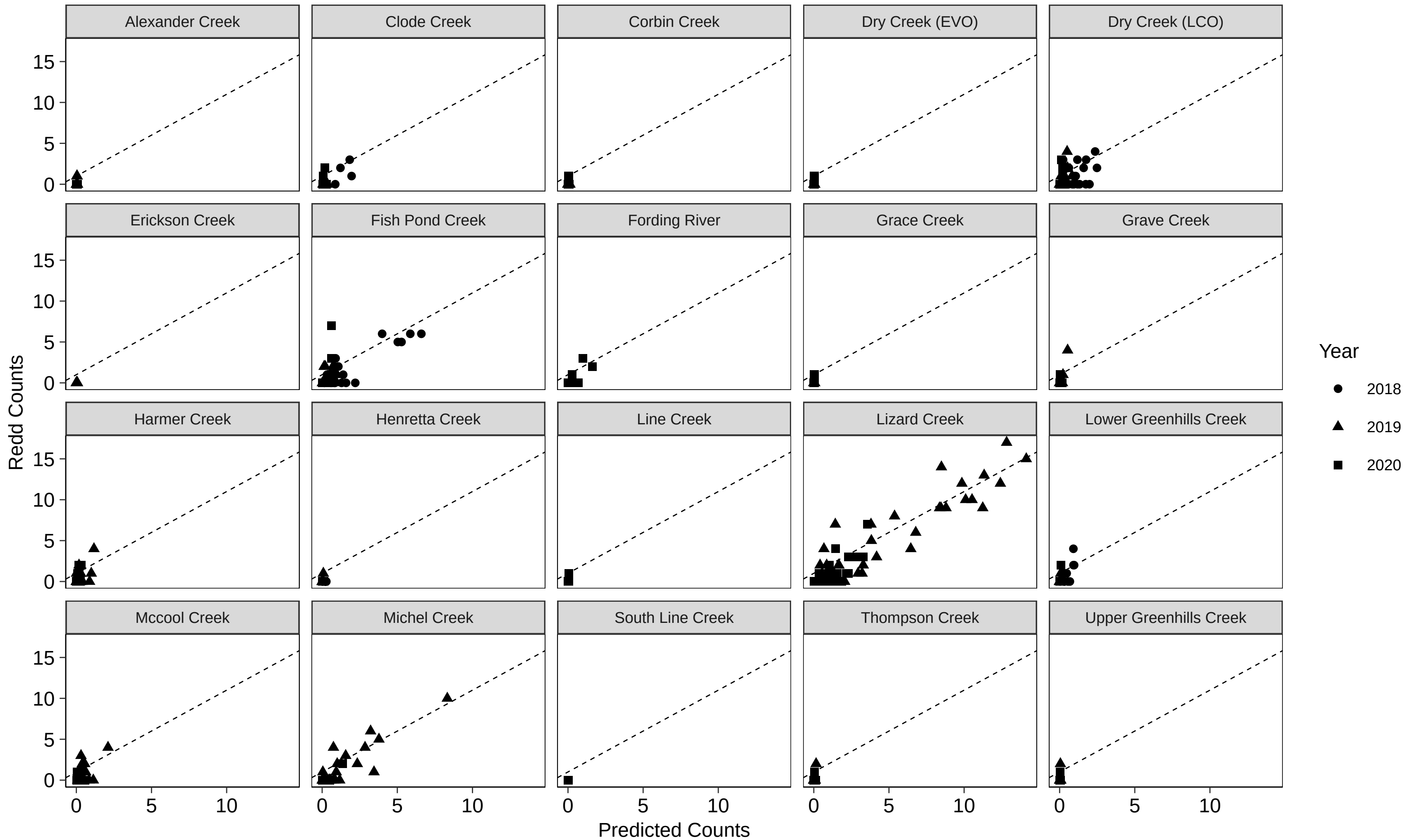


Figure 5: Predicted Redd Counts Versus Actual Redd Counts by Stream for the Top Selected Westslope Cutthroat Trout Boosted Regression Tree Redd Count Model Including Streams in the Elk Valley, 2018 to 2020

Notes: Top model contains nine parameters: Calcite concretion and presence, FHAP area, mean velocity, proportion of resident gravel area, functional LWD talley, pH and tempearature. Hatched line represents a 1:1 relationship.

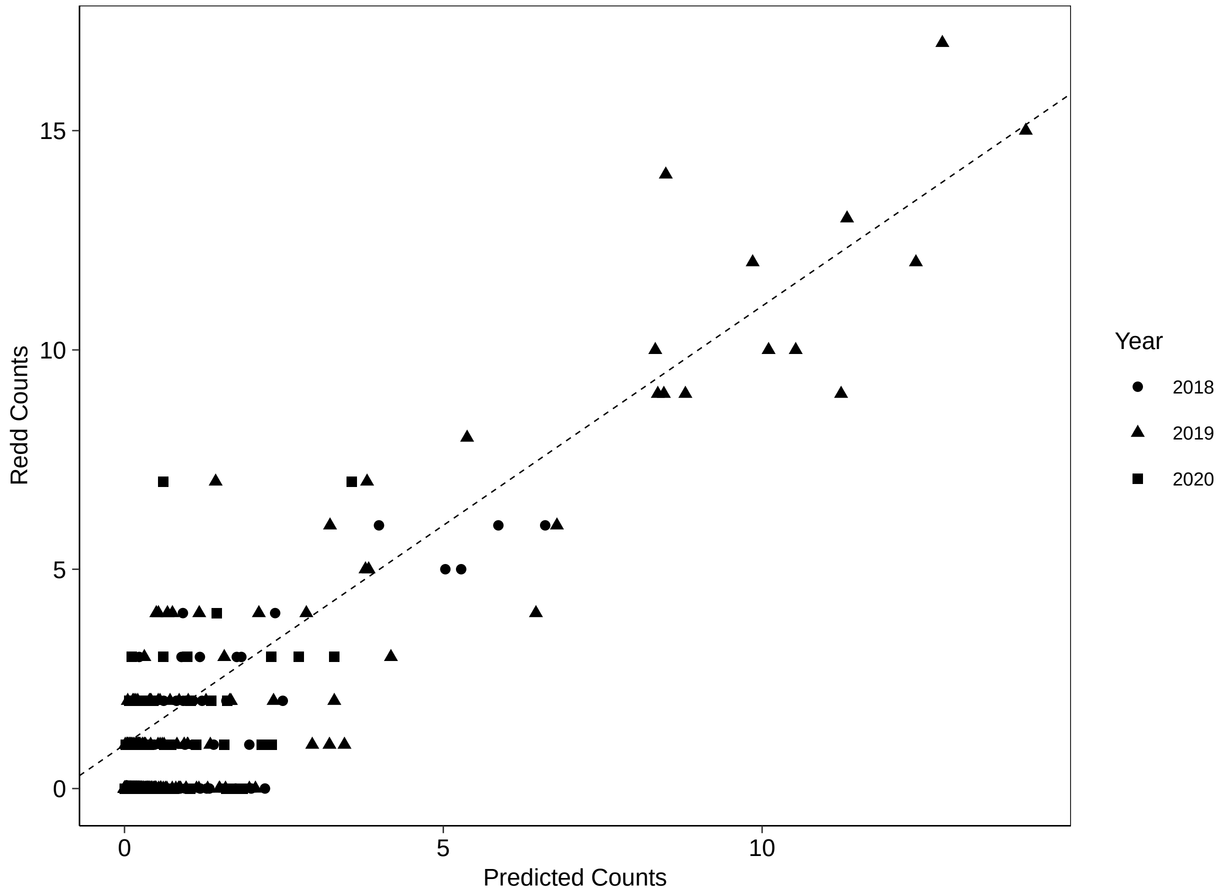


Figure 6: Predicted Redd Counts Versus Actual Redd Counts by Stream for the Top Selected Westslope Cutthroat Trout Boosted Regression Tree Redd Count Model Including Streams in the Elk Valley, 2018 to 2020

Notes: Top model contains nine parameters: Calcite concretion and presence, FHAP area, mean velocity, proportion of resident gravel area, functional LWD talley, pH and tempearature. Hatched line represents a 1:1 relationship.

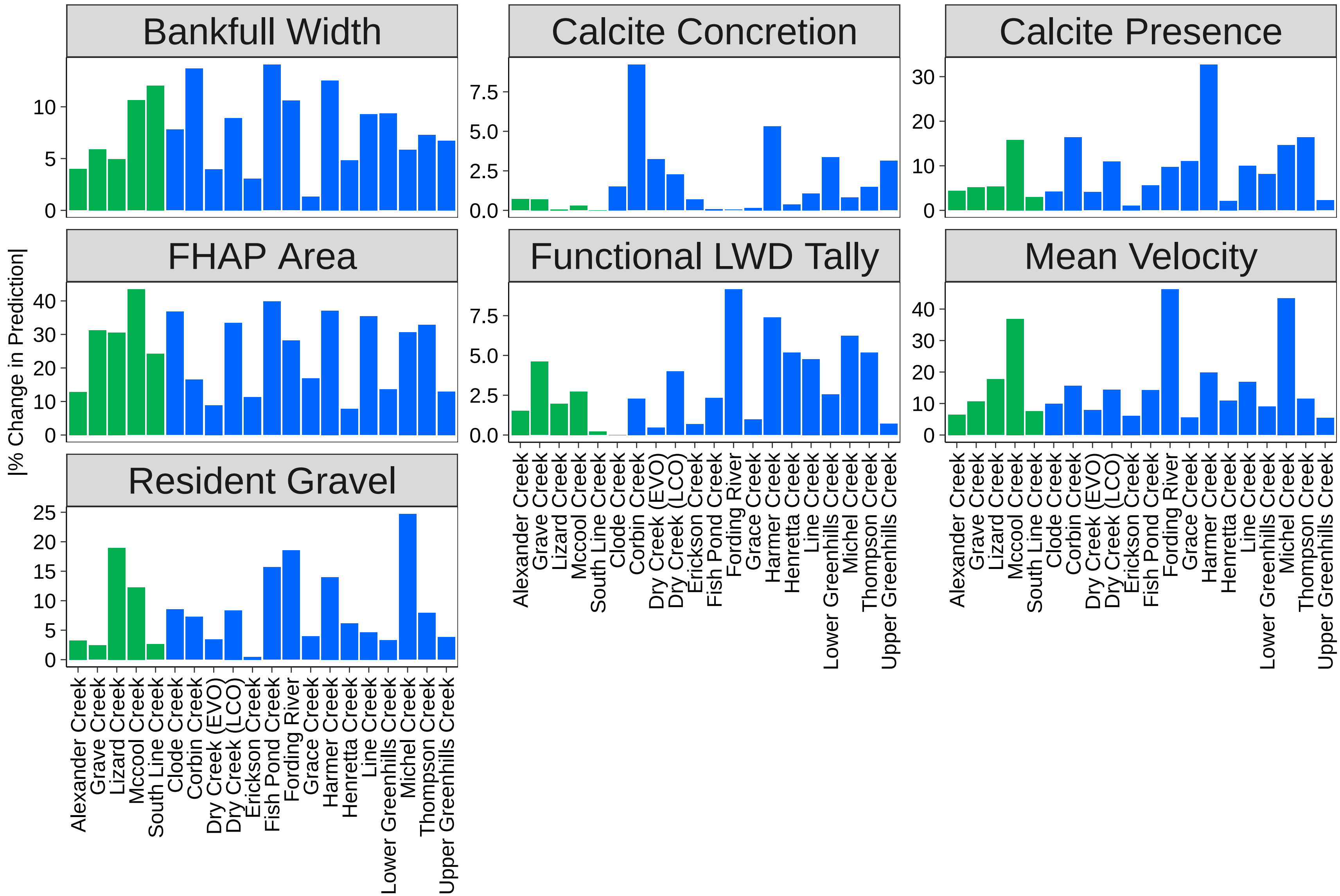


Figure 7: Absolute Relative Change for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Presence in Elk Valley Streams, 2018 to 2020

Notes: Relative change calculated from breakdown analysis measuring the influence of parameters on stream−level prediction for each mesohabitat unit. Reference streams in green and mine−exposed in blue.

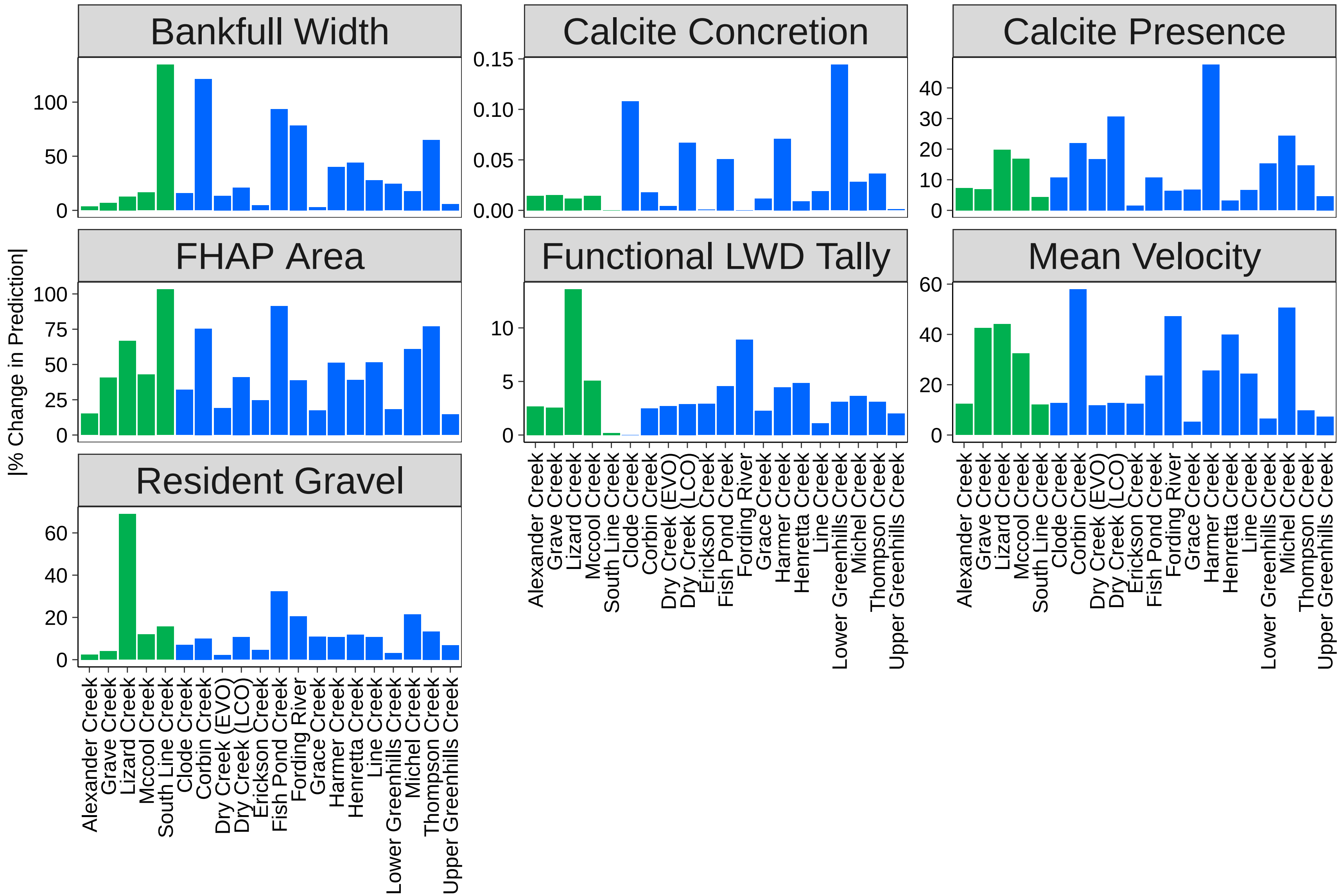


Figure 8: **Absolute Relative Change for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Counts in Elk Valley Streams, 2018 to 2020**

Notes: Relative change calculated from breakdown analysis measuring the influence of parameters on stream−level prediction for each mesohabitat unit. Reference streams in green and mine−exposed in blue.

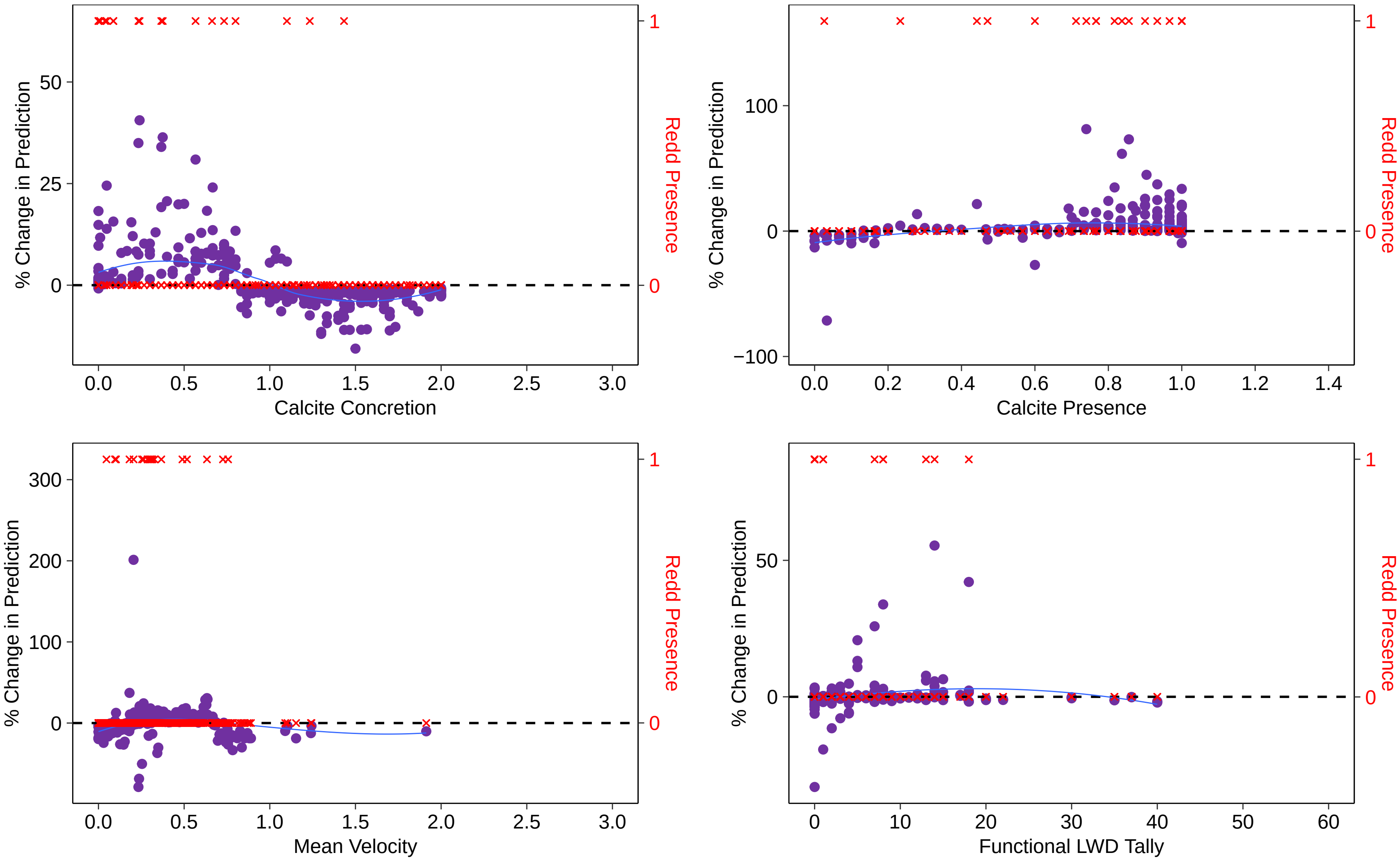


Figure 9: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Presence for High Calcite Elk Valley Streams, 2018 to 2020

Notes: Red X denote redd presence (1) or absence (0). Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

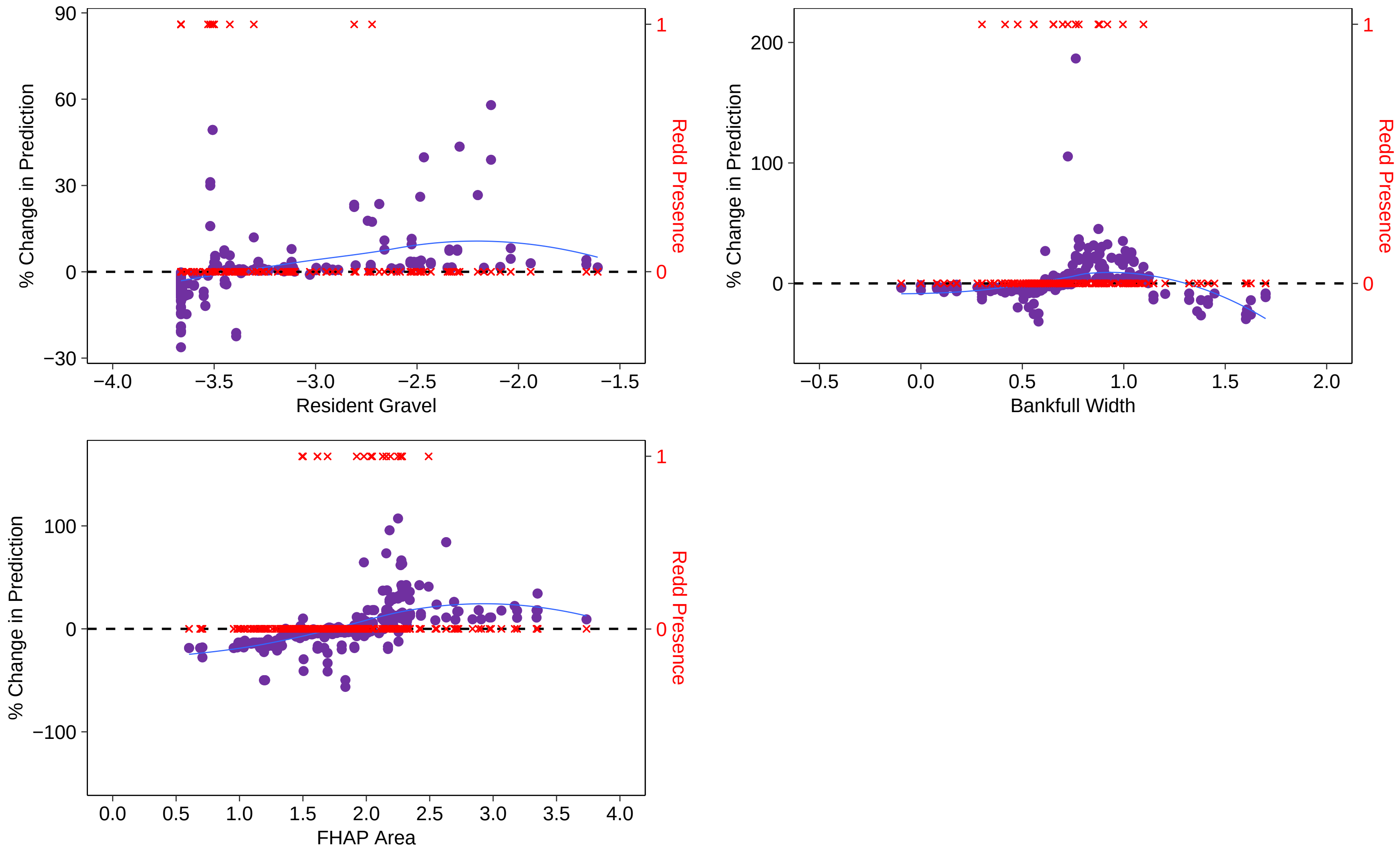


Figure 9: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Presence for High Calcite Elk Valley Streams, 2018 to 2020

Notes: Red X denote redd presence (1) or absence (0). Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

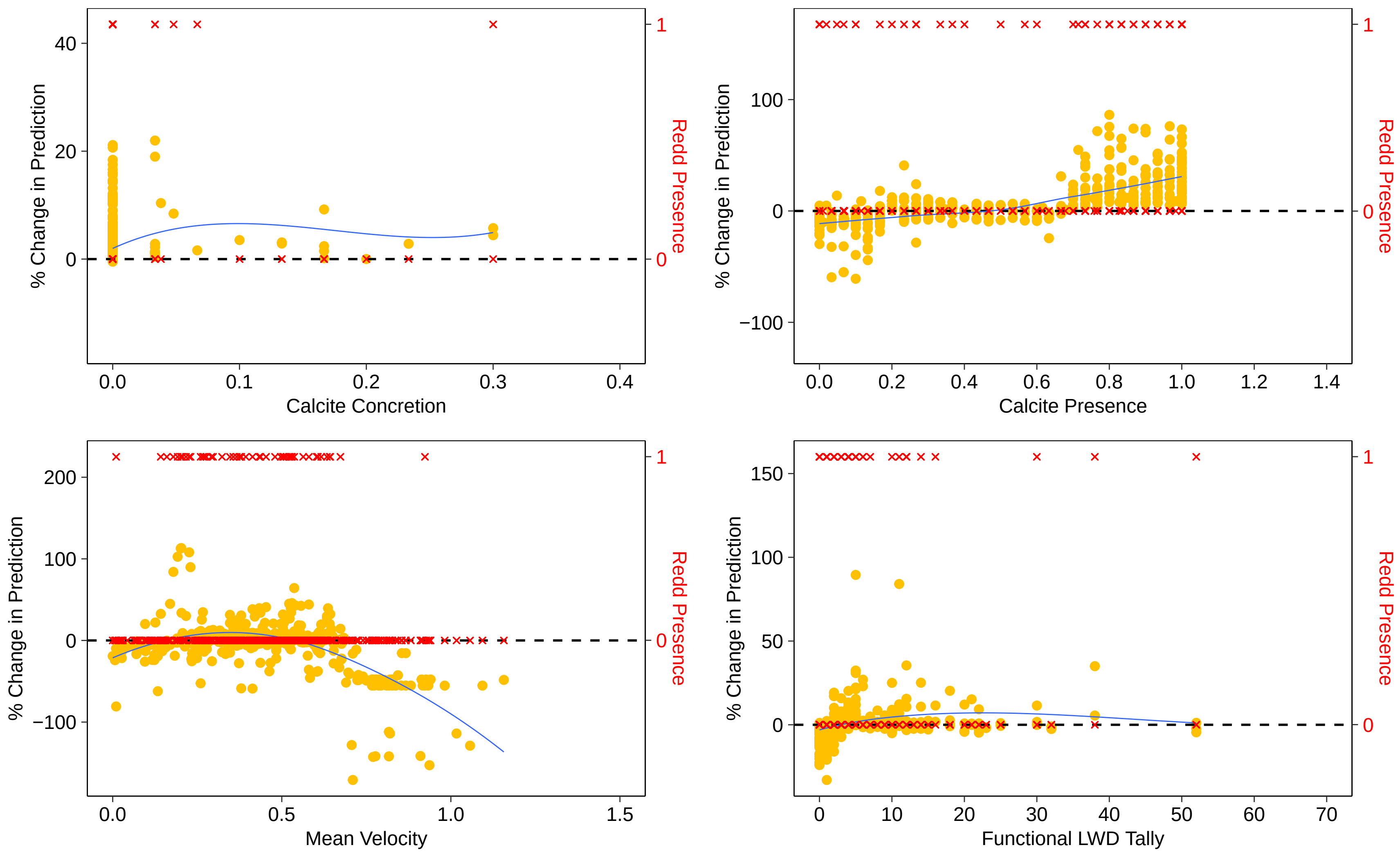


Figure 10: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Presence for Medium Calcite Elk Valley Streams, 2018 to 2020

Notes: Red X denote redd presence (1) or absence (0). Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

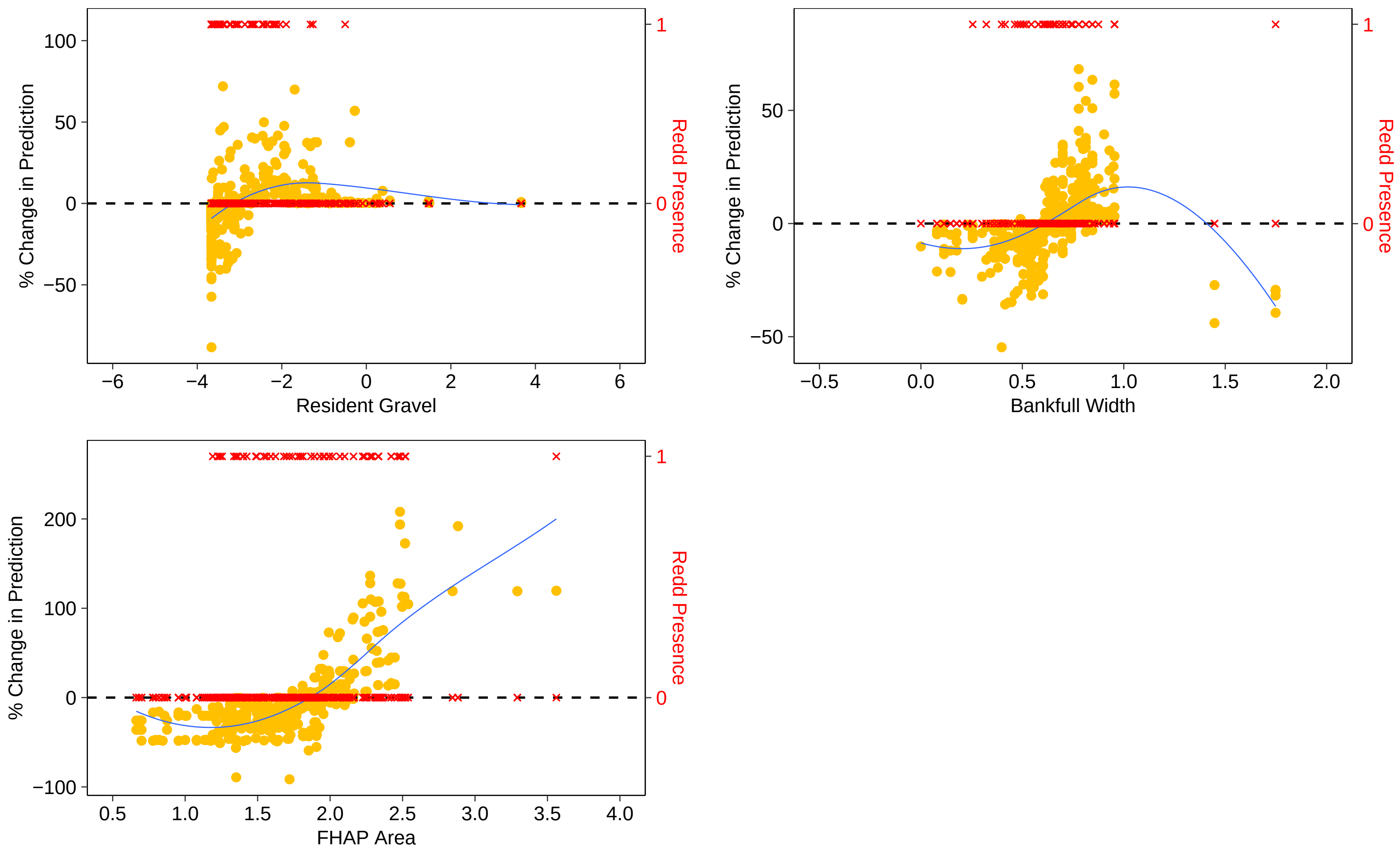


Figure 10: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Presence for Medium Calcite Elk Valley Streams, 2018 to 2020

Notes: Red X denote redd presence (1) or absence (0). Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

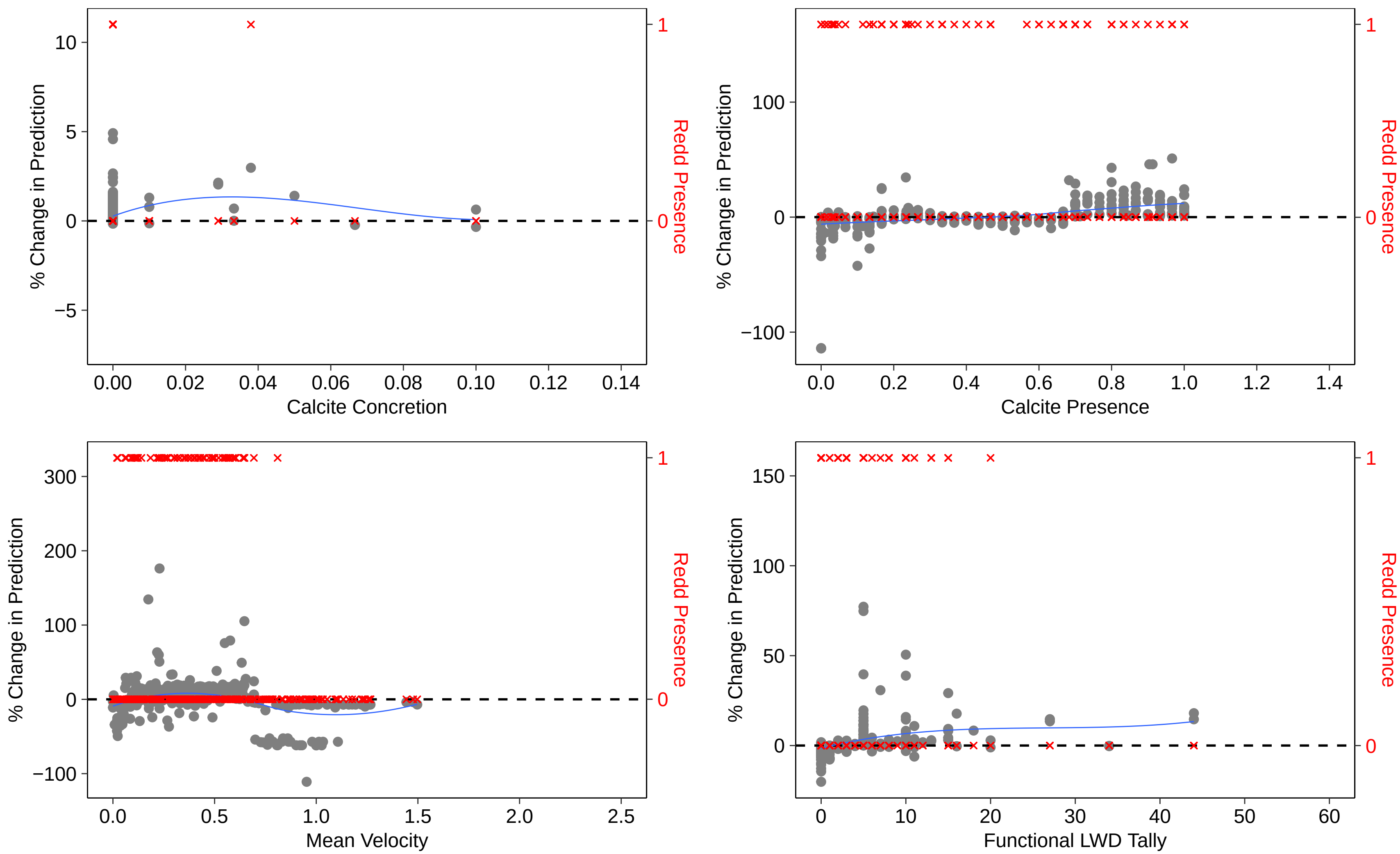


Figure 11: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Presence for Low Calcite Elk Valley Streams, 2018 to 2020

Notes: Red X denote redd presence (1) or absence (0). Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

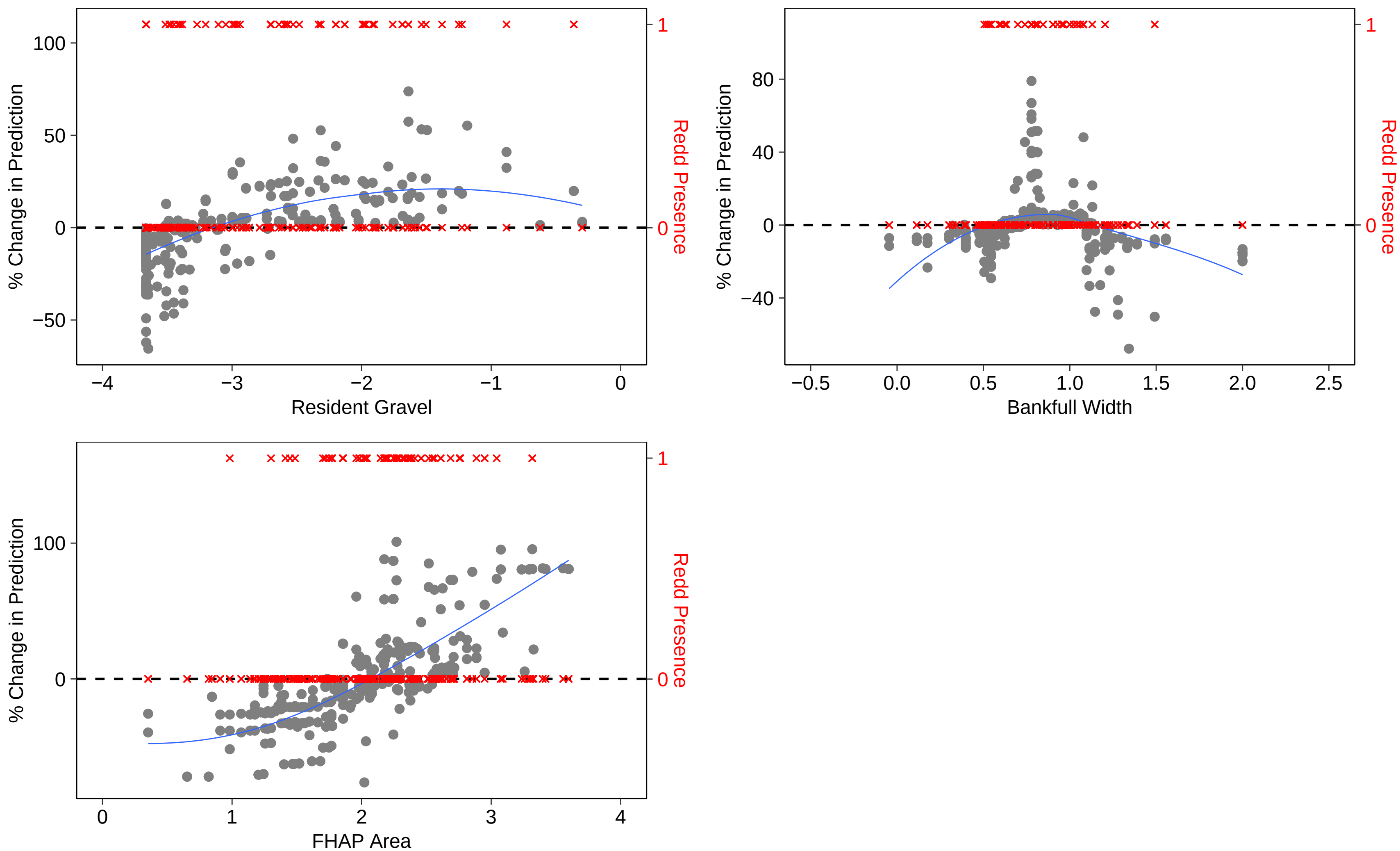


Figure 11: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Presence for Low Calcite Elk Valley Streams, 2018 to 2020

Notes: Red X denote redd presence (1) or absence (0). Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

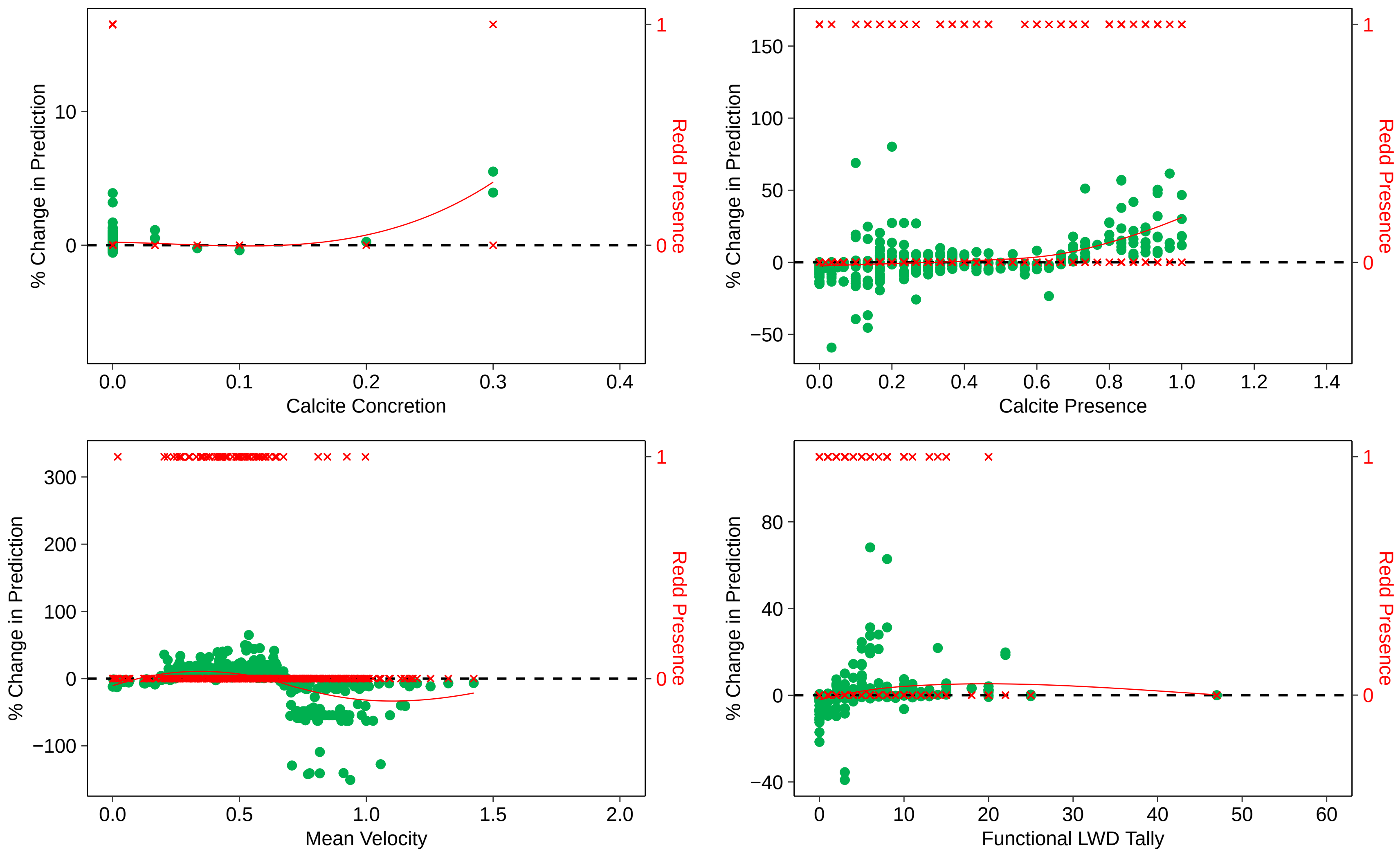


Figure 12: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Presence for Reference Streams in the Elk Valley, 2018 to 2020

Notes: Redd presence (1) or absence (0) presented with a red X on a secondary axis. Trend line (red) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

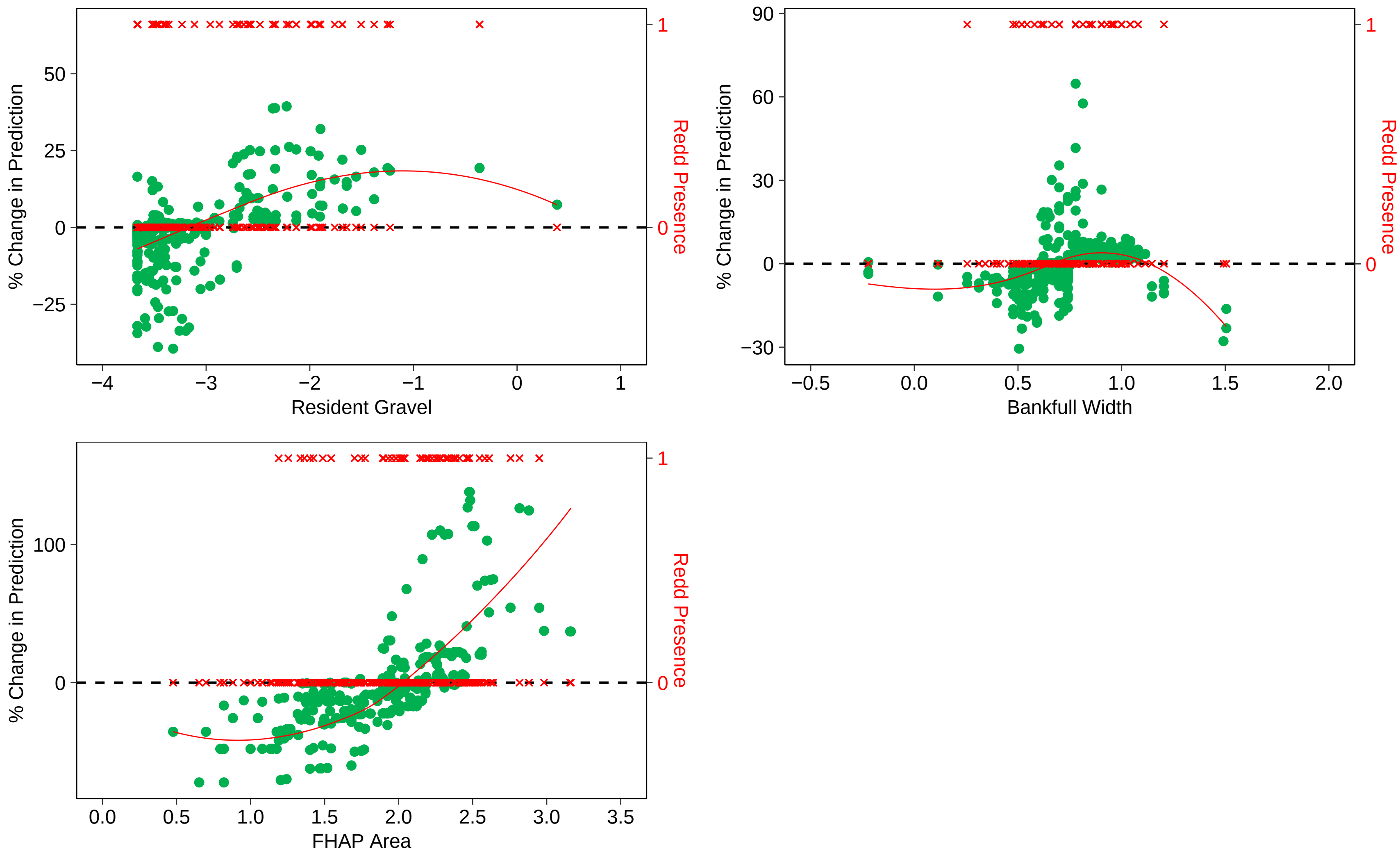


Figure 12: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Presence for Reference Streams in the Elk Valley, 2018 to 2020

Notes: Redd presence (1) or absence (0) presented with a red X on a secondary axis. Trend line (red) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

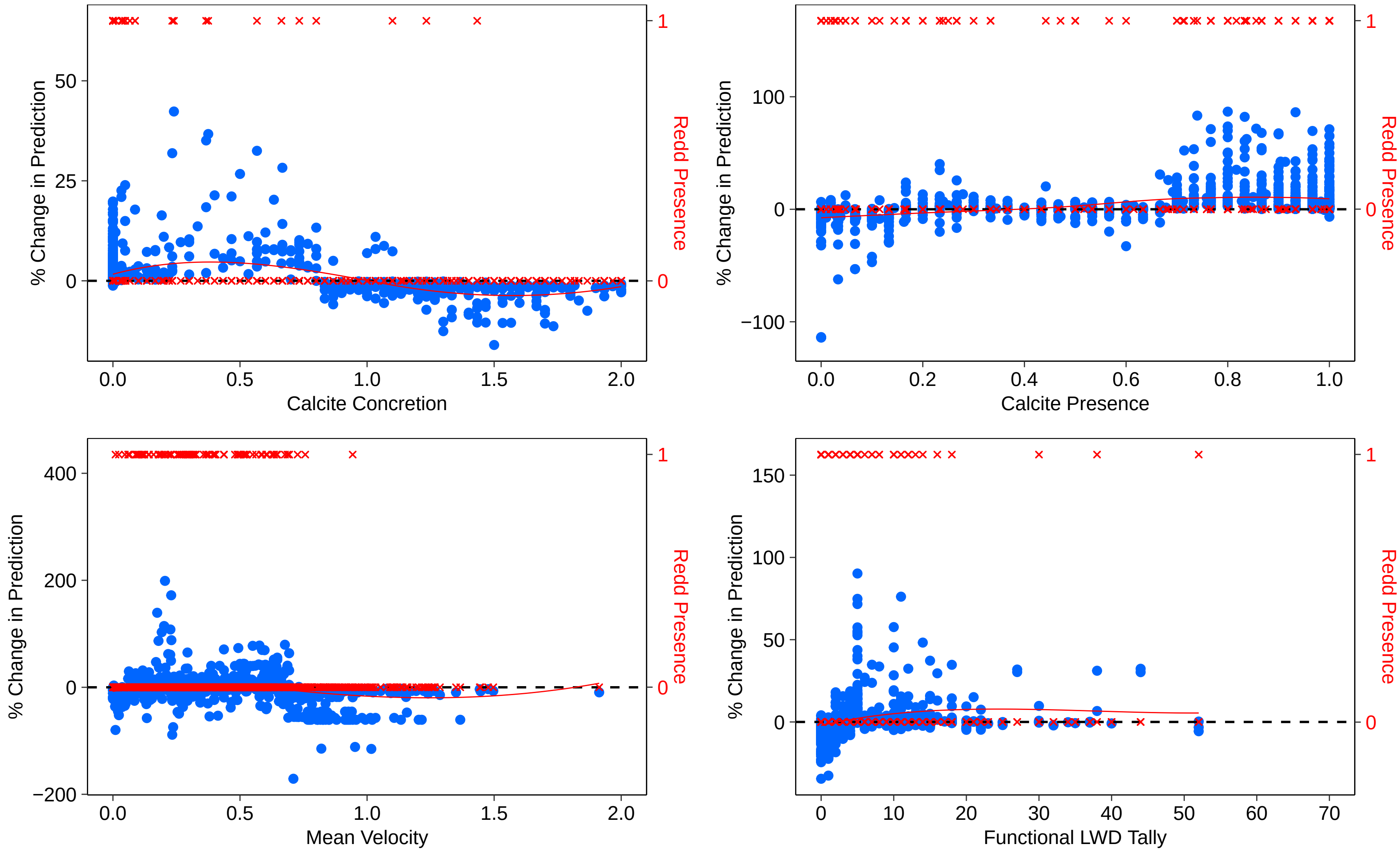


Figure 13: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Presence for Mine−exposed Elk Valley Streams, 2018 to 2020

Notes: Redd presence (1) or absence (0) presented with a red X on a secondary axis. Trend line (red) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

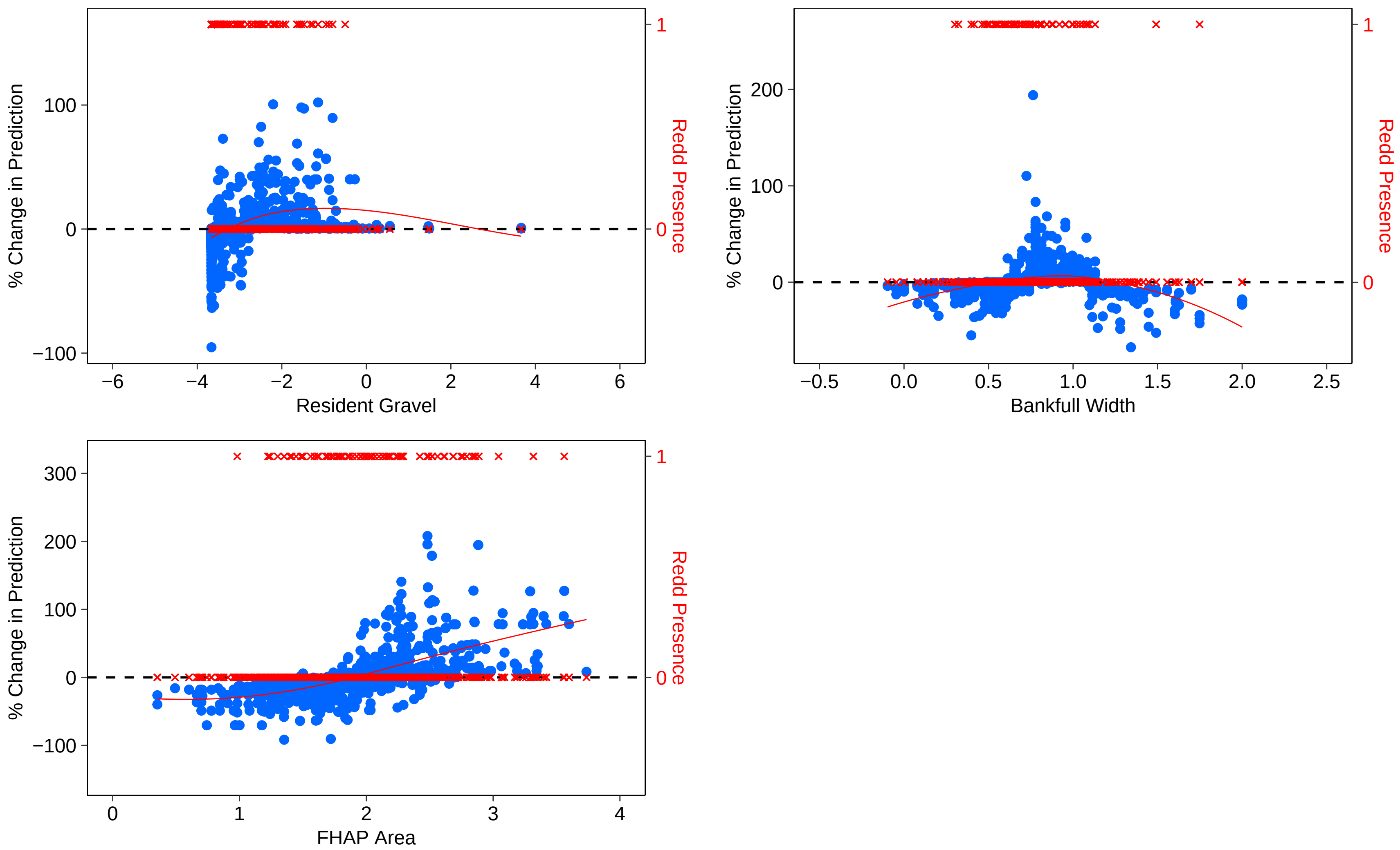


Figure 13: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Presence for Mine−exposed Elk Valley Streams, 2018 to 2020

Notes: Redd presence (1) or absence (0) presented with a red X on a secondary axis. Trend line (red) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

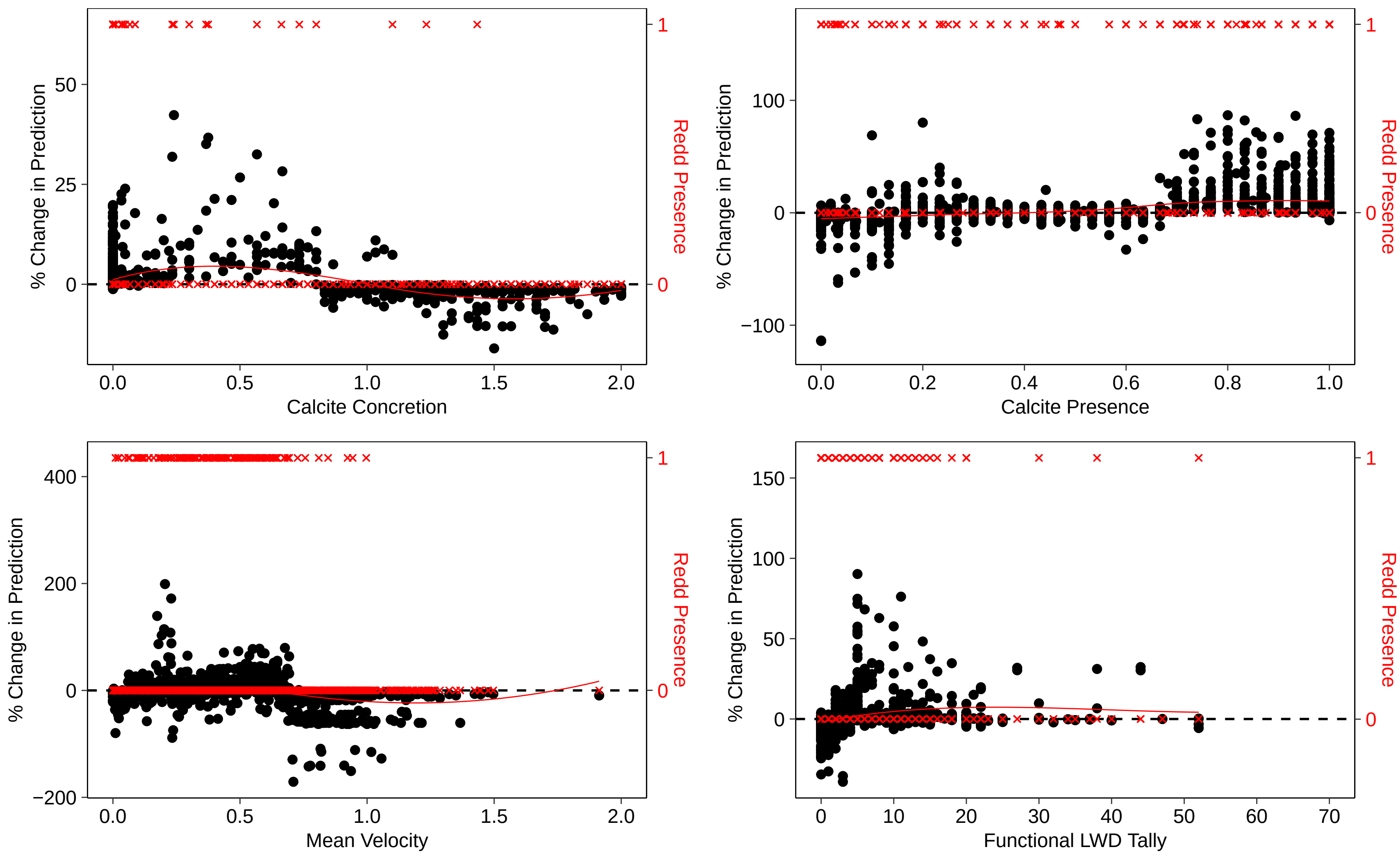


Figure 14: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Presence for Elk Valley Streams, 2018 to 2020

Notes: Redd presence (1) or absence (0) presented with a red X on a secondary axis. Trend line (red) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

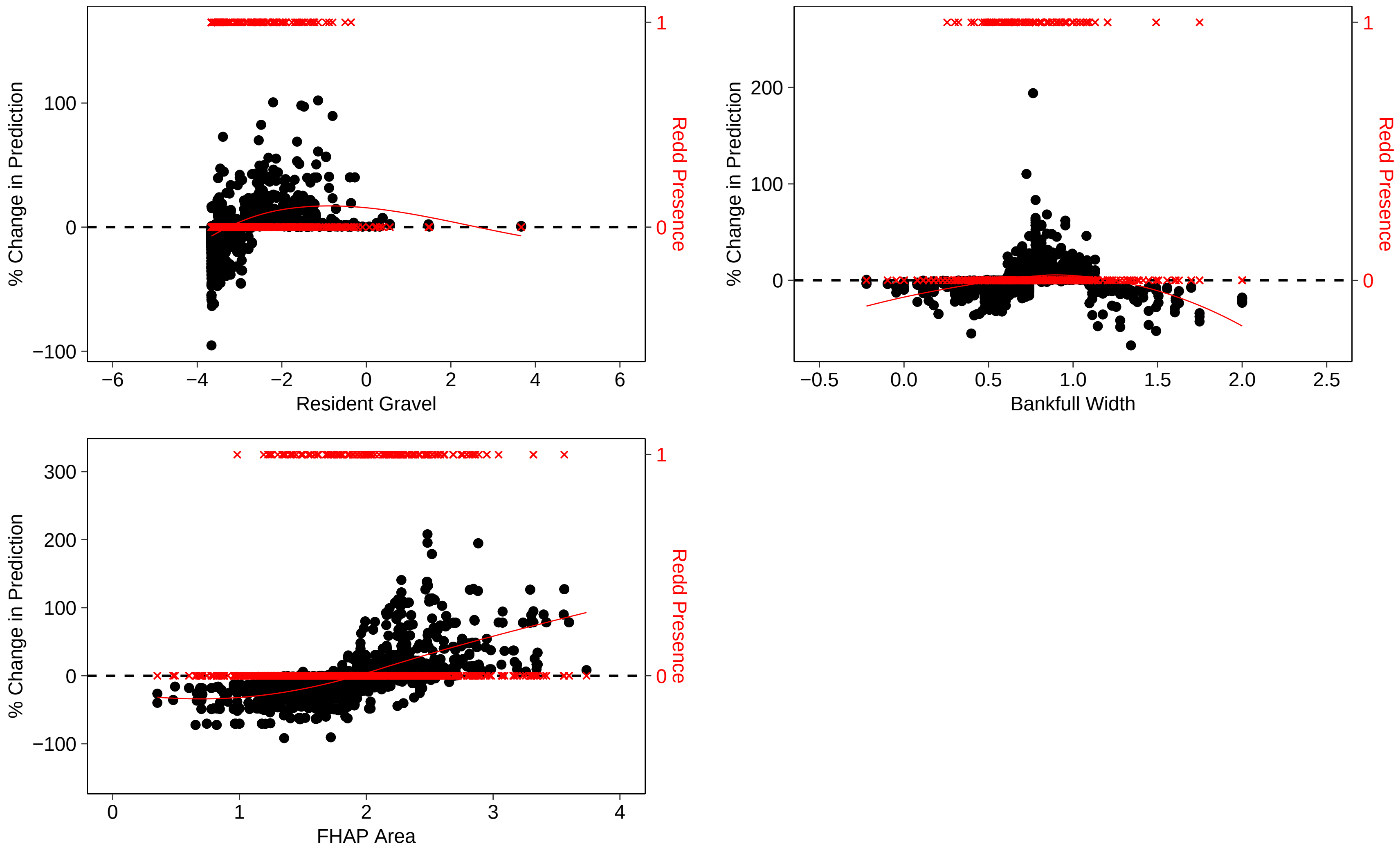


Figure 14: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Presence for Elk Valley Streams, 2018 to 2020

Notes: Redd presence (1) or absence (0) presented with a red X on a secondary axis. Trend line (red) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

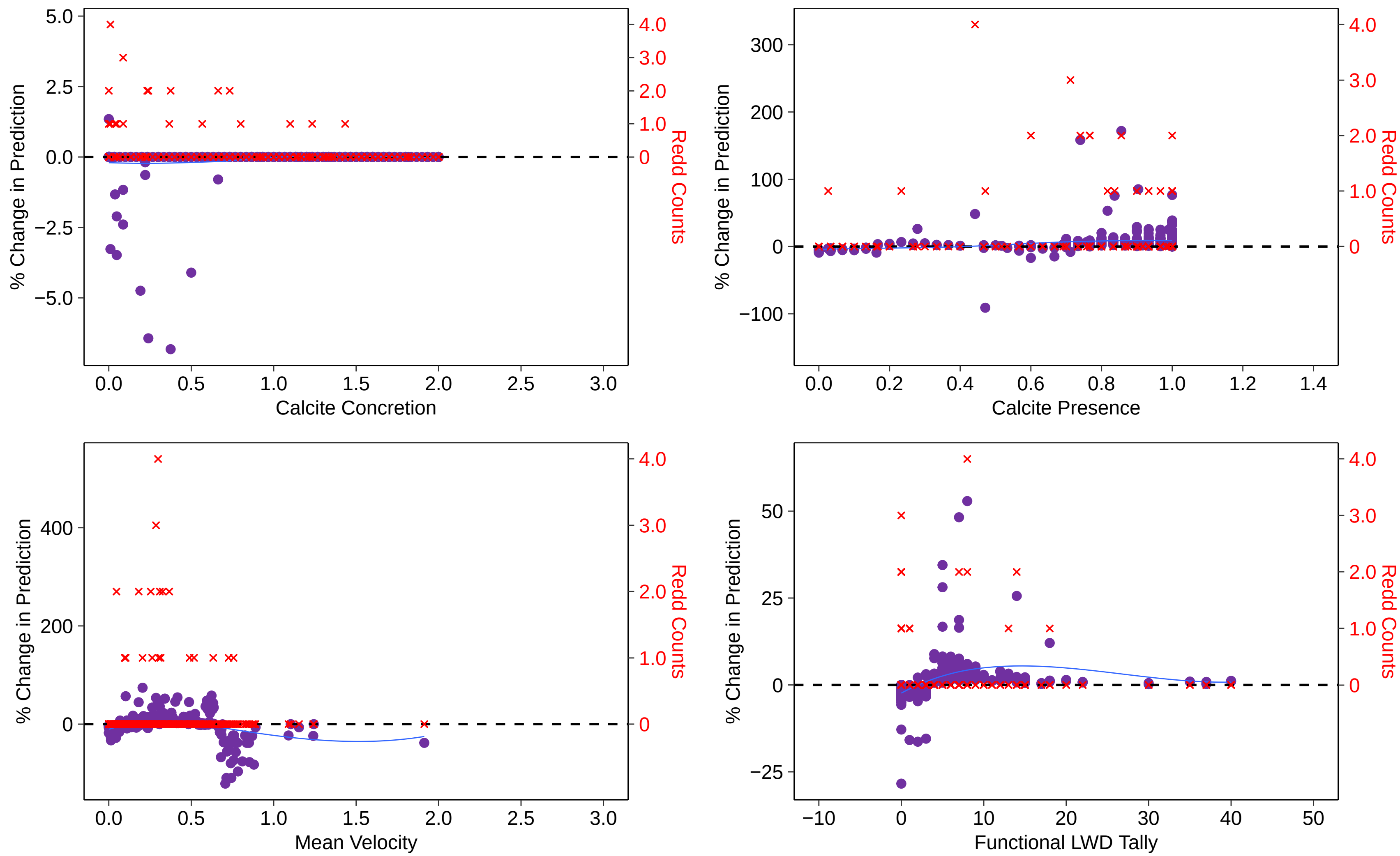


Figure 15: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Counts for High Calcite Elk Valley Streams, 2018 to 2020

Notes: Redd counts presented with a red X on a secondary axis. Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

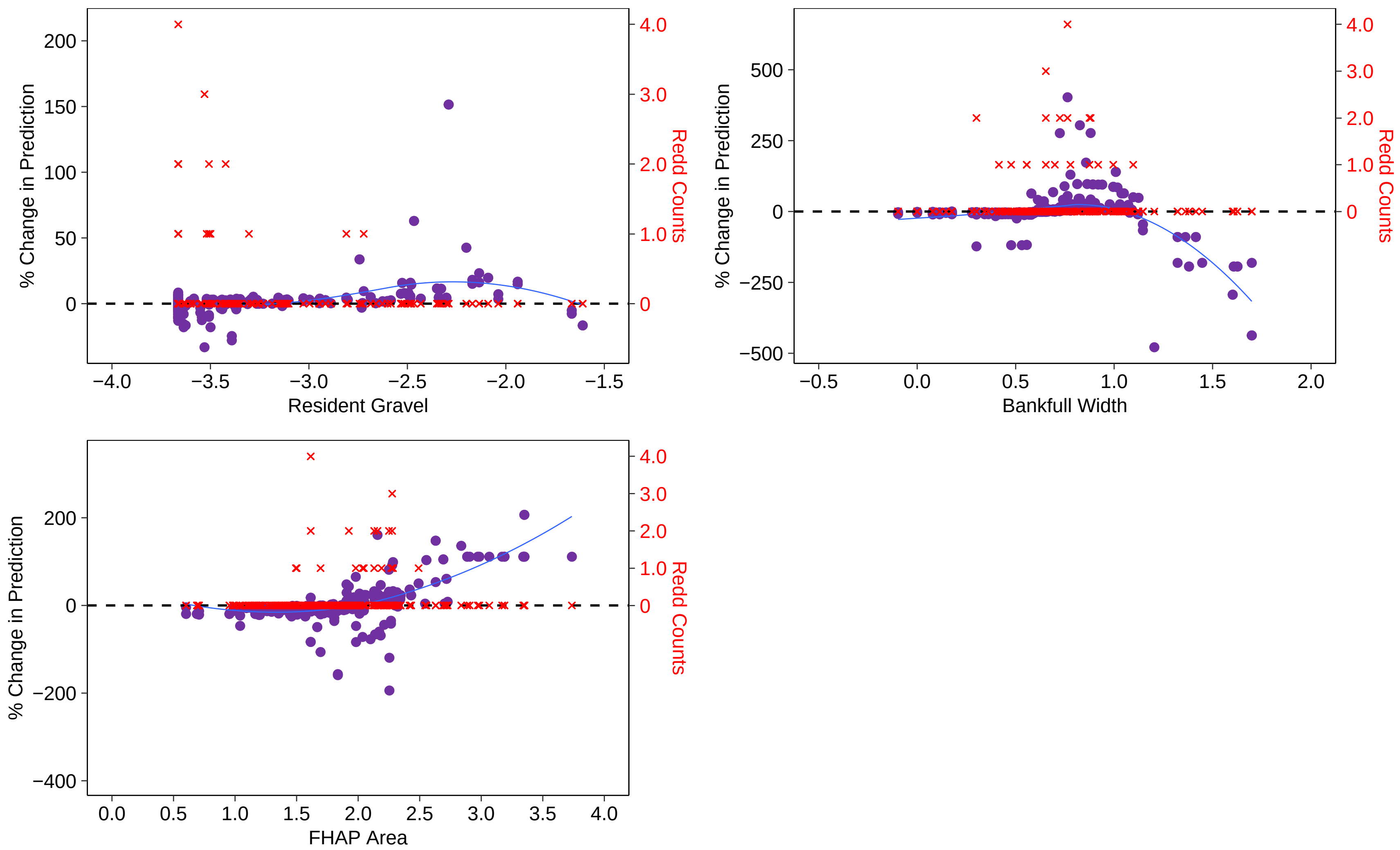


Figure 15: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Counts for High Calcite Elk Valley Streams, 2018 to 2020

Notes: Redd counts presented with a red X on a secondary axis. Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

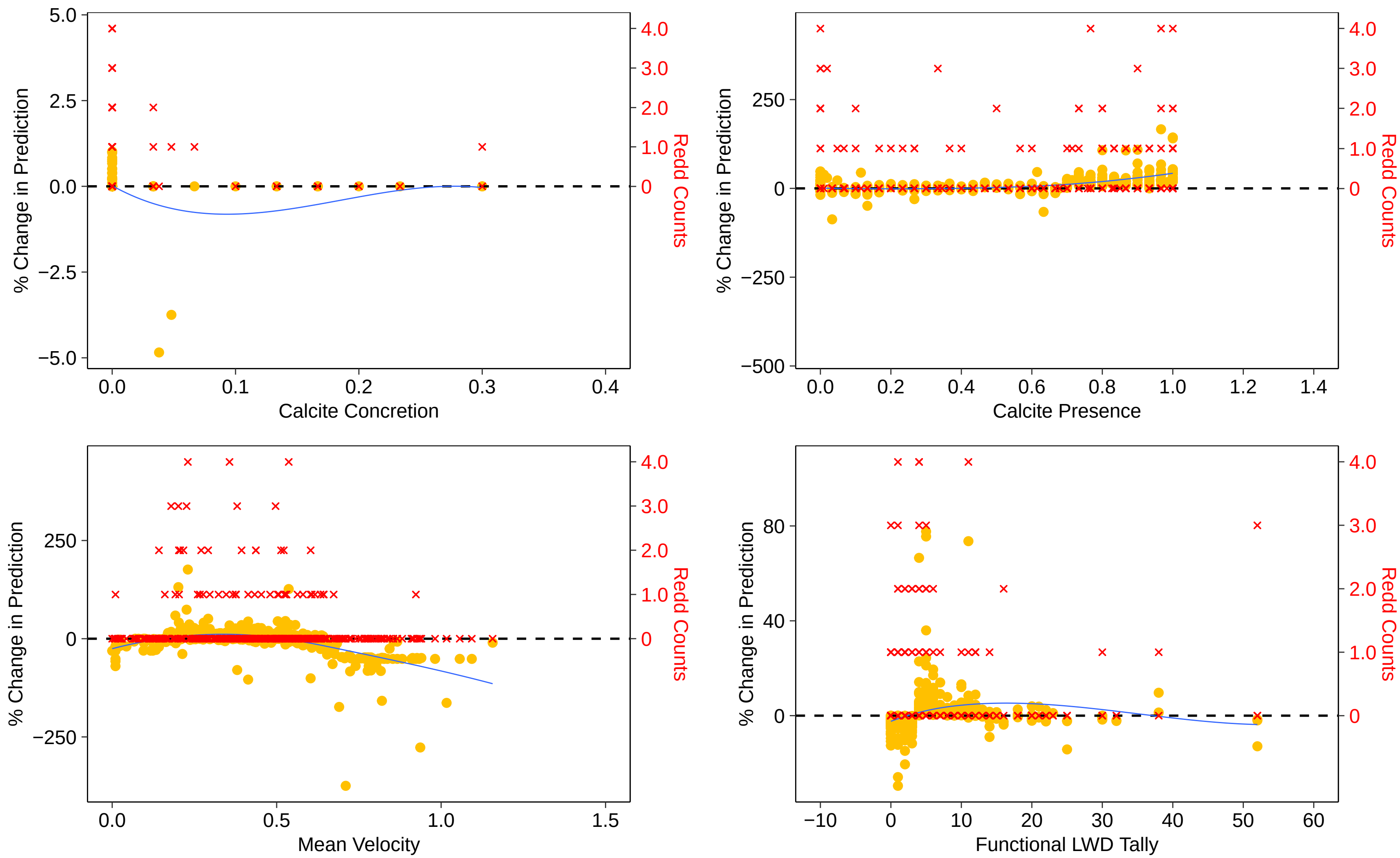


Figure 16: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Counts for Medium Calcite Elk Valley Streams, 2018 to 2020

Notes: Redd counts presented with a red X on a secondary axis. Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

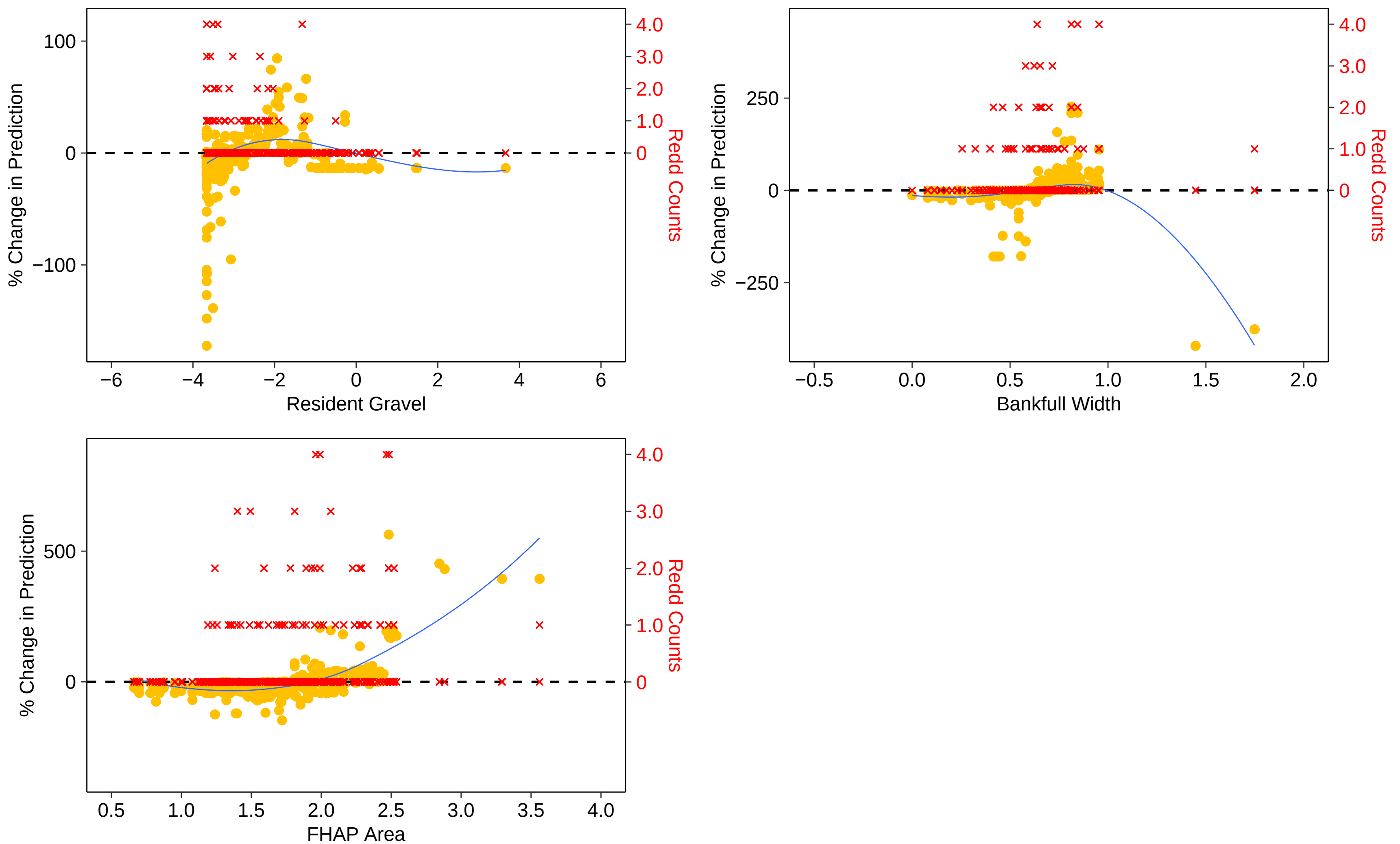


Figure 16: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Counts for Medium Calcite Elk Valley Streams, 2018 to 2020

Notes: Redd counts presented with a red X on a secondary axis. Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

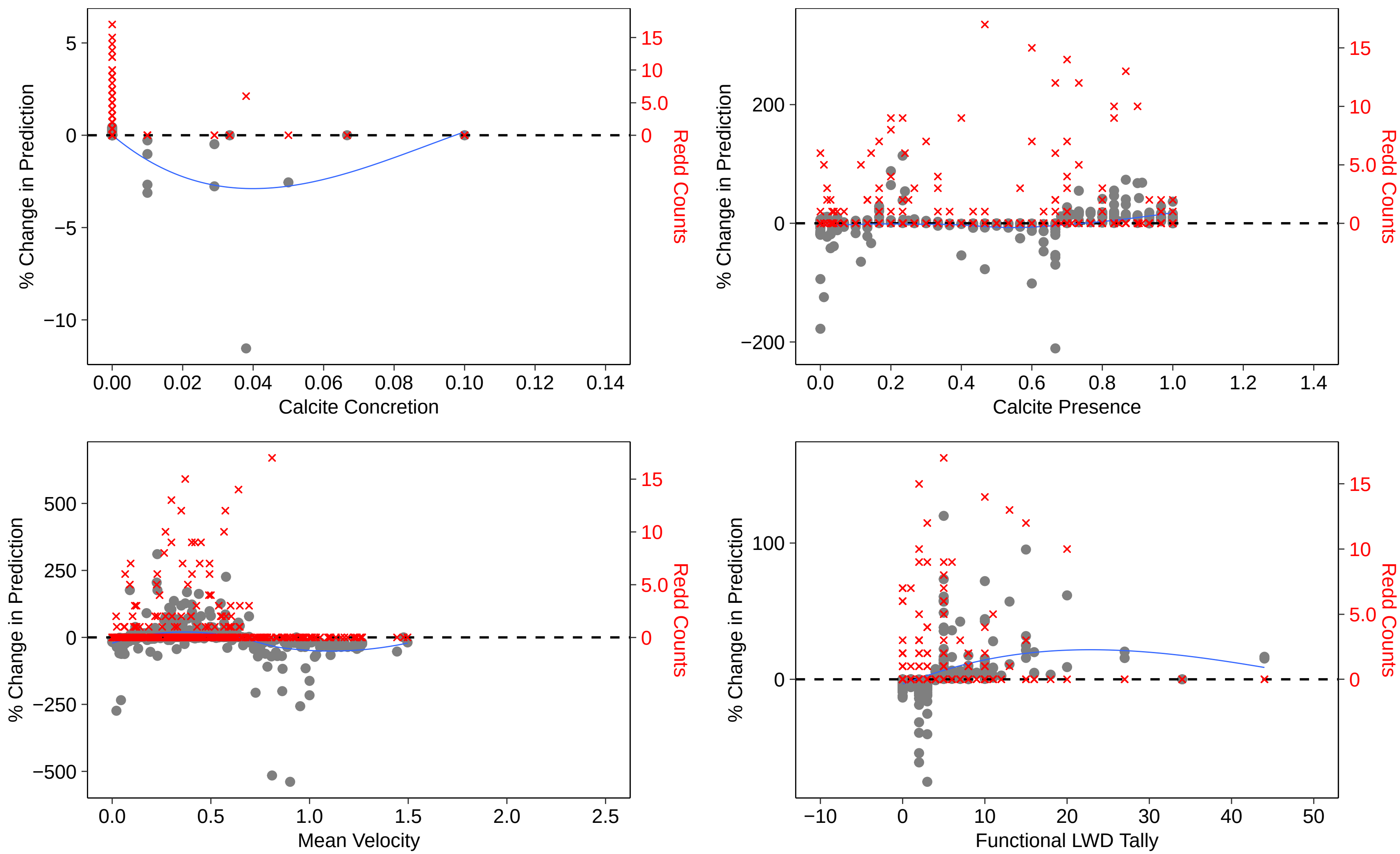


Figure 17: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Counts for Low Calcite Elk Valley Streams, 2018 to 2020

Notes: Redd counts presented with a red X on a secondary axis. Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

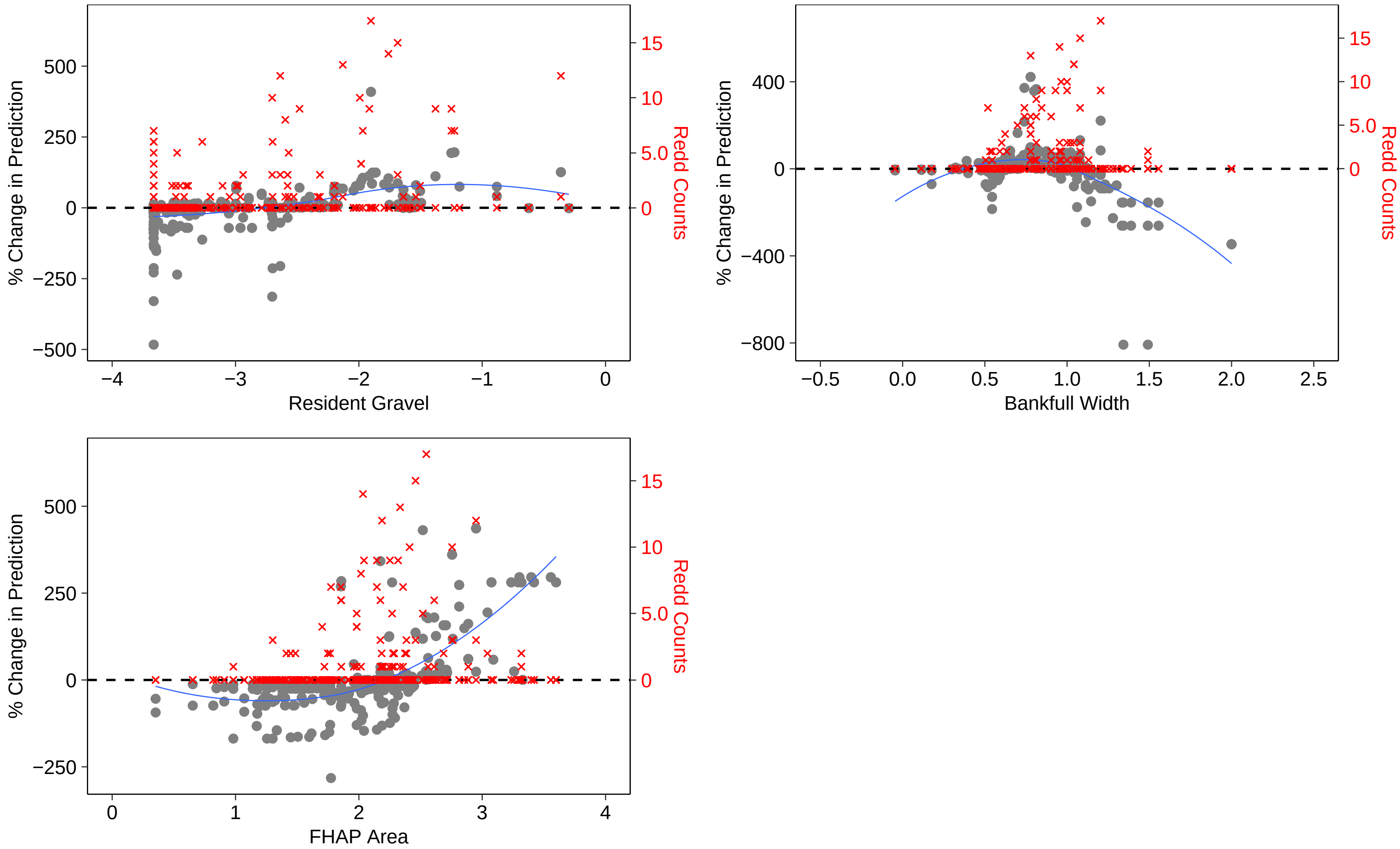


Figure 17: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Counts for Low Calcite Elk Valley Streams, 2018 to 2020

Notes: Redd counts presented with a red X on a secondary axis. Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

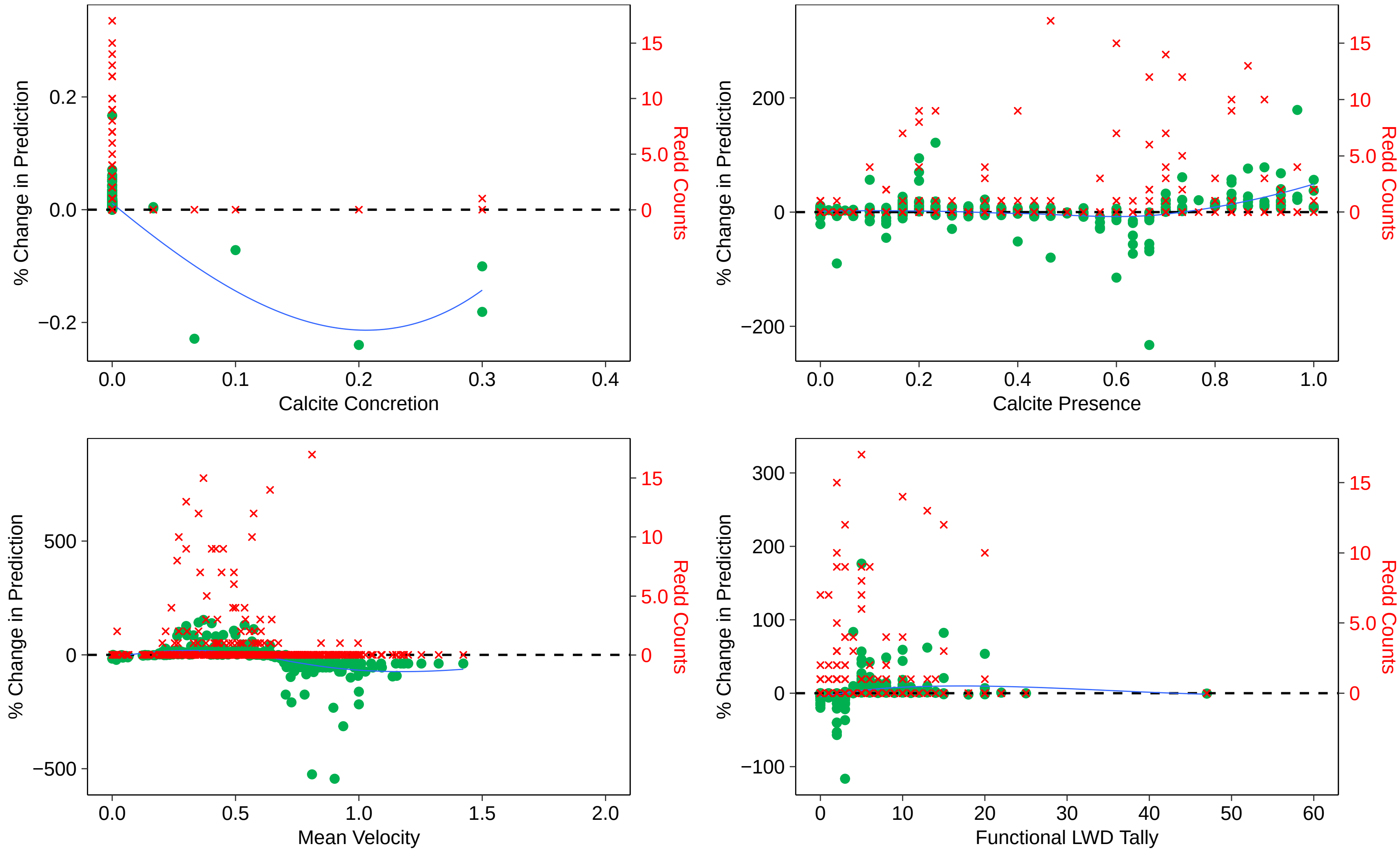


Figure 18: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Counts for Reference Elk Valley Streams, 2018 to 2020

Notes: Redd counts presented with a red X on a secondary axis. Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull width plotted on the log10 scale and proportion of resident gravel on the logit scale.

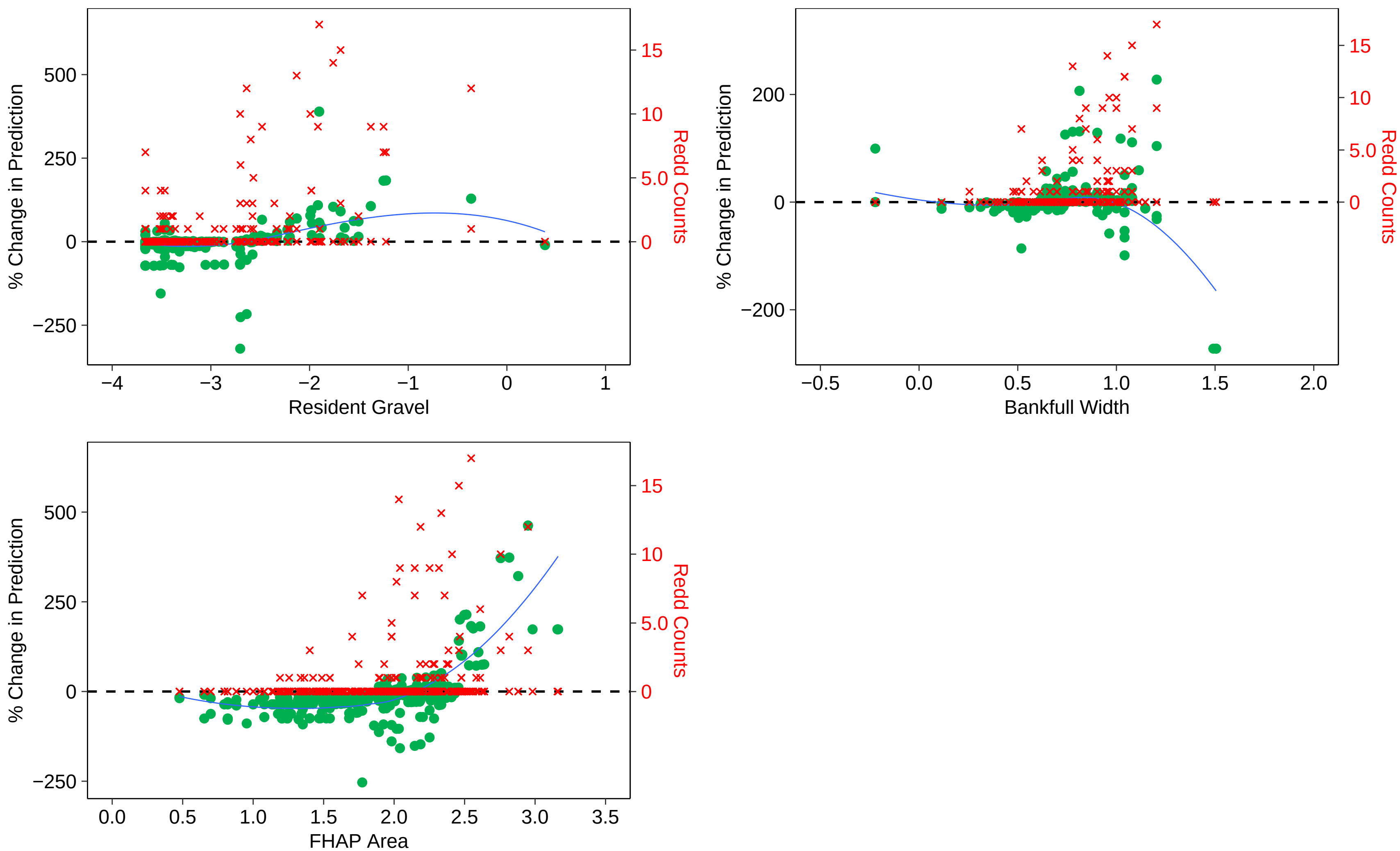


Figure 18: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Counts for Reference Elk Valley Streams, 2018 to 2020

Notes: Redd counts presented with a red X on a secondary axis. Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull width plotted on the log10 scale and proportion of resident gravel on the logit scale.

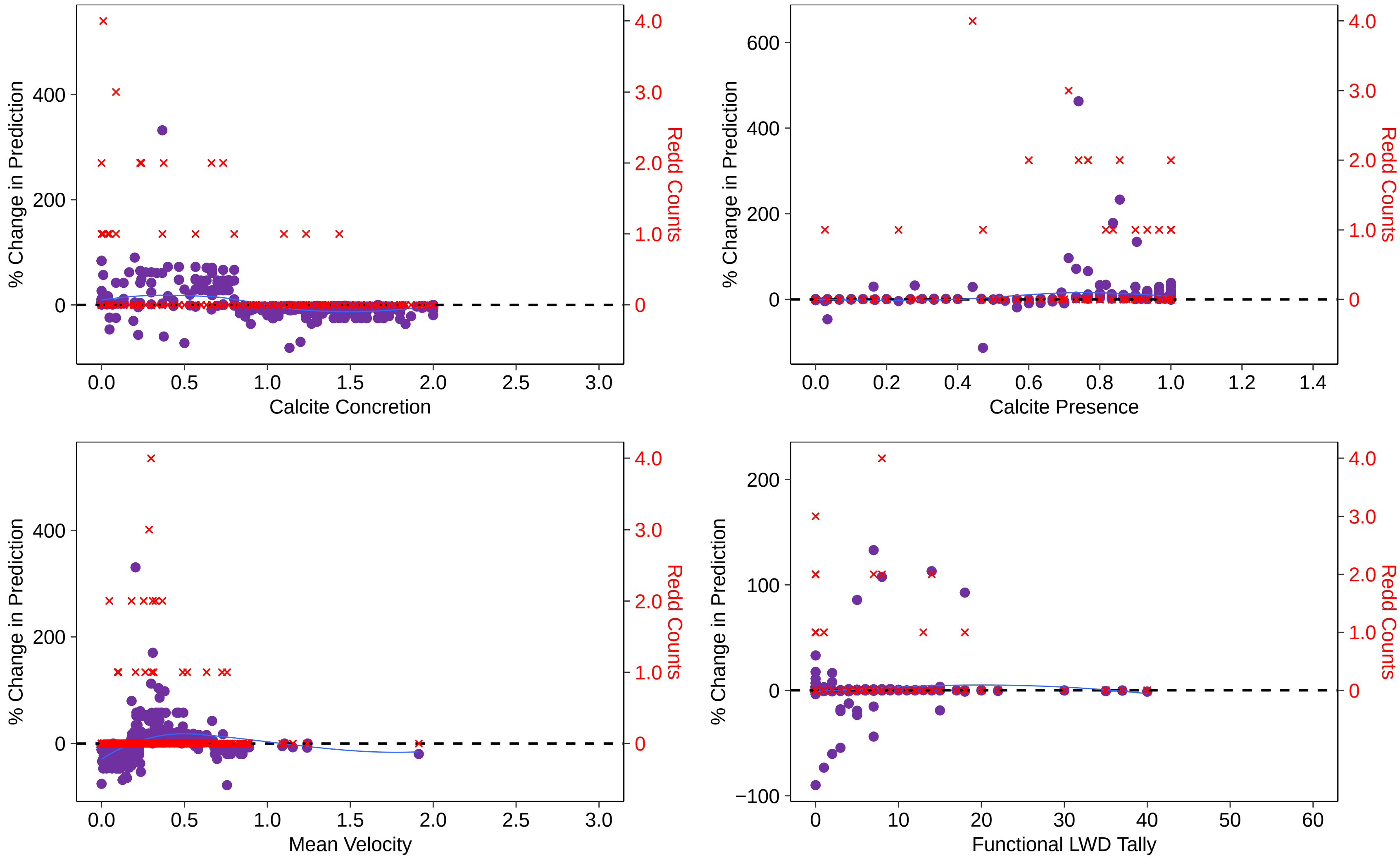


Figure 19: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Counts for High Calcite Elk Valley Streams Using Only Streams with High and Medium Concretion, 2018 to 2020

Notes: Redd counts presented with a red X on a secondary axis. Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

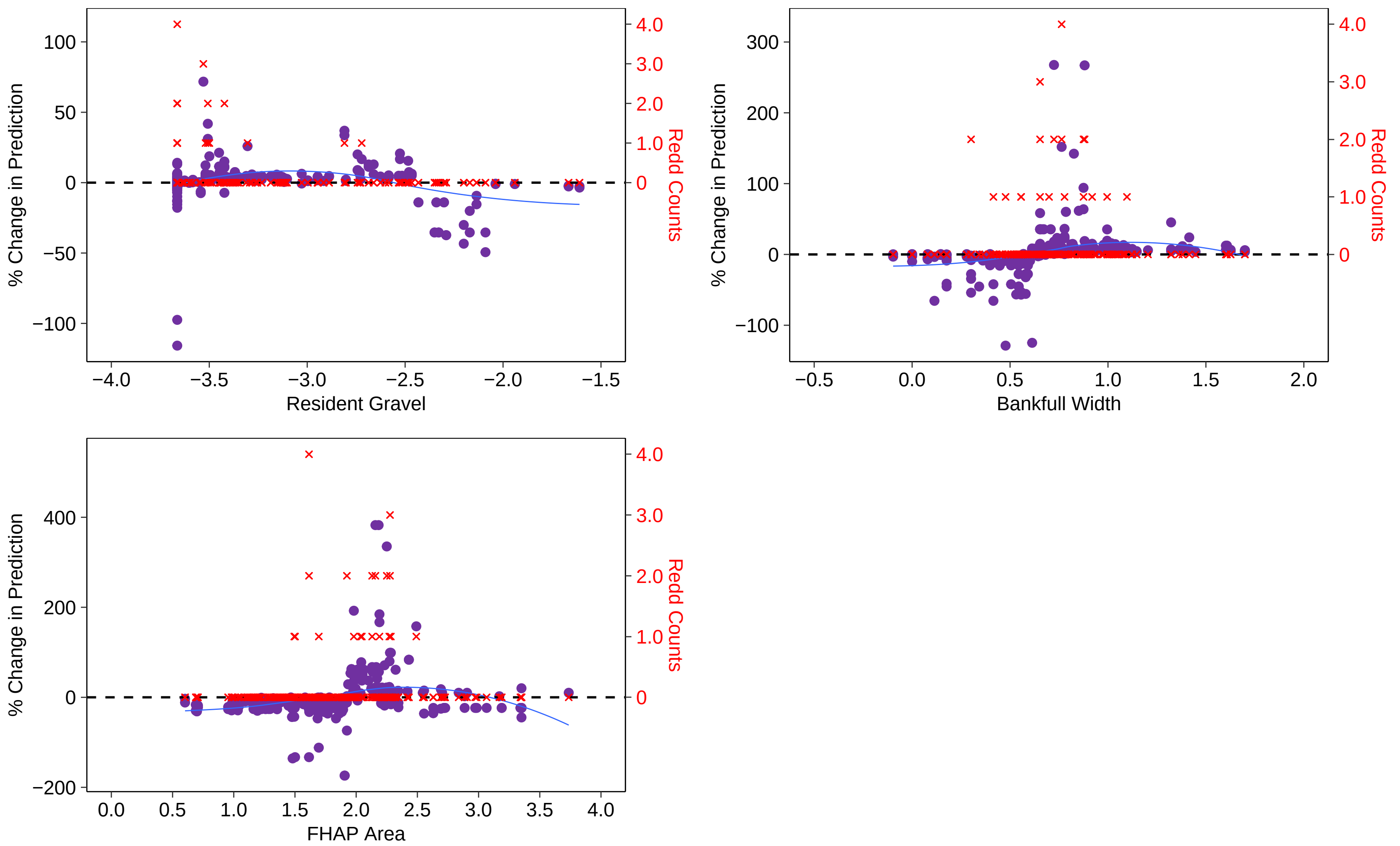


Figure 19: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Counts for High Calcite Elk Valley Streams Using Only Streams with High and Medium Concretion, 2018 to 2020

Notes: Redd counts presented with a red X on a secondary axis. Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

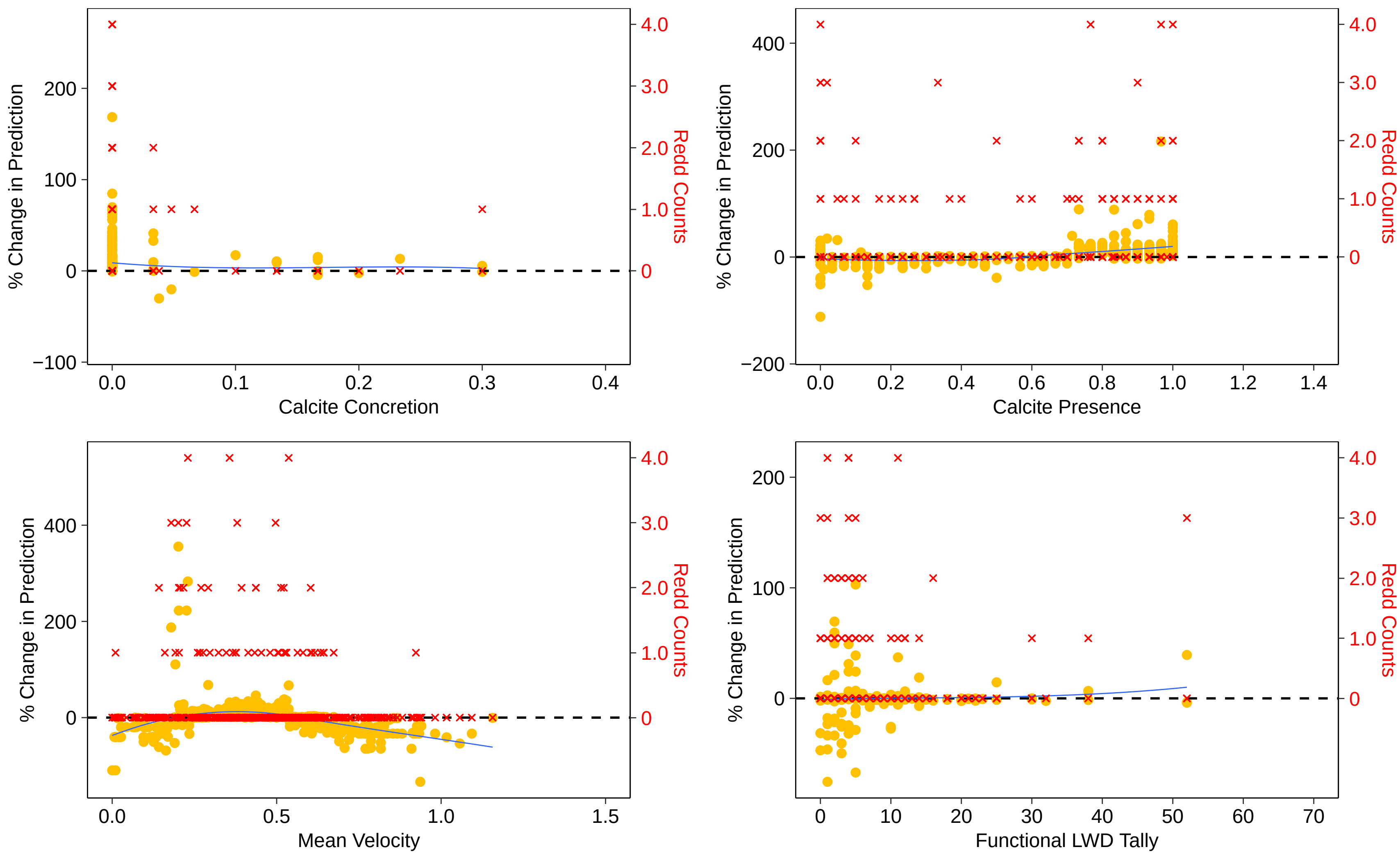


Figure 20: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Counts for Medium Calcite Elk Valley Streams Using Only Streams with High and Medium Concretion, 2018 to 2020

Notes: Redd counts presented with a red X on a secondary axis. Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

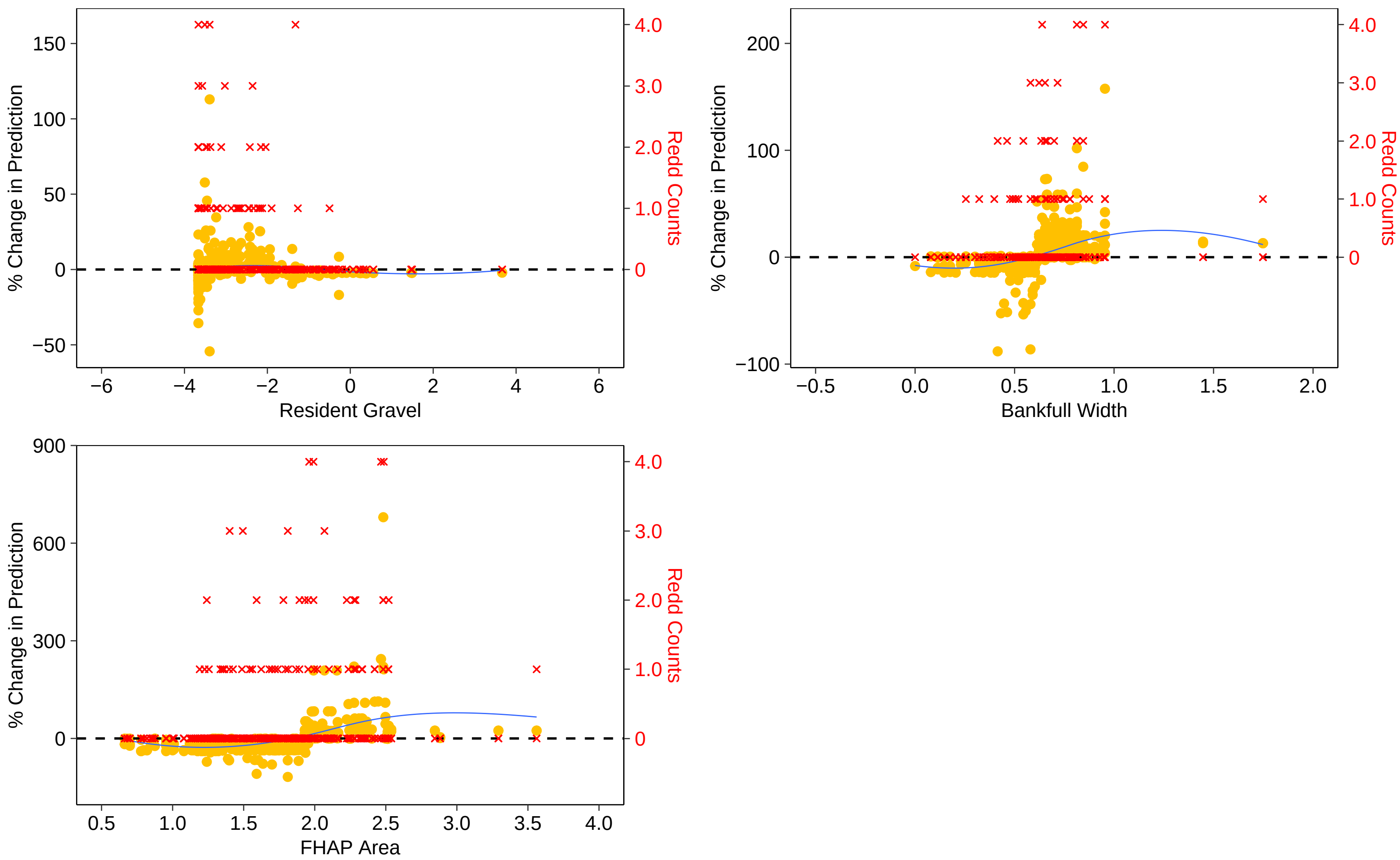


Figure 20: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Counts for Medium Calcite Elk Valley Streams Using Only Streams with High and Medium Concretion, 2018 to 2020

Notes: Redd counts presented with a red X on a secondary axis. Trend line (blue) estimated with a local polynomial regression (LOESS) model. Bankfull Width plotted on the log10 scale and proportion of resident gravel on the logit scale.

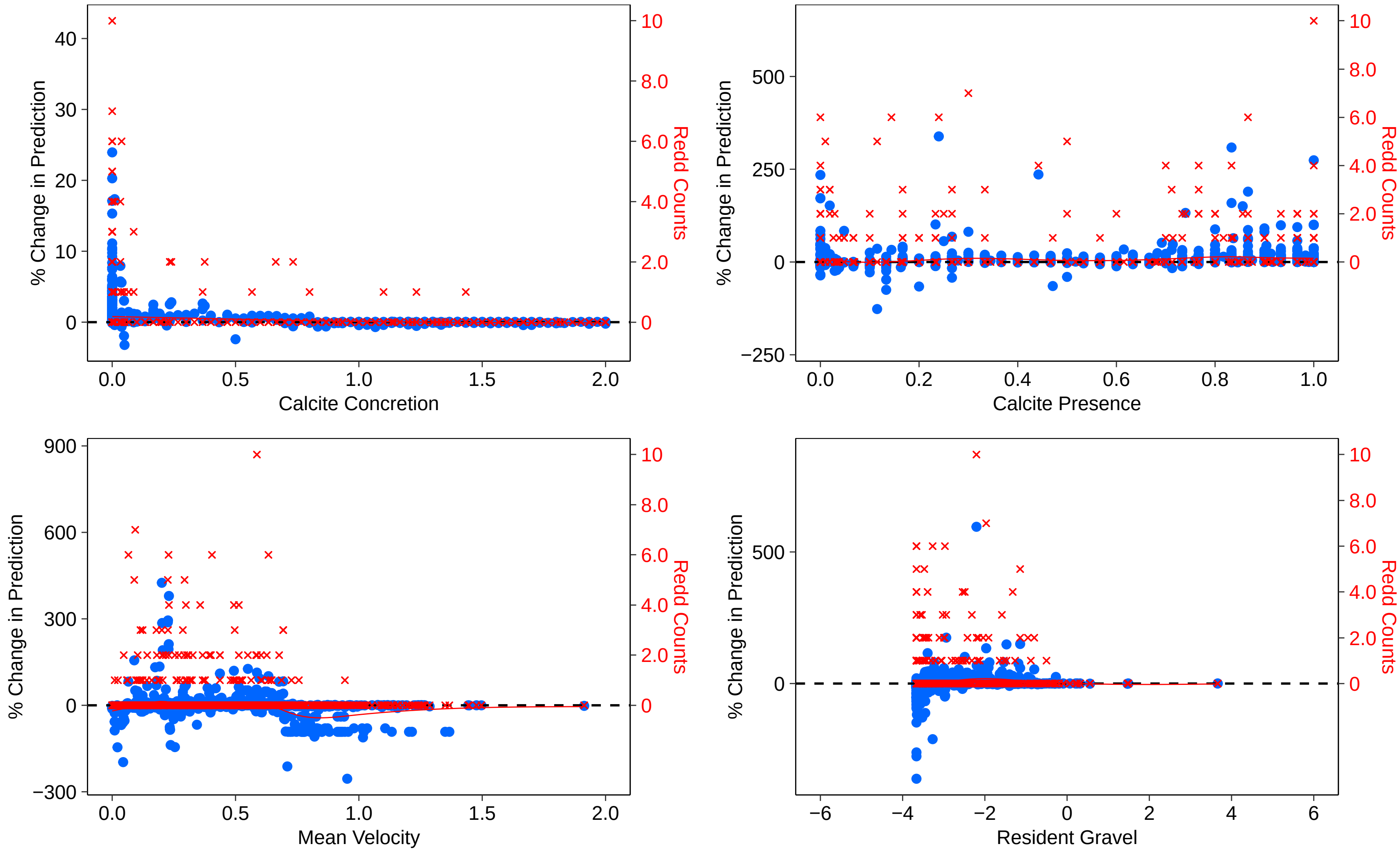


Figure 21: Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Counts for Mine−exposed Elk Valley Streams, 2018 to 2020

Notes: Redd counts presented with a red X on a secondary axis. Trend line (red) estimated with a local polynomial regression (LOESS) model. Bankfull width plotted on the log10 scale and proportion of resident gravel on the logit scale.

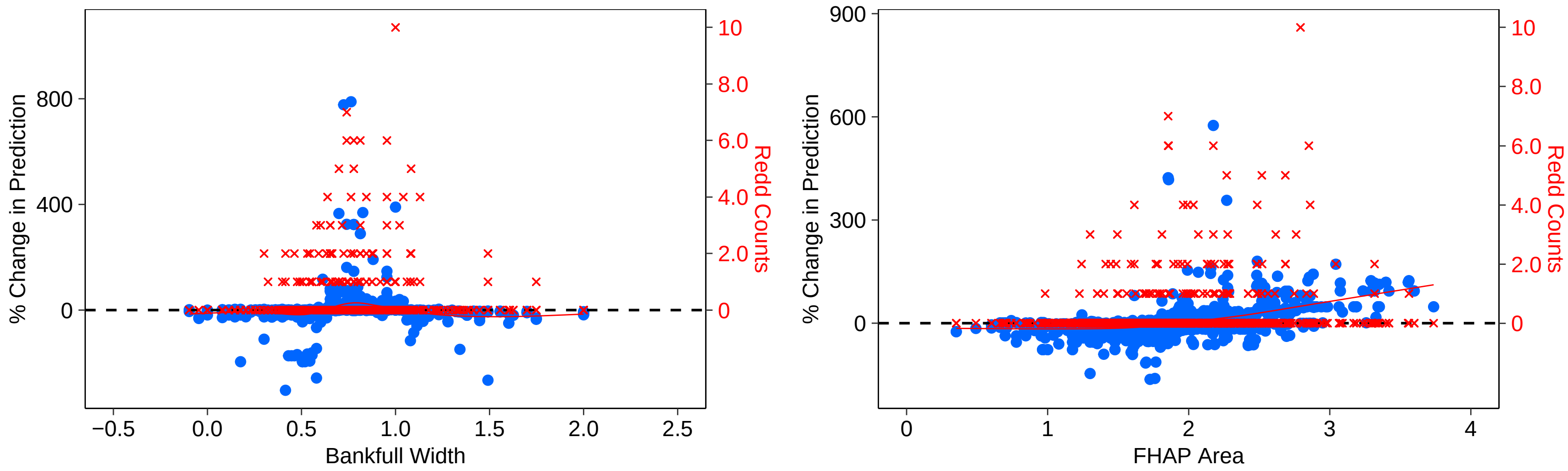


Figure 21: **Percent Change in Prediction for Boosted Regression Tree Model Parameters Describing Westslope Cutthroat Trout Redd Counts for Mine−exposed Elk Valley Streams, 2018 to 2020**

Notes: Redd counts presented with a red X on a secondary axis. Trend line (red) estimated with a local polynomial regression (LOESS) model. Bankfull width plotted on the log10 scale and proportion of resident gravel on the logit scale.

Table 1. Calcite Concretion and the Resulting Groupings for Streams in the Elk Valley, 2018 to 2020

Stream	Calcite Concretion				
	Group	Mean	Standard Deviation	Min	Max
Alexander Creek	None	0	0	0	0
Grave Creek	None	0	0	0	0
Line Creek	None	0	0	0	0
South Line Creek	None	0	0	0	0
Fish Pond Creek	Low	0.0014	0.0070	0	0.050
Fording River	Low	0.0013	0.0067	0	0.033
Henretta Creek	Low	0.0011	0.0050	0	0.029
Lizard Creek	Low	0.0018	0.012	0	0.10
Thompson Creek	Low	0.0015	0.012	0	0.10
Michel Creek	Low	0.0018	0.012	0	0.10
Dry Creek (LCO)	Medium	0.0022	0.016	0	0.17
Grace Creek	Medium	0.0029	0.017	0	0.17
Harmer Creek	Medium	0.0082	0.035	0	0.23
Mccool Creek	Medium	0.0092	0.048	0	0.30
Clode Creek	High	0.38	0.50	0	1.9
Corbin Creek	High	1.2	0.54	0	2.0
Dry Creek (EVO)	High	1.2	0.44	0.17	2.0
Lower Greenhills Creek	High	0.23	0.46	0	2.0
Upper Greenhills Creek	High	1.2	0.45	0.13	2.0
Erickson Creek	High	1.1	0.16	0.73	1.5

Notes: Streams were grouped into no, low (>0 and <=0.1), medium (> 0.1 and >0.5) and high calcite (>0.5) concretion groups based on the maximum calcite concretion within the stream.

Table 2. First Run Multivariate Model Sets Designed to Establish Westslope Cutthroat Trout Redd Presence and Counts in Streams in the Elk Valley, 2018 to 2020

Name	Calcite Concretion	Calcite Presence	Conductivity	FHAP Area	Mean Velocity	Proportion of Resident Gravel	pH	Temperature	Functional LWD Tally	Pebble Size	Bankfull Depth	Bankfull Width
Mult1	X	X	-	X	X	X	X	-	-	-	-	-
Mult2	X	X	-	X	X	X	-	X	-	-	-	-
Mult3	X	X	-	X	X	X	-	-	X	-	-	-
Mult4	X	X	-	X	X	X	-	-	-	X	-	-
Mult5	X	X	-	X	X	X	-	-	-	-	X	-
Mult6	X	X	-	X	X	X	-	-	-	-	-	X
Mult7	X	X	-	X	X	X	X	X	X	X	X	X
Mult8	X	X	-	X	X	X	-	X	X	X	X	X
Mult9	X	X	-	X	X	X	X	-	X	X	X	X
Mult10	X	X	-	X	X	X	X	X	-	X	X	X
Mult11	X	X	-	X	X	X	X	X	X	-	X	X
Mult12	X	X	-	X	X	X	X	X	X	X	-	X
Mult13	X	X	-	X	X	X	X	X	X	X	X	-
Mult14	-	-	X	X	X	X	X	-	-	-	-	-
Mult15	-	-	X	X	X	X	-	X	-	-	-	-
Mult16	-	-	X	X	X	X	-	-	X	-	-	-
Mult17	-	-	X	X	X	X	-	-	-	X	-	-
Mult18	-	-	X	X	X	X	-	-	-	-	X	-
Mult19	-	-	X	X	X	X	-	-	-	-	-	X
Mult20	-	-	X	X	X	X	X	X	X	X	X	X
Mult21	-	-	X	X	X	X	-	X	X	X	X	X
Mult22	-	-	X	X	X	X	X	-	X	X	X	X
Mult23	-	-	X	X	X	X	X	X	-	X	X	X
Mult24	-	-	X	X	X	X	X	X	X	-	X	X
Mult25	-	-	X	X	X	X	X	X	X	X	-	X
Mult26	-	-	X	X	X	X	X	X	X	X	X	-

Notes: "X" = included parameter in model set.

Table 3. Second Run Multivariate Model Sets Designed to Establish Westslope Cutthroat Trout Redd Presence and Counts in Streams in the Elk Valley, 2018 to 2020

Name	Calcite Concretion	Calcite Presence	Conductivity	FHAP Area	Mean Velocity	Proportion of Resident Gravel	Functional LWD Tally	pH	Temperature	Pebble Size	Bankfull Depthl	Bankfull Width
Mult1	X	X	-	X	X	X	X	X	X	-	-	-
Mult2	X	X	-	X	X	X	X	X	X	X	X	X
Mult3	X	X	-	X	X	X	X	X	X	-	X	X
Mult4	X	X	-	X	X	X	X	X	X	-	-	X
Mult5	X	X	-	X	X	X	X	X	X	X	-	X
Mult6	X	X	-	X	X	X	X	-	-	-	-	-
Mult7	X	X	-	X	X	X	X	-	-	X	X	X
Mult8	X	X	-	X	X	X	X	-	-	-	X	X
Mult9	X	X	-	X	X	X	X	-	-	-	-	X
Mult10	X	X	-	X	X	X	X	-	-	X	-	X
Mult11	-	-	X	X	X	X	X	X	X	-	-	-
Mult12	-	-	X	X	X	X	X	X	X	X	X	X
Mult13	-	-	X	X	X	X	X	X	X	-	X	X
Mult14	-	-	X	X	X	X	X	X	X	-	-	X
Mult15	-	-	X	X	X	X	X	X	X	X	-	X
Mult16	-	-	X	X	X	X	X	-	-	-	-	-
Mult17	-	-	X	X	X	X	X	-	-	X	X	X
Mult18	-	-	X	X	X	X	X	-	-	-	X	X
Mult19	-	-	X	X	X	X	X	-	-	-	-	X
Mult20	-	-	X	X	X	X	X	-	-	X	-	X

Notes: "X" = included parameter in model set.

Table 4. Absolute Relative Influence for Model Variables used in a Boosted Regression Tree Model Quantifying Westslope Cutthroat Trout Redd Presence for Streams in the Elk Valley, 2018-2020

Stream	Calcite Concretion Group	Calcite Concretion	Calcite Presence	Mean Velocity	Functional LWD Tally	Resident Gravel	Bankfull Width	FHAP Area
Alexander Creek	None	0.72	4.7	6.5	1.3	3.8	4.1	13
Grave Creek	None	0.70	4.9	12	3.6	2.4	5.8	31
Line Creek	None	0.97	11	21	4.1	4.9	9.7	38
South Line Creek	None	0.0	3.2	6.8	0.14	3.0	12	24
Fish Pond Creek	Low	0.075	6.0	14	2.2	16	13	40
Fording River	Low	0.078	10	48	7.7	20	11	27
Henretta Creek	Low	0.42	2.4	11	3.6	6.5	5.0	8.2
Lizard Creek	Low	0.061	5.6	17	1.7	19	4.7	31
Thompson Creek	Low	1.5	18	12	3.9	7.9	7.8	31
Michel Creek	Low	0.95	15	45	5.6	25	5.4	31
Dry Creek (LCO)	Medium	2.4	11	14	3.6	8.2	9.2	33
Grace Creek	Medium	0.13	12	6.0	1.1	3.5	1.5	17
Harmer Creek	Medium	5.5	34	21	7.4	14	13	36
Mccool Creek	Medium	0.29	16	37	2.7	12	10	43
Clode Creek	High	1.4	4.1	10	0.0	8.6	7.3	37
Corbin Creek	High	8.6	26	19	2.3	7.6	15	17
Dry Creek (EVO)	High	3.2	4.0	8.5	0.43	4.0	4.4	9.1
Lower Greenhills Creek	High	3.2	8.3	8.9	2.8	3.7	9.3	14
Upper Greenhills Creek	High	3.4	2.2	5.3	0.68	4.5	6.9	12
Erickson Creek	High	0.66	1.2	5.8	0.53	0.55	3.7	11
Mean	-	1.7	10	16	2.8	8.8	8.0	25

Notes: Relative Influence calculated as the average amount of influence each variable has on mesohabitat unit redd presence predicted probability within each stream. Influence is presented as a percentage of the average stream prediction and expressed as an absolute value (i.e., no direction).

Table 5. Absolute Relative Influence for Model Variables used in a Boosted Regression Tree Model Quantifying Westslope Cutthroat Trout Redd Counts for Streams in the Elk Valley, 2018-2020

Stream	Calcite Concretion Group	Calcite Concretion	Calcite Presence	Mean Velocity	Functional LWD Tally	Resident Gravel	Bankfull Width	FHAP Area
Alexander Creek	None	0	7.4	13	3.4	2.2	3.9	16
Grave Creek	None	0	6.7	39	2.8	3.5	5.6	38
Line Creek	None	0	7.0	26	0.50	9.5	24	50
South Line Creek	None	0	4.8	14	0.34	17	123	100
Fish Pond Creek	Low	0.17	11	26	3.9	37	82	88
Fording River	Low	0	6.3	51	6.6	20	64	47
Henretta Creek	Low	0.13	4.4	36	4.8	17	32	37
Lizard Creek	Low	0	18	40	13	73	13	63
Thompson Creek	Low	0	15	13	3.9	19	58	78
Michel Creek	Low	0	26	52	4.1	23	15	61
Dry Creek (LCO)	Medium	0.10	31	14	3.3	9.8	18	43
Grace Creek	Medium	0	6.7	5.2	2.9	13	2.9	16
Harmer Creek	Medium	0	45	27	4.3	12	33	51
Mccool Creek	Medium	0	16	31	3.6	10	17	42
Clode Creek	High	0.20	10	13	0	6.3	17	31
Corbin Creek	High	0	22	54	1.7	13	111	73
Dry Creek (EVO)	High	0	17	10	3.4	2.2	13	20
Lower Greenhills Creek	High	0.29	15	6.9	3.6	3.0	25	19
Upper Greenhills Creek	High	0	4.2	7.4	2.5	4.7	6.2	15
Erickson Creek	High	0	1.5	13	3.3	4.6	4.9	25
Mean All	-	0.047	14	25	3.6	16	35	47
Mean for high and medium concretion streams	-	0.059	17	18	2.9	8	25	33

Notes: Relative Influence calculated as the average amount of influence each variable has on mesohabitat unit redd count predictions within each stream. Influence is presented as a percentage of the average stream prediction and expressed as an absolute value (i.e., no direction).

Table 6. Absolute Relative Influence for Model Variables used in a Boosted Regression Tree Model Quantifying Westslope Cutthroat Trout Redd Counts for Streams with Medium and High Concretion Streams in the Elk Valley, 2018-2020

Stream	Calcite Concretion Group	Calcite Concretion	Calcite Presence	Mean Velocity	Functional LWD Tally	Resident Gravel	Bankfull Width	FHAP Area
Alexander Creek	None	-	-	-	-	-	-	-
Grave Creek	None	-	-	-	-	-	-	-
Line Creek	None	-	-	-	-	-	-	-
South Line Creek	None	-	-	-	-	-	-	-
Fish Pond Creek	Low	-	-	-	-	-	-	-
Fording River	Low	-	-	-	-	-	-	-
Henretta Creek	Low	-	-	-	-	-	-	-
Lizard Creek	Low	-	-	-	-	-	-	-
Thompson Creek	Low	-	-	-	-	-	-	-
Michel Creek	Low	-	-	-	-	-	-	-
Dry Creek (LCO)	Medium	9.9	22	23	5.5	3.0	11	30
Grace Creek	Medium	0.10	5.0	7.3	0.10	4.1	8.7	28
Harmer Creek	Medium	21	27	15	3.9	6.3	11	31
Mccool Creek	Medium	0.22	17	25	1.9	3.5	12	33
Clode Creek	High	6.9	15	15	0	8.1	11	31
Corbin Creek	High	33	19	20	3.5	4.1	9.3	29
Dry Creek (EVO)	High	18	17	32	1.5	3.9	9.9	28
Lower Greenhills Creek	High	7.5	16	16	7.1	4.5	16	26
Upper Greenhills Creek	High	13	4.9	14	0.53	8.0	15	21
Erickson Creek	High	-	-	-	-	-	-	-
Mean	-	12	16	19	2.7	5.0	12	29

Notes: "-" = not included in the model due to low calcite or zero counts for all units in all years (Erickson Creek). Relative Influence calculated as the average amount of influence each variable has on mesohabitat unit redd count predictions within each stream. Influence is presented as a percentage of the average stream prediction and expressed as an absolute value (i.e., no direction).