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Technical Report Overview

Report: 2018 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 2018 study focused on Westslope Cutthroat Trout in the upper Fording River watershed.

This report was prepared for Teck by Ecofish Research Ltd.

For More Information

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Teck Coal Ltd

2018 Calcite Effects to Spawning Habitat Suitability of Westslope Cutthroat Trout



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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 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). Within the AMP, Teck is addressing two key management questions related to calcite effects, including a) is calcite being managed effectively to meet site performance objectives and to protect the aquatic ecosystem?; and b) does monitoring indicate that mine-related changes in aquatic ecosystem conditions are consistent with expectations? The AMP supports 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.

The purpose of this study is to assess potential effects of calcite on Westslope Cutthroat Trout spawning and incubation success. The study design built on outcomes 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 with varying levels of calcite. 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 habitat suitability. The objective of the current study was to test the link between stream bed calcite and spawning habitat suitability for Westslope Cutthroat Trout including a test of the following research hypothesis:

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

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

A field study was conducted in June and July 2018 at five tributary streams of the upper Fording River watershed. The study measured Westslope Cutthroat Trout presence and numbers of redds, calcite, and other fish habitat data (e.g., substrate composition, water quality, mesohabitat type and structure) at Lower Greenhills, Line Creek Operations (LCO) Dry, Clode, Fish Pond, and Henretta creeks. These watercourses were selected as they have habitats used by Westslope Cutthroat Trout for spawning and have a range of calcite cover. Results were used to model relationships between calcite and spawning use, taking into consideration other components of fish habitat (i.e., covariates). A model that accounts for fish habitat variables in addition to calcite will provide greater confidence in our assessment of calcite effects than a simpler model and will provide a broader understanding of spawning habitat suitability across a range of fish habitat conditions in the Elk Valley.

Redd surveys

Two spawning surveys were conducted for each tributary, one in late June and the second in mid-July. Westslope Cutthroat Trout and redds were observed in Lower Greenhills, LCO Dry, Clode and Fish Pond creeks. No fish or redds were observed in Henretta Creek, although moderate quality spawning habitat was noted.

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. The number of redds per mesohabitat unit was standardized by the area of the mesohabitat unit to derive a measure of redd density (redds/m^2).

Lower Greenhills Creek and Clode Creek had the highest median redd densities (0.1 redds/m^2), while having relatively low variability in redd density. Dry Creek and Fish Pond Creek showed lower median densities than Greenhills and Clode creeks at 0.003 and 0.006 redds/m^2, respectively. However, Dry Creek and Fish Pond Creek had higher variability in redd density.

Calcite Index

Calcite levels on the streambed were quantified using the calcite index (CI). CI scores were measured using the same detection and survey methodology as Teck Regional Calcite Monitoring program, but were calculated at a mesohabitat unit scale to match with the spawning assessment data. Within each sample stream, CI was measured at a maximum of 10 spawning sites (where spawning was observed) and an equivalent number of each mesohabitat type where redds were not observed (null sites).

CI varied spatially in the study area, as expected from previous studies (Minnow Environmental 2016, Robinson *et al.* 2016, Wright *et al.* 2017; 2018), although calcite data did not span the full range of CI scores possible (range observed = 0 to 1.66). The lowest CI was measured in LCO Dry Creek (n = 20, median = 0.00, range = 0.00 to 0.65), followed by Henretta Creek (n = 9, median = 0.02, range = 0.00 to 0.94). The highest CI was measured in Clode Creek (median = 1.00), where CI ranged from 0.51 to 1.66 among the 4 assessed sites, and Lower Greenhills Creek (median = 0.89, range = 0.16 to 1.40). CI in Fish Pond Creek ranged from 0.00 to 0.86 (median = 0.03).

Fish Habitat

A Level 1 Fish Habitat Assessment Procedure (FHAP) was completed in Clode, Fish Pond and Henretta creeks. An FHAP was completed in LCO Dry Creek in 2016 (Buchanan *et al.* 2016) and Lower Greenhills Creek in 2017 (Wright *et al.* 2017; 2018). Fish habitat data encompassed both spawning sites and null sites and included streamflow, velocity, depth, width, substrate, cover, spawning gravel and water quality. Mesohabitat unit types were classified as pools, glides, runs, riffles and cascades 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, etc.) need to be considered as potential covariates when developing a response relationship between calcite and spawning suitability. Initial data exploration of explanatory variables used to predict redd presence and density was carried out following Zuur *et al.*'s (2010) protocol. Data exploration revealed collinearity among fish habitat variables. The final set of fish habitat variables used to predict redd presence and density included CI, mean velocity, proportion of spawning gravel, bankfull depth, and water temperature. All of these fish habitat variables were hypothesized to affect spawning suitability.

Modelling Methods of Redd Presence and Redd Density

Three different modelling approaches were used to test the relationship between spawning suitability and calcite condition: a redd presence absence model, a beta regression model, and a quantile regression model. The beta regression and quantile regression models used redd density (redds/m^2) as the response variable. Relationships of redd presence and redd density versus explanatory variables were investigated a using a model selection approach where alternate models with different combinations of explanatory variables were competed against one another and ranked using Akaike Information Criterion (AICc) scores (McCullagh and Nelder 1989; Burnham and Anderson 2002; Zuur *et al.* 2009; Grueber *et al.* 2011). All analyses were conducted using the R Statistical Language (R Core Team 2018).

Results

Variability in the presence of redds was not strongly explained by the measured CI scores nor any of the stream habitat variables. Mean CI scores were similar between spawning sites and null sites and did not show a relationship between calcite and redd presence.

Variability in density of redds in the streams surveyed was modeled using beta regression, and was also not strongly explained by the measured CI scores. CI was found to be the second most important variable to explain redd density, and its effect was negative, which is consistent with the predicted direction of effect. However, all explanatory variables, including CI, had coefficients with confidence intervals that overlapped with zero, which indicates that there is relatively high uncertainty associated with the results.

The clearest result of the three modelling approaches was observed with quantile regression applied to the redd density data. Quantile regression methods model the outer bounds of the wedge-shaped relationship between calcite and redd density; this is a useful analytical method to examine 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).

Westslope Cutthroat Trout redds were found throughout the range of CI observed. However, high redd densities were only found at low levels of CI. Above a CI of ~0.5, redd densities were low and did not exceed 0.025 redds/m^2 of habitat.

Other habitat variables were also found to predict Westslope Cutthroat Trout spawning. Water velocity was weakly negatively related to redd presence, which suggests that redds occur less frequently in slow water habitats such as pools. Bankfull depth had the highest variable importance among the explanatory variables explaining redd density in the beta regression model. The effect of bankfull depth was negative, which suggests that redds are less common in deep water. In the quantile regression model, bankfull depth and proportion spawning gravel were the most important predictors of redd density. The proportion of each mesohabitat area covered by spawning gravel has a positive effect on redd density, while deeper water sites such as pools support lower redd density.

A key limitation of the present study was that the mesohabitat locations measured had low to moderate calcite scores; no high CI scores were measured. The highest average CI occurred in Clode Creek (mean CI = 1.00, maximum CI = 1.66). CI can range from 0 to a maximum of 3, but the relationship between CI and redd presence and density across the full range of possible calcite conditions was not able to be tested. The current study design was chosen based on their location in the Upper Fording River watershed and focus on the Westslope Cutthroat Trout population. Future sampling efforts could focus on streams and mesohabitats in areas other than the Upper Fording River watershed with higher levels of calcite, especially CI scores between 2 and 3.

Conclusion

A redd presence absence model and two different redd density models were developed to test if calcite conditions influence spawning habitat suitability for Westslope Cutthroat Trout in the upper Fording River watershed. Overall, based on the streams sampled in 2018, we conclude that redds may be present across the full range of CI scores sampled (up to ~1.7) and there was no apparent decline in suitability for redd presence over this range of CI. However, there is evidence for an influence of CI on redd density. The highest redd densities were only found at low levels of CI. Above a CI score of ~0.5, redd densities were low and did not exceed 0.025 redds/m^2 of habitat. Our conclusions should be considered preliminary, as the results are based on a fairly low sample size and therefore have broad confidence intervals. Nevertheless, the results suggest there may be two different response curves between calcite and spawning habitat; one response curve that describes a relationship for the presence of redds, and a second relationship for density of redds. Habitat heterogeneity at moderate levels of calcite may allow some spawning but not high density of spawning. Additional field work and analysis are required to reduce uncertainties in the results presented here and to improve the predictive ability of the spawning habitat response curves. At this time, a study design for 2019 work is advancing, which will incorporate recommendations from this 2018 study.

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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 can 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 turbid 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 2016).

In the Elk River watershed, there are wide ranges in the spatial extent of calcite cover, as well as seasonal fluctuations in 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.* 2018). There are concerns that high levels of calcite may have effects 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 and managing mine-related calcite formation such 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 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 takes advantage of 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 spawning habitat and incubation conditions, 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 test the link between streambed calcite and spawning habitat availability for Westslope Cutthroat Trout (i.e., impact hypothesis H2). Additional follow-up studies may be designed and implemented depending on the outcome of the current study. 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 addresses Management Question 4 within 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 current SPO for calcite under the AMP includes two CI thresholds related to the extent of calcite concretion (CI_{conc}) and total calcite (CI_{total}). Both SPOs (CI_{conc} and CI_{total}) identify CI $\leq$ 0.50 as protective of fish and aquatic life.

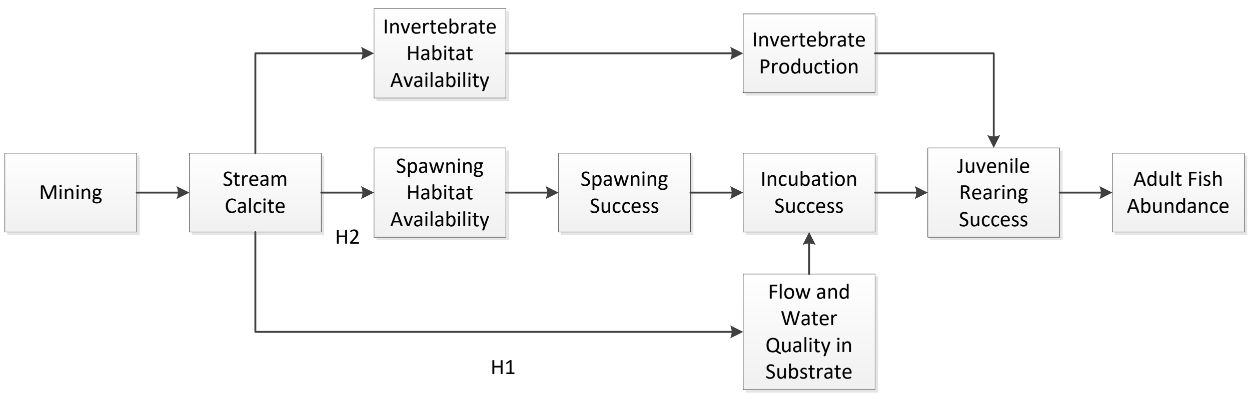


Figure 1. Effect pathway diagram linking calcite on the streambed to fish production.

1.1. Study Questions and Hypotheses

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_01 (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 an effect on hyporheic flow and dissolved oxygen.

H_02 (null): Observed calcite conditions on stream substrates have no effect on suitability of fish spawning habitat.

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

Habitat use by fish is well known in the upper Fording River and tributaries (Cope *et al*. 2016), so the research hypotheses were tested by empirically assessing incubation conditions and spawner use in tributaries to the upper Fording River. 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.

2. METHODS

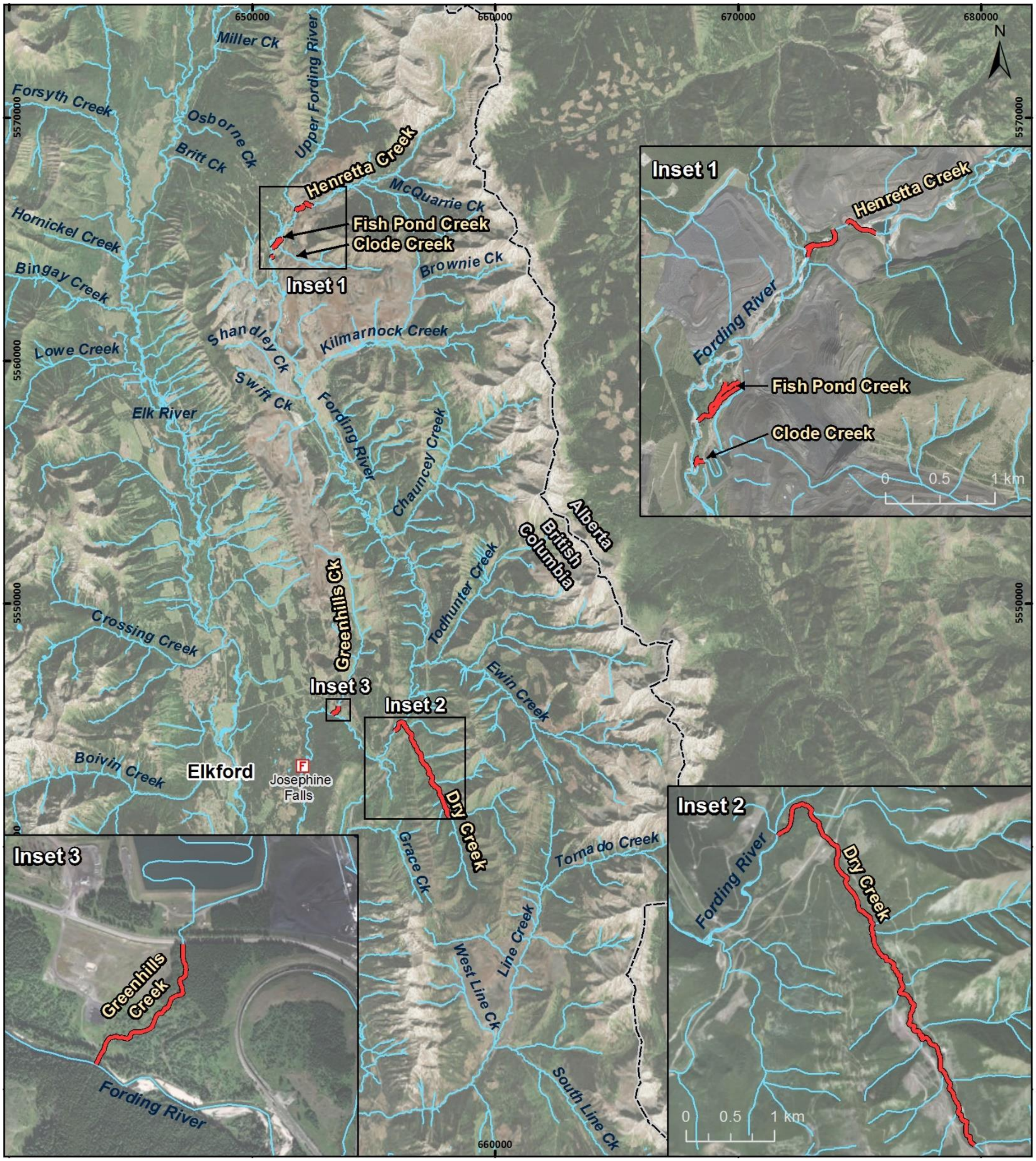
2.1. Study Area

The study was conducted in the upper Fording River watershed. The Fording River is a tributary to the Elk River and is located in the East Kootenay region of south-eastern British Columbia. Study sites were selected to represent tributary spawning habitat used by Westslope Cutthroat Trout in the upper Fording River watershed above Josephine Falls (Cope *et al*. 2016, Minnow Environmental 2016, Beswick 2007) and to represent a range of calcite conditions based on previous calcite monitoring (Minnow Environmental 2016, Robinson *et al*. 2016, Wright *et al*. 2017; 2018).

Data collection in 2018 occurred in five tributaries to the upper Fording River: Greenhills, LCO Dry, Clode, Fish Pond, and Henretta creeks (Map 1). These watercourses were selected as they have habitats used by Westslope Cutthroat Trout for spawning and include habitats influenced by calcite cover (see definition of CI in Section 2.3.2). Calcite prevention activities have begun on Lower Greenhills Creek in reach GREE1 (Smithson *et al*. 2019; Teck 2019), which may decrease CI over the long term. Habitat improvements are also being completed on Fish Pond and Henretta creeks to support Westslope Cutthroat Trout (Teck 2016). Spawning was previously confirmed (i.e., redds and/or fry present) in the lower reach of Greenhills Creek (Cope *et al*. 2016), in LCO Dry Creek (Buchanan *et al*. 2016; Cope *et al*. 2016; Faulkner *et al*. 2018), and in Henretta, Clode and Fish Pond creeks (Cope *et al*. 2016). These watercourses are representative of calcite conditions and Westslope Cutthroat Trout spawning habitats in the upper Fording River watershed and also representative of other lotic habitats in the Elk Valley.

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

Study Area and Sampling Locations



Legend

Spawner Surveys
Stream

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 1 2 3 4 5 6 7 km

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Date Saved: 02/11/2018
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 1

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2.2. Experimental Design and Objectives

The 2018 study extends work undertaken in previous years related to effects of calcite on incubation conditions (e.g., see Wright *et al.* 2017; 2018). Work completed in 2018 assesses the relationship between calcite and spawning habitat conditions. The focus continues to be on tributary habitats to the upper Fording River rather than the mainstem. The three objectives of this component of the study are to:

1. Develop a response curve between calcite and Westslope Cutthroat Trout spawning habitat suitability;
2. Apply the response curve within the Elk River tributaries affected by Teck operations to assess the availability of suitable spawning habitats; and
3. Assess temporal trends in the availability of suitable spawning habitats in relation to calcite concentrations.

The relationship between calcite and spawning habitat will be referred to here as a response curve (conceptual curve shown in Figure 2), which quantitatively describes the influence of calcite (i.e., one aspect of habitat) on Westslope Cutthroat Trout habitat quality (i.e., biological response). A response curve can be used in combination with habitat surveys to describe the status of spawning habitat in an area. It can thus be used for direct quantitative estimation of habitat availability, including trend monitoring of fish habitat (i.e., habitat availability over time). The response variables used in this study were redd presence and redd density.

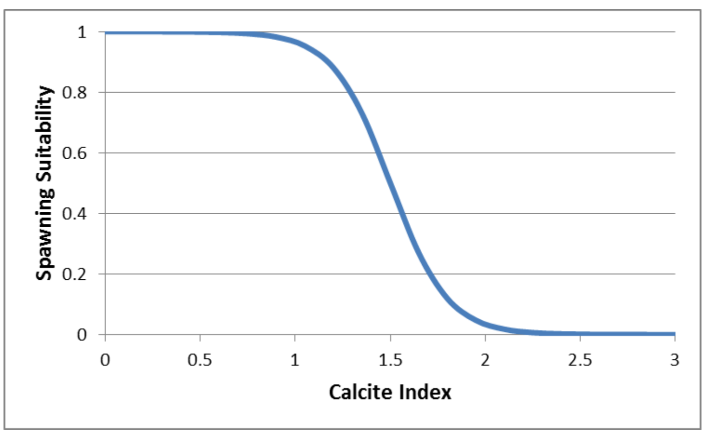


Figure 2. Conceptual response curve for calcite as it relates to spawning habitat suitability for Westslope Cutthroat Trout.

There are two fundamental challenges to developing a response curve for calcite, which need to be considered when developing a study design. First, calcite is one of many influences on fish and fish habitat, and these other influences (e.g., substrate type, cover, gradient, water quality, etc.) need to be considered as potential covariates when developing the response curve. Likewise, it is necessary to assess where fish are spawning as well as where they are not spawning, or the response curve will be incomplete. 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 Westslope Cutthroat Trout that includes the key variable of interest, calcite, but also other potential fish habitat drivers.

Second, detecting and measuring Westslope Cutthroat Trout spawning density in the upper Fording is fraught with challenges, such as variable spawn timing, variable longevity of detectability of redds, distinguishing between redds and other disturbances, and field conditions like water clarity. These challenges suggest that a response curve likely needs to be developed over multiple spawning seasons, rather than a single season. Furthermore, it suggests that the response curve may require review and inputs from experts with local knowledge.

The overall experimental design requires that redd data, calcite data and fish habitat data be collected at a mesohabitat scale in all tributaries. Calcite and habitat data were measured at a maximum of 10 spawning sites (where redds were observed) at each stream. The experimental design also requires that calcite and habitat data be collected at an equivalent number of "null" sites where spawning redds are absent. An equivalent number of null sites were selected from the remaining mesohabitat units where redds were absent in each stream. Null sites are locations where Westslope Cutthroat Trout *could* spawn in, although spawning was not observed in 2018. Null sites were selected at random from roughly an equivalent number of null sites as spawning sites by mesohabitat type. Methods for field data collection of these components in 2018 and subsequent data analysis are described in sections 2.3 and 2.5 below.

2.3. Field Data Collection

Sampling in 2018 included a combination of redd surveys, CI measures and fish habitat assessments in five tributaries of the upper Fording River. Maps highlighting mesohabitat units, redd locations, and calcite assessment sites within each stream are presented in Appendix A.

2.3.1. Redd Surveys

Redd surveys will support the study objectives described in Section 2.2 by:

1. Providing response data (redds) for development of the calcite response curve;
2. Assessing whether spawning locations can be predicted by habitat characteristics including calcite; and
3. Understanding spatial variation of spawning within important spawning tributaries.

Two spawning surveys were conducted for each tributary, one in late June and the second in mid-July. Westslope Cutthroat Trout are known for variable spawning behaviours, which can make predicting peak spawning times difficult. Therefore, prior to undertaking the redd surveys, information on weather, flows, turbidity, and fish behaviour were obtained to maximize the likelihood of observing 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 avoid 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 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. Visibility 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 section below on methods for habitat and calcite surveys). 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. The number of redds per mesohabitat unit was further standardized by the area of the mesohabitat unit to derive a measure of redd density (redds per m^2).

Maps of each stream showing the mesohabitat units containing redds are presented in Appendix A. Redd data for each mesohabitat unit is summarized in Appendix B.

2.3.2. Calcite Index

Calcite index scores were measured at the mesohabitat unit scale to match with the redd survey data, which is a finer scale than the Teck Calcite Regional Monitoring program. Within each sample stream, CI was measured at a maximum of 10 spawning sites (where spawning was observed) and an equivalent number of each mesohabitat type where redds were not observed (null sites).

CI measurement methods followed the practices and procedures used by Teck in their Calcite Regional Monitoring Program (Robinson and MacDonald 2014, Minnow Environmental 2016, Robinson *et al.* 2016, Smithson *et al.* 2018). Prior to field work, the crew received training in determining calcite presence/absence and CI procedures from Ecofish staff involved in the 2017 Calcite study. The procedures employed in this study are described below.

At each mesohabitat unit, the observer systematically moved 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 (3 to 100 m). If the substrate selected was < 2 mm in diameter, this was noted and another pebble was chosen for a total count of 100 pebbles.

100 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 1). 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 A).

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

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

where,

$CI_{Total} = Calcite\ Index$

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

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

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

Table 1. 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	-	256-4000
Bedrock	-	>4000

2.3.3. Fish Habitat

A Level 1 Fish Habitat Assessment Procedure (FHAP), as described by Johnston and Slaney (1996), was used to quantify fish habitat in Fish Pond, Henretta and Clode creeks in 2018. The FHAP was completed within the restored reach of Fish Pond Creek upstream of the confluence with the Fording River. On Henretta Creek, the FHAP was completed from the Fording River confluence to the outfall of Henretta Lake. On Clode Creek, the FHAP was completed from the Fording River confluence to the culvert draining the Lower Clode Creek Sediment Pond. An FHAP was completed on Greenhills Creek in 2017 (Wright *et al.* 2017; 2018), and on LCO Dry Creek in 2016 (Buchanan *et al*. 2016).

Mesohabitat unit types were classified as pools, glides, runs, riffles and cascades according to definitions in Johnston and Slaney (1996). Johnston and Slaney (1996) recommend using only pools, glide, riffle, cascade and "other"; however, we added "run" to define a broader range of mesohabitat unit types. 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, glide mesohabitat units have a defined thalweg, whereas run mesohabitat units have uniform flow and lack a defined thalweg.

Table 2 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 1. 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 3).

During the FHAP, a spawning gravel assessment was also completed to provide more 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 resident spawning fish using a gravel size range of 10 to 75 mm thought to represent the preferred substrate size range for spawning Westslope Cutthroat Trout. Available spawning habitat was further determined by summing the functional gravel area for all patches in each mesohabitat unit.

Mesohabitat units identified within each stream are presented in Appendix A, and a summary of habitat data collected at mesohabitat units during the calcite assessment is presented in Appendix B.

Table 2. Physical parameters, units of measure and equipment used during the FHAP.

Parameter	Unit	Measured or Estimated	Equipment Used
Banfull Width	m	Measured	Meter Tape or Rangefinder
Bed Material Tyipe	n/a	Visual Estimate	Visual
Cover Proportions	n/a	Visual Estimate	Visual
Cover Types	n/a	Visual Estimate	Visual
Gradient	%	Measured	Clinometer
Habitat Unit Length	m	Measured	Meter Tape or Rangefinder
Maximum Pool Depth	m	Measured	Meter Stick
Wetted Depth	m	Measured	Meter Stick
Wetted Width	m	Measured	Meter Tape or Rangefinder

Table 3. 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

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 all spawning and null sites during the calcite assessment. A summary of physical habitat data collected during the calcite assessment is presented in Appendix B.

In situ measures of water quality (dissolved oxygen (DO), water temperature, pH, and electrical conductivity) were collected in triplicate using a calibrated YSI Pro Plus. 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 (average, minimum, maximum and standard deviation) were calculated for DO (% saturation and mg/L), water temperature (°C), pH and specific conductivity (µS/cm) at each sampling site.

Velocity was measured at a minimum of 20 stations 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.

Water quality and velocity data were collected in the immediate vicinity of redds within spawning sites, and in representative location of mesohabitat in the null sites.

2.4. Data QA/QC

All field data were entered into Ecofish's proprietary 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 publishing.

2.5. Data Analysis

2.5.1. Data Exploration and Variable Selection

The exploration and modeling of the relationship between environmental variables and the presence and density of redds was carried out in a two-stage approach, including development of redd presence absence models and redd density models. Arguably, there may be two different response curves (e.g., Figure 2) to develop; one response curve that determines the threshold for the presence of redds, and a second for determining the threshold for the density of redds. For example, redds may be present in mesohabitat units with CI scores >1 or even >2. However, high redd densities may not occur above a lower threshold of CI.

Prior to modelling, summary statistics were calculated from the redd survey, calcite, FHAP and water quality data. Redd density (redds/m^2) and proportion of spawning gravel were respectively calculated by dividing the total number of redds and the total area of functioning spawning gravel by the mesohabitat unit area (calculated as unit length × bankfull width). Water quality summary statistics (average, minimum, maximum and standard deviation) were calculated for DO (% saturation and mg/L), water temperature (°C), pH and specific conductivity (µS/cm) at each sampling site.

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

As a first step of data exploration of explanatory variables, we analyzed collinearity between the values of calcite index (CI = CI_{Total}), and its components, *i.e.* calcite presence score (CI_{Pres}), and calcite concretion score (CI_{Conc}). We found very high correlation between CI_{Total} and CI_{Pres} (r = 0.977), high correlation between CI_{Total} and CI_{Conc} (r = 0.796), and modest correlation between CI_{Pres} and CI_{Conc} (r = 0.65) (Figure 3).

The remaining data exploration of explanatory variables was carried out following Zuur *et al.*'s (2010) protocol. The explanatory variables initially hypothesized to affect Westslope Cutthroat Trout spawning included CI, mesohabitat type, streamflow, mean water velocity, bankfull depth, bankfull width, mean substrate size, grain size distribution, proportion spawning gravel, water temperature, DO, specific conductivity and pH. 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 substantial collinearity among explanatory variables (Figure 4). For example, mesohabitat type (e.g., pool, riffle) was highly correlated to bankfull depth and water velocity. CI was also found to be correlated to mean substrate size measured during the calcite data collection as well as stream pH. Therefore, a number of variables were excluded from consideration due to collinearity and challenges with model fitting. The final set of explanatory variables included CI, mean velocity, proportion spawning gravel, bankfull depth, and water temperature (Table 4).

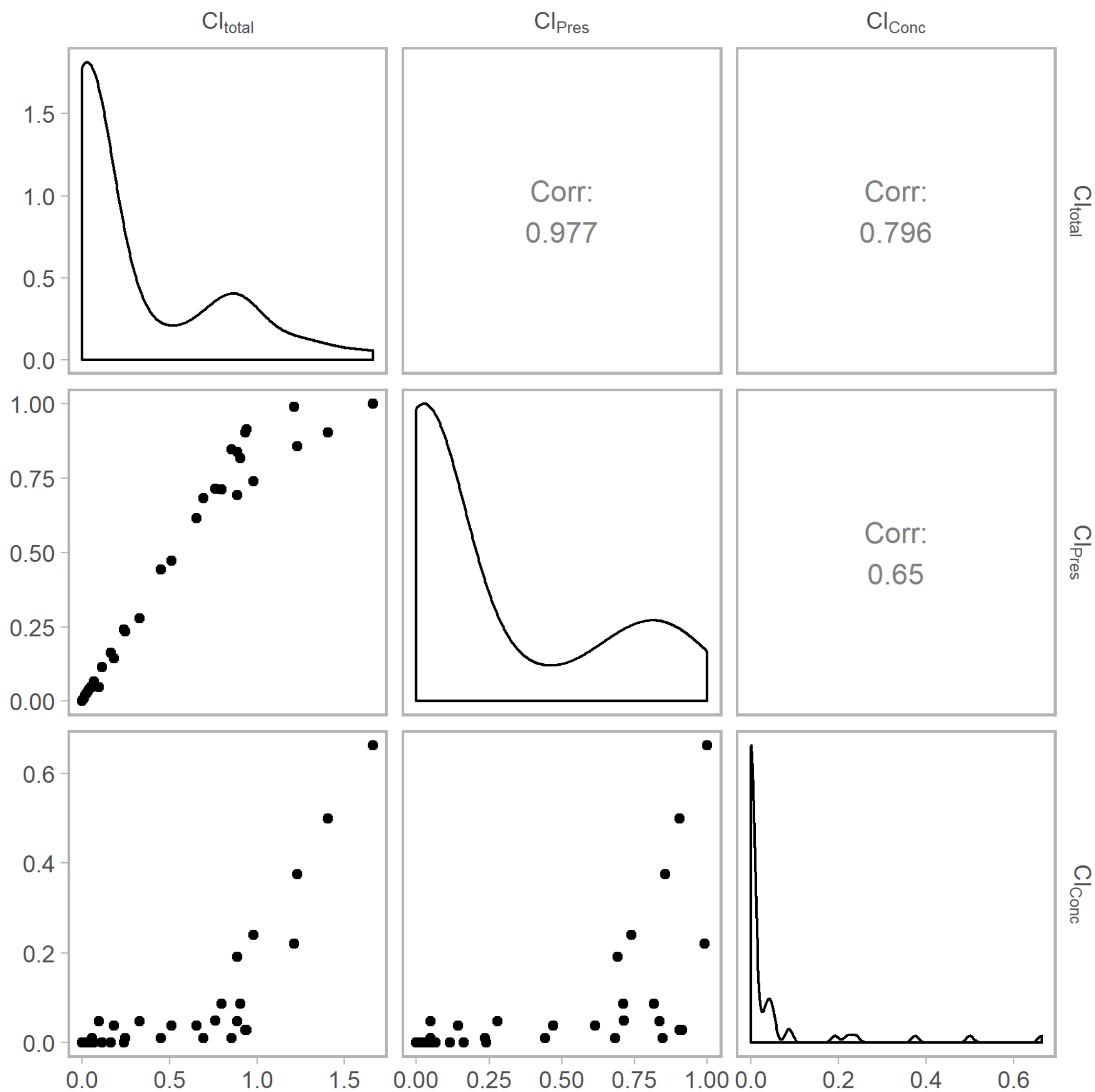


Figure 3. **Correlation matrix of calcite index (CI = CI_{Total}), calcite presence score (CI_{Pres}), and calcite concretion score (CI_{Conc}). Main diagonal: density plots showing the distribution of each variable. Lower triangle: scatterplots for combinations of variables. Upper triangle: correlation coefficients.**

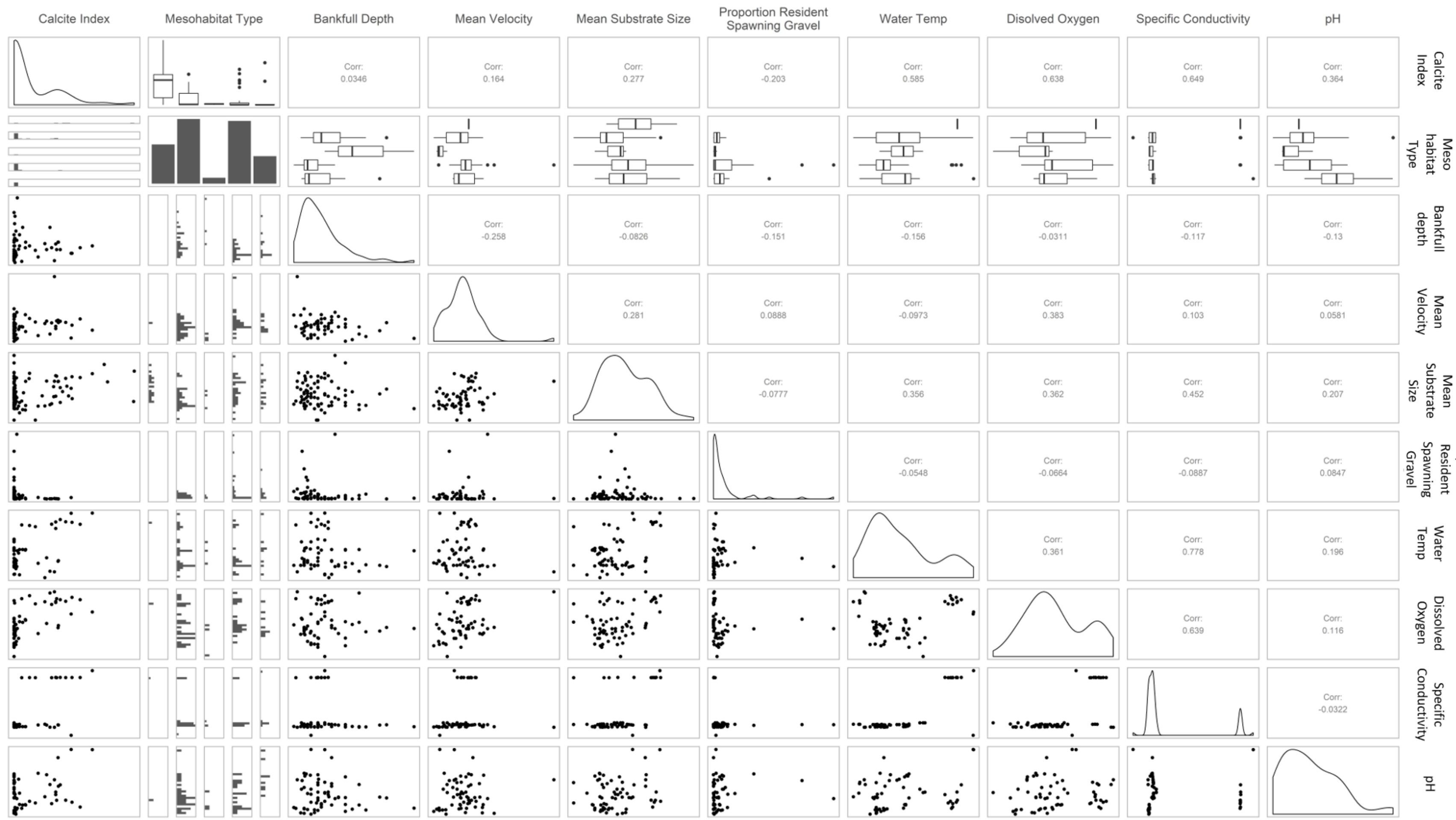


Figure 4. **Correlation matrix of explanatory variables. Main diagonal: density plots for continuous variables, and histograms for categorical variables. Lower triangle: scatterplots for combinations of continuous-continuous variables, and histograms for combinations of variables that involve a categorical variable. Upper triangle: correlation coefficient for combinations of continuous-continuous variables, and side-by-side boxplots for combinations of variables that involve a categorical variable.**

2.5.2. Model Development

Relationships of redd presence and redd density vs. explanatory variables were investigated a using a model selection procedure on a series of generalized linear mixed-effects models (McCullagh and Nelder 1989; Burnham and Anderson 2002). Redd density was analyzed using two approaches: using a beta regression procedure and quantile regression. Tributary stream was used as a random effect in all models to account for the spatial correlation of samples collected within each stream (Table 4).

The probability of redd presence was modelled as a generalized linear model, where the response variable followed a binomial distribution, with a logit link function. This step was implemented using the "stats" package in the R Statistical Language (R Core Team 2018).

To model redd density, we first excluded all sites where there was no presence of redds. Redd density assume values between 0 and 1. Therefore, we modelled it using fixed-dispersion, beta regression models (Ferrari and Cribari-Neto 2004, Cribari-Neto and Zeileis 2010). This approach incorporates features such as heteroskedasticity or skewness, commonly observed in data such as rates or proportions (Cribari-Neto and Zeileis 2010). Analyses were performed assuming a logit link, using the "betareg" package (Cribari-Neto and Zeileis 2010) in R (R Core Team 2018).

Linear modelling describes differences in the mean of response variables, but is not able to detect heterogenous effects of covariates at different quantiles of the response variable. To obtain a more complete characterization of the distribution of redd density, we used a quantile regression approach (Huang *et al*. 2017). 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 90^{th} quantile is a robust model to describe the upper bounds of wedge-shaped relationships (Scharf *et al*. 1998, Armstrong *et al*. 2010, Hocking *et al*. 2013). A 90^{th} quantile regression model of redd density versus explanatory variables was performed using the "quantreg" package (Koenker 2018) in the R Statistical Language (R Core Team 2018).

Model selection techniques were used to assess the relative importance of each predictor variable, including CI, in explaining redd presence and redd density (e.g., Zuur *et al*. 2009, Grueber *et al*. 2011). The predictor variables were all scaled by subtracting their respective means, and dividing by twice their respective standard deviations, to allow for direct comparisons of predictor effects at the same scale (see Grueber *et al*. 2011).

Once the initial 'global model' was determined, which included all explanatory variables, the second step of the model selection procedure involved an all-model-combinations model selection approach where candidate models containing all possible combinations of each predictor variable were competed against one another to find the top models that best describe redd presence and redd density. For each candidate model, the parsimony was quantified 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 redd density, 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.

We conducted an initial evaluation of the effects of the components of CI (CI_{Pr} and CI_{Conc}) on the probability of presence of redds and on redd density. To do this, we carried out the same analyses as described above but replaced CI with CI_{Pr} and CI_{Conc}. We found virtually identical results when we replaced CI by CI_{Pr}, in terms of the model selection and parameter estimates of the best models. This makes sense because CI and CI_{Pr} have a correlation of 0.977 (Figure 3). When we replaced CI with CI_{Conc} we found minor differences in the model results, although the conclusions were not affected. Therefore, we do not present the detailed results for each component of CI in Section 3 below. Further work could be completed in Year 2 of this study to determine the calcite versus spawning suitability curve for the components of CI when the dataset is larger.

Table 4. Summary and description of variables selected for modelling and included in the final model set.

Variable Type	Variable[1]	Description
Response	Redd Density	Measure of the density of redds per square meter of stream habitat. Calculated as number of redds divided by mesohabitat unit area (mean bankfull width x unit length)
	Redd Presence/Absence	Categorical variable indicating presence (1) or absence (0) of redds within a mesohabitat unit.
Random Effects	Tributary Stream	Categorical variable indicating waterbody where sampling occurred (Greenhills, LCO Dry, Clode, Fish Pond, and Henretta Creeks).
Fixed Effects	Calcite Index (CI)	Calcite index, calculated as the sum of Calcite presence and calcite concretion scores.
	Mesohabitat Type*	Categorical variable indicating mesohabitat unit type (Pool, Glide, Run, Riffle, Cascade).
	Streamflow*	Volume of water (m^3/s) moving through the mesohabitat unit .
	Bankfull Depth	Water depth (m) within mesohabitat unit at bankfull flow conditions.
	Bankfull Width*	Width of wetted channel (m) at bankfull flow conditions.
	Mean Velocity	Mean stream velocity (m/s) of mesohabitat unit.
	Mean Substrate Size*	Mean size of pebbles (mm) within each habitat unit, assessed during calcite index measures.
	Proportion Resident Spawning Gravel	Proportion of mesohabitat unit with gravels suitable for spawning. Calculated as the total area of functioning resident gravel divived by the mesohabitat unit area (mean bankfull width x unit length).
	Water Temperature	Water temperature (°C) within mesohabitat unit, collected during calcite index measures.
	Dissolved Oxygen*	Mean in situ measure of dissolved oxygen (mg/L and % saturation), collected within each mesohabitat unit.
	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.

[1] * identifies explanatory variables removed from final dataset due to collinearity.

3. RESULTS

A total of 62 mesohabitat units were surveyed in 2018, which includes spawning sites (redds present) and null sites (redds absent). Dry Creek and Fish Pond Creek had the greatest sampling effort (n=20 in each stream) due to the high numbers of redds observed and greater overall habitat area, followed by Greenhills Creek and Henretta Creek (n=9 in each stream; Figure 5). The smallest sample size was on Clode Creek (n=4, Figure 5) due to the low quantity of habitat available to sample. Mesohabitat types sampled the most were glides (n=30), followed by riffles (n=21), runs (n=8), and pools (n=3).

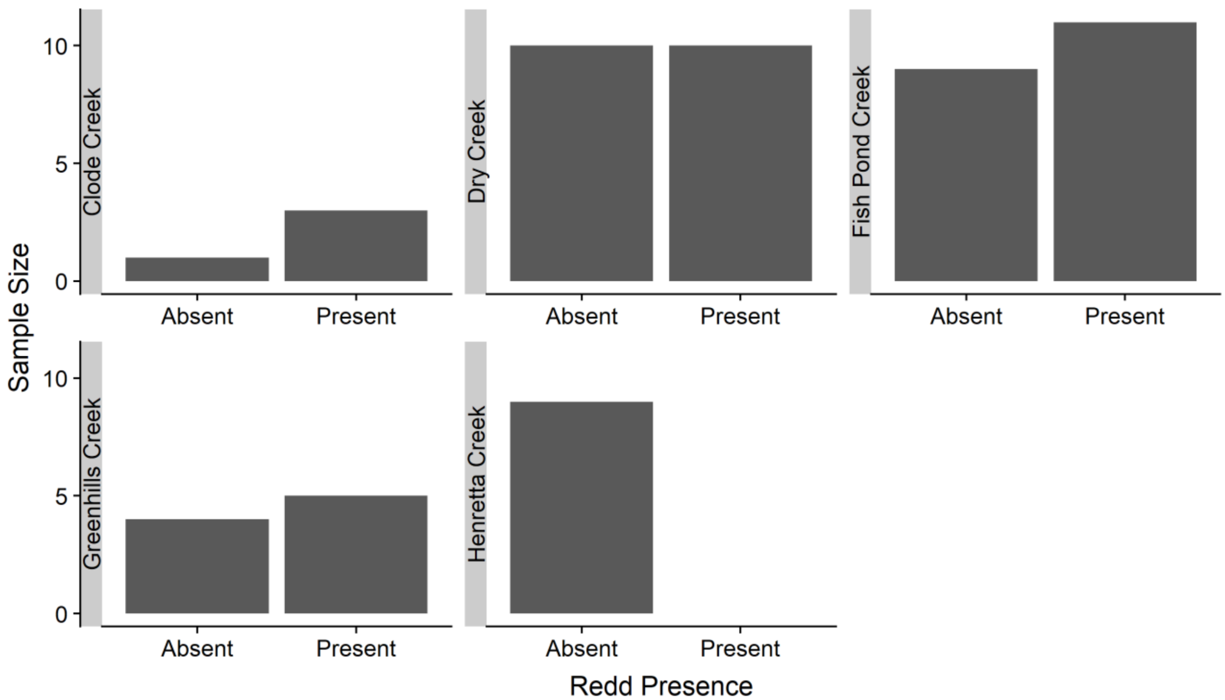


Figure 5. Number of mesohabitats surveyed, including spawning sites (redds present) and null sites (redds absent), by tributary in the upper Fording River watershed.

3.1. Redd Surveys

Westslope Cutthroat Trout redds were observed in LCO Dry, Fish Pond, Clode and Greenhills creeks (Figure 6, to Figure 9). No redds were observed in Henretta Creek. Greenhills Creek and Clode Creek had the highest median redd densities (0.1 redds/m^2), while having relatively low variability in redd density (Figure 10). Dry Creek and Fish Pond Creek showed lower median densities than Greenhills and Clode creeks at 0.003 and 0.006 redds/m^2, respectively. However, Dry Creek and Fish Pond Creek also had higher variability in redd density, including mesohabitats with the highest redd density measured at 0.10 – 0.15 redds/m^2.

Redd density varied by mesohabitat type (Figure 11). Redds were observed in only 1 pool, at very low density. Therefore, median redd density was lowest in this mesohabitat type (0.00 redds/m^2). Median redd density was also very low (zero) in riffles, although a few riffles supported up to 0.10 redds/m^2. Median redd density was low in glides (0.003 redds/m^2), but highly variable with several observations above 0.06 redds/m^2 and reaching values of up to 0.15 redds/m^2 in site FPC-CI21-3-sp. Median redd density was highest in runs (median: 0.01 redds/m^2), with lower variability (maximum density: 0.05 redds/m^2, Figure 11). A summary of redd locations and density by stream and mesohabitat type is also presented in Appendix A and Appendix B.

Figure 6. Redds observed (circles) in LCO Dry Creek on July 19, 2018 at LCDRY-CI42-SP.

Figure 7. Redd observed (circle) in Fish Pond Creek on July 14, 2018 at FCP-CI19-SP.

Figure 8. Redds observed (circles) at Clode Creek on July 13, 2018 at CLO-CI02-SP.

Figure 9. Redd observed (circle) at Greenhills Creek on July 10, 2018 at GRE-CI34-SP.

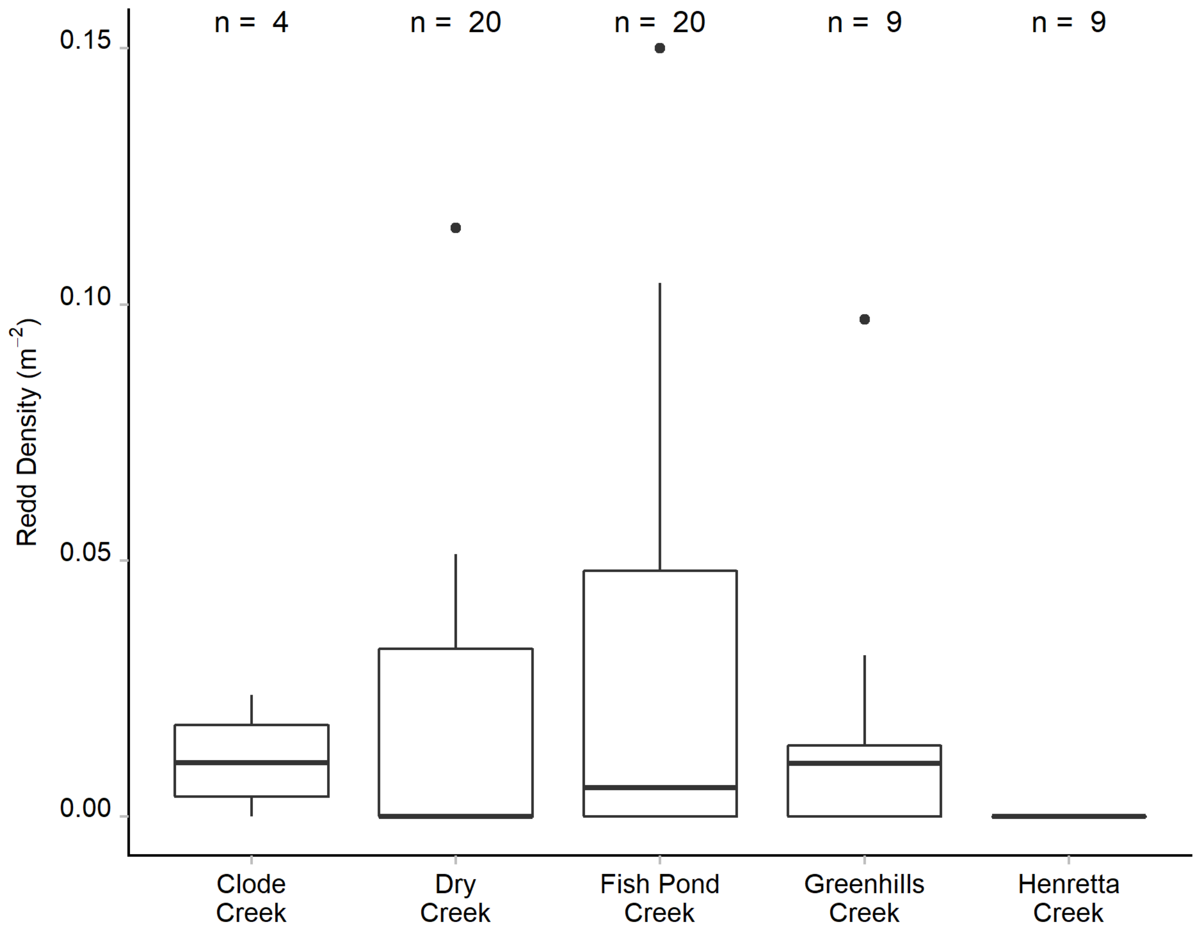


Figure 10. **Westslope Cutthroat Trout redd density by tributary stream in the upper Fording River watershed. The darker line represents the median, the upper and lower limits of the box represent the 75% and 25% quantiles (interquartile range), the whiskers extend to 1.5 times the interquartile range, and data beyond 1.5 times the interquartile range are represented as dots (outliers). The sample size (number of mesohabitat units) per creek is indicated above each boxplot.**

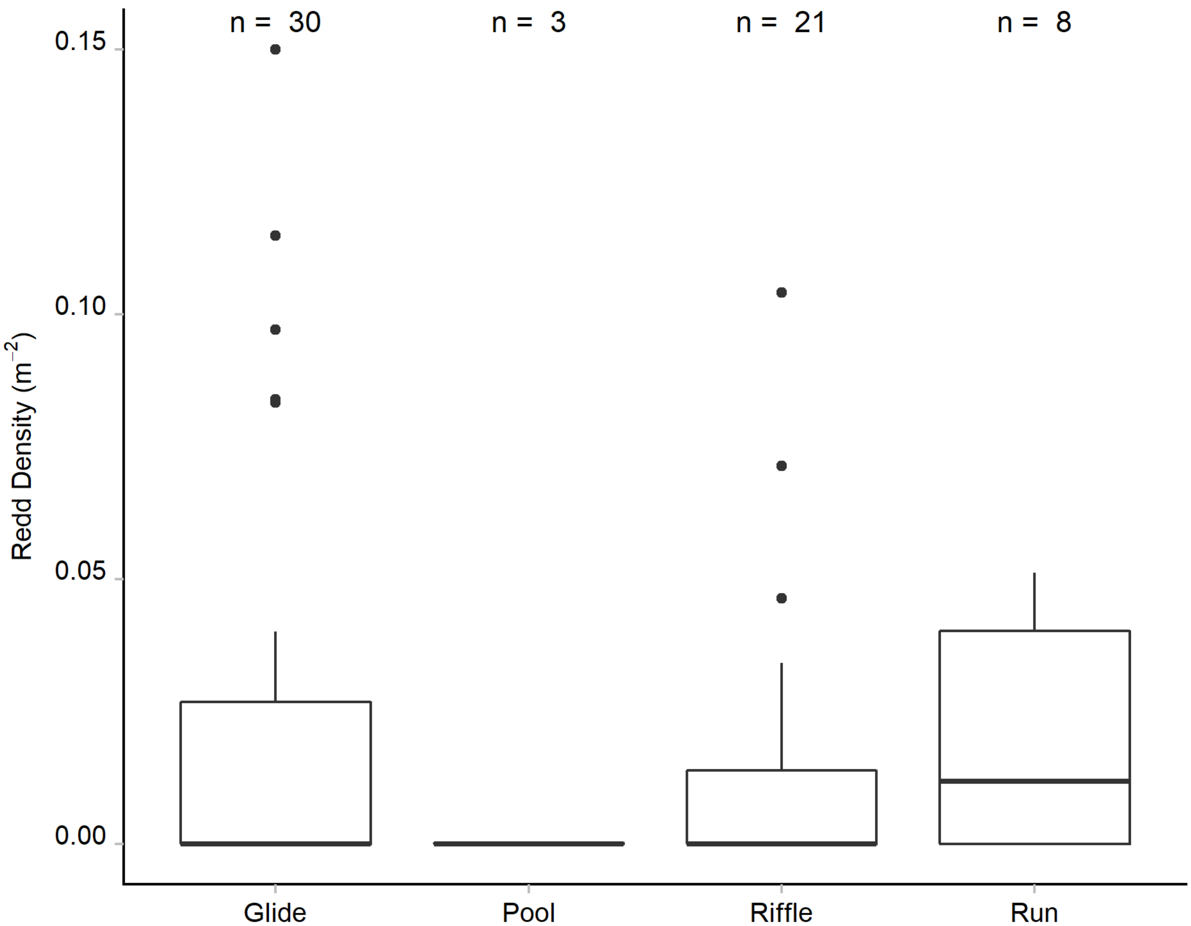


Figure 11. **Westslope Cutthroat Trout redd density by mesohabitat type across all sampled streams in the upper Fording River watershed. The darker line represents the median, the upper and lower limits of the box represent the 75% and 25% quantiles (interquartile range), the whiskers extend to 1.5 times the interquartile range, and data beyond 1.5 times the interquartile range are represented as dots (outliers). The sample size per mesohabitat type is indicated above each boxplot.**

3.2. Calcite Index and Fish Habitat

Calcite levels varied spatially throughout the study area (Figure 12), as expected from previous studies (Minnow Environmental 2016, Robinson *et al.* 2016, Wright *et al.* 2017; 2018), although calcite data did not span the full range of CI scores possible (0 to 3). The highest CI was recorded at Clode Creek (CI = 1.66, CLO-CI04). Greenhills Creek and Clode Creek had the highest median CI scores of 0.89 and 1.00, respectively (Figure 12). The lowest median CI was measured in LCO Dry Creek, with 13 out of 20 readings of 0.00 (median CI = 0.00). The second lowest median (median CI = 0.02) was recorded in Henretta Creek, although the values recorded were highly variable. Fish Pond Creek showed relatively low variability and a median CI of 0.03.

Calcite levels did not vary strongly by mesohabitat type (Figure 13). Median calcite levels were low in all mesohabitat types; CI was lowest in runs (mean = 0.00), followed by riffles (0.03), pools (0.04), and glides (0.07). In terms of variability, the lowest variability was recorded in pools (sd = 0.03), followed by glides (sd = 0.04), riffles (sd = 0.5), and runs (sd = 0.07). The distribution of calcite index scores by mesohabitat unit type in each stream is shown in Table 5.

All mesohabitat units identified within each waterbody as well as the individual mesohabitat units selected for calcite sampling are presented in Appendix A. Calcite, FHAP, water quality and spawning data at each mesohabitat unit sampled during the calcite assessment is summarized in Appendix B.

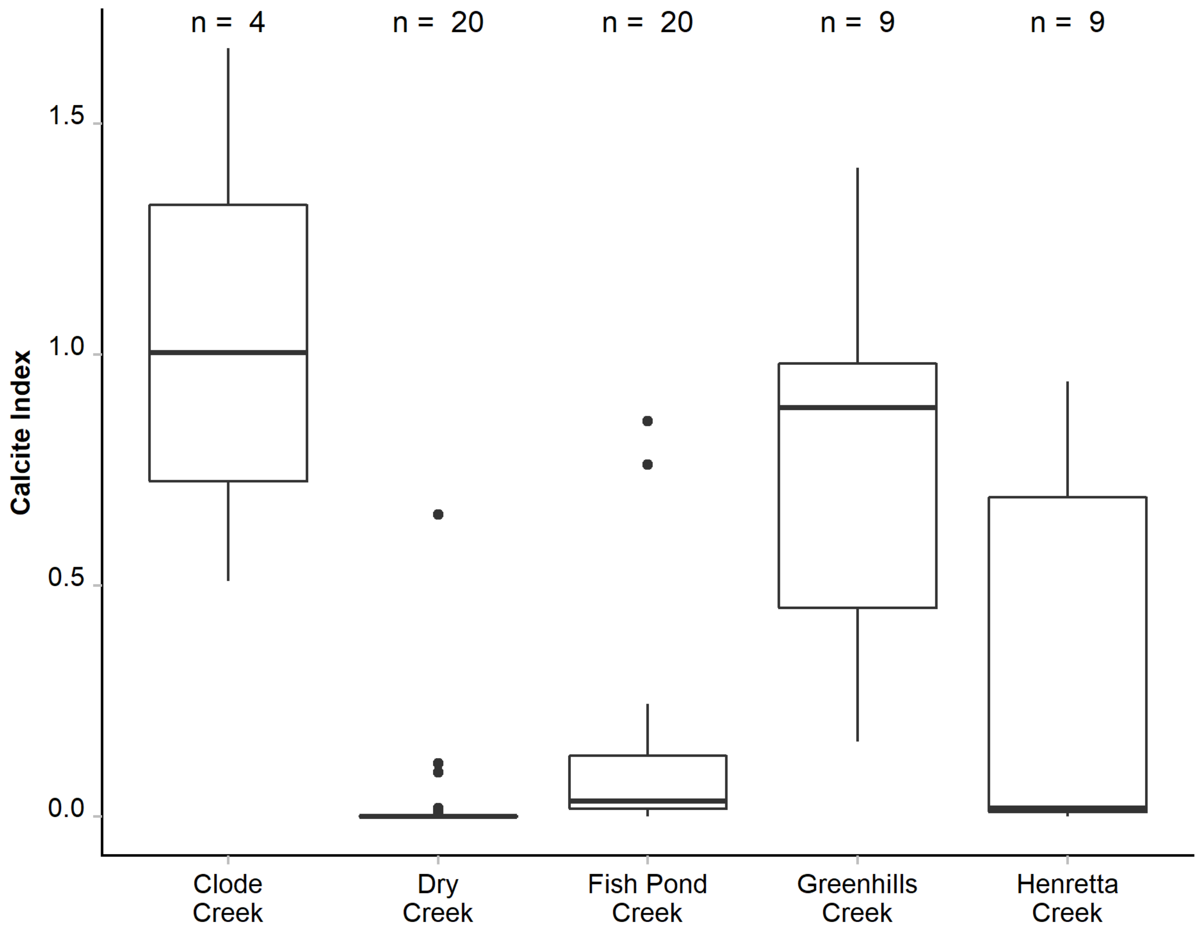


Figure 12. **CI scores by tributary stream in the upper Fording River watershed. The darker line represents the median, the upper and lower limits of the box represent the 75% and 25% quantiles (interquartile range), the whiskers extend to 1.5 times the interquartile range, and data beyond 1.5 times the interquartile range are represented as dots (outliers). The sample size per creek is indicated above each boxplot.**

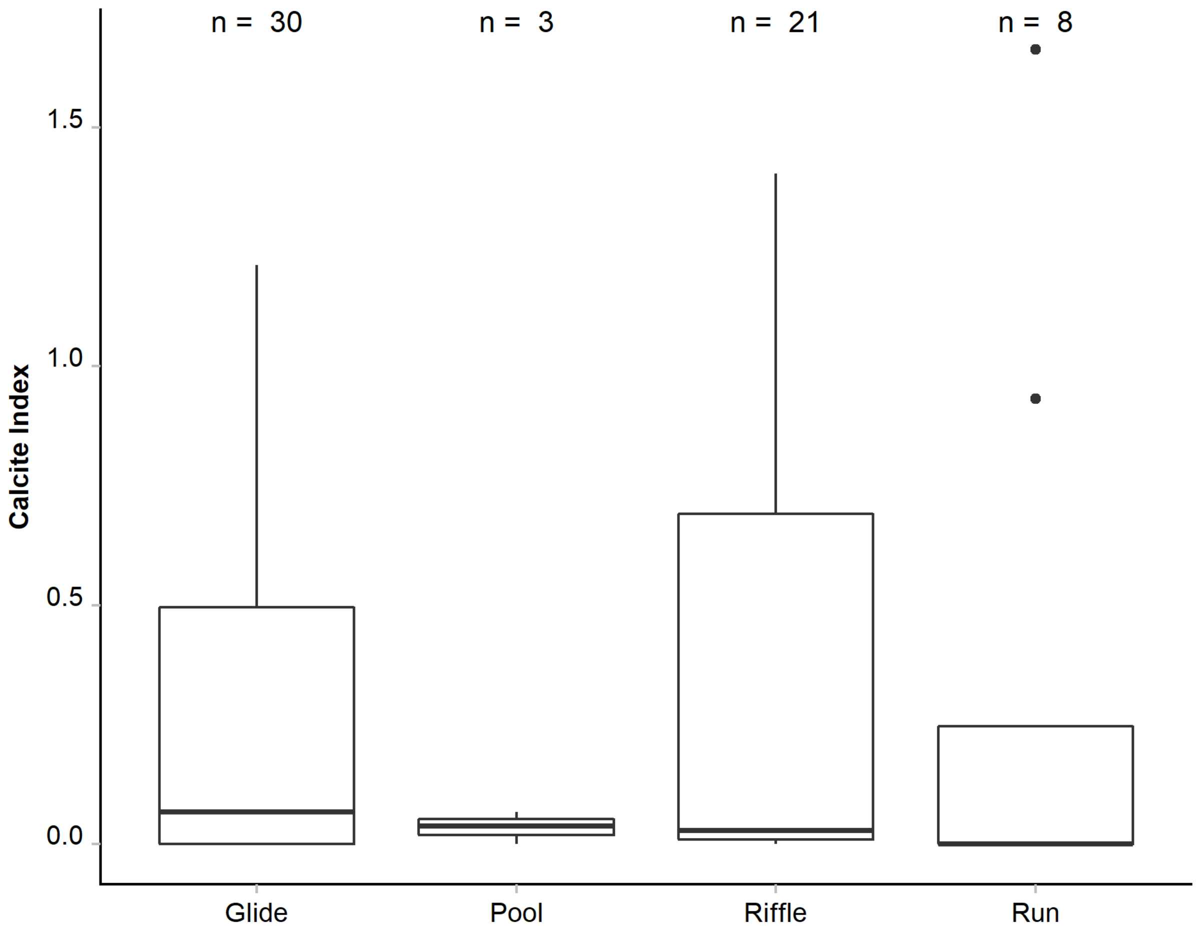


Figure 13. **CI scores by mesohabitat type in the upper Fording River watershed. The darker line represents the median, the upper and lower limits of the box represent the 75% and 25% quantiles (interquartile range), the whiskers extend to 1.5 times the interquartile range, and data beyond 1.5 times the interquartile range are represented as dots (outliers). The sample size per mesohabitat type is indicated above each boxplot.**

Table 5. Mean calcite index ± standard error (se) by tributary stream and mesohabitat type sampled. The number of mesohabitat units (n) sampled per stream and mesohabitat type is shown.

Stream	Glide			Pool			Riffle			Run		
	n	mean	se	n	mean	se	n	mean	se	n	mean	se
Clode Creek	3	0.84	0.20	-	-	-	-	-	-	1	1.66	-
Dry Creek	7	0.11	0.09	1	0.00	-	7	0.02	0.02	5	0.00	0.00
Fish Pond Creek	11	0.15	0.07	2	0.05	0.01	7	0.14	0.12	-	-	-
Greenhills Creek	5	0.69	0.12	-	-	-	4	0.94	0.27	-	-	-
Henretta Creek	4	0.01	0.00	-	-	-	3	0.56	0.26	2	0.48	0.46

3.3. Redd Presence

Variability in the presence of redds in the streams surveyed was not strongly explained by CI scores nor any of the stream habitat variables (Figure 14, Figure 15). Mean CI scores were similar between spawning sites and null sites (Figure 14a) and did not show a calcite response as conceptualized in Section 2.2 (Figure 14b). All explanatory variables, including CI, had coefficients with confidence intervals that overlapped with zero (p-values > 0.05 in Figure 15). The top models explaining redd presence all received relatively similar empirical support (model weights were all 0.10 or less) and were not significantly better than the null model with only a random intercept term. Model selection statistics for the top 10 models are presented in Table 6. The model with the highest weight included only water velocity and not CI.

The evidence for individual explanatory variables can be evaluated by summing the weights of models that contain the same explanatory variable (e.g., the four of the first five best models contain the term water velocity: Table 6), to derive a score called relative variable importance (RVI; Figure 15). Mean water velocity had the highest relative variable importance (RVI = 0.58), whereas CI score was not present in most of the top models (RVI = 0.22).

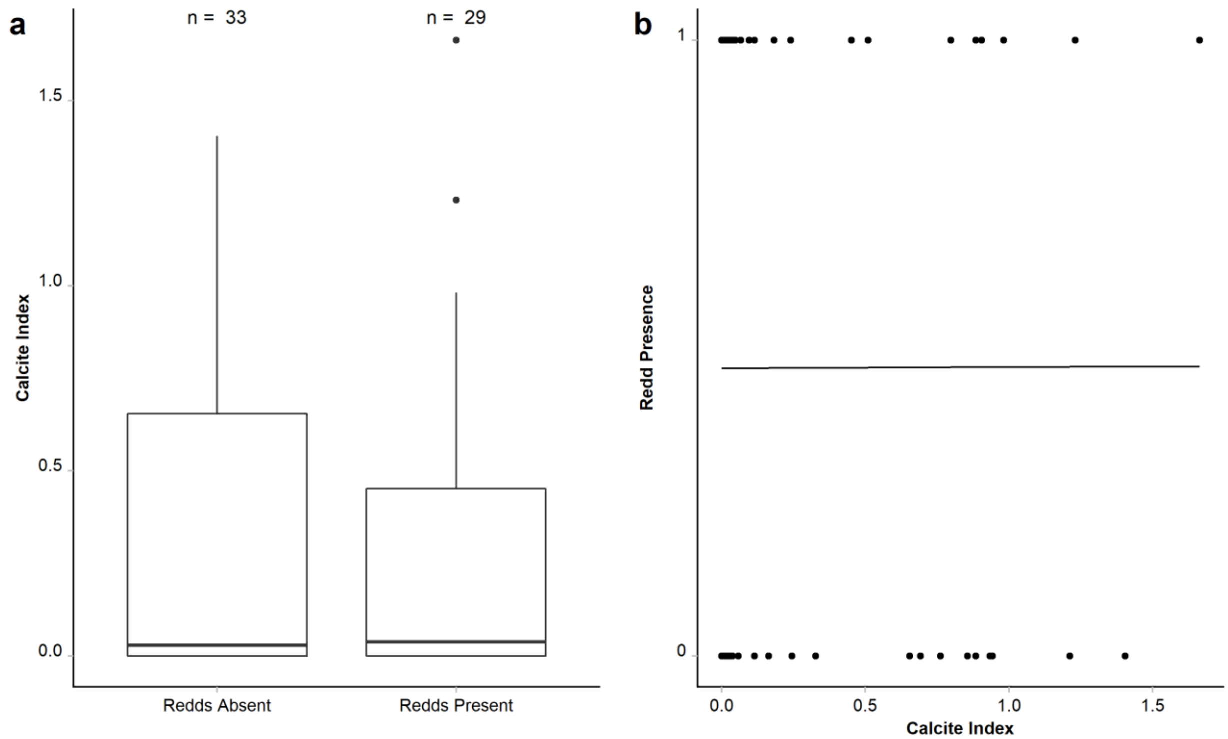


Figure 14. **(a) Average CI score at spawning sites (redds present) and null sites (redds absent) in the upper Fording River watershed. (b) Redd presence versus CI. The solid line represents the probability of redd presence as a function of CI (estimated from a logistic regression model: model averaged parameter estimates for calcite shown in Figure 15).**

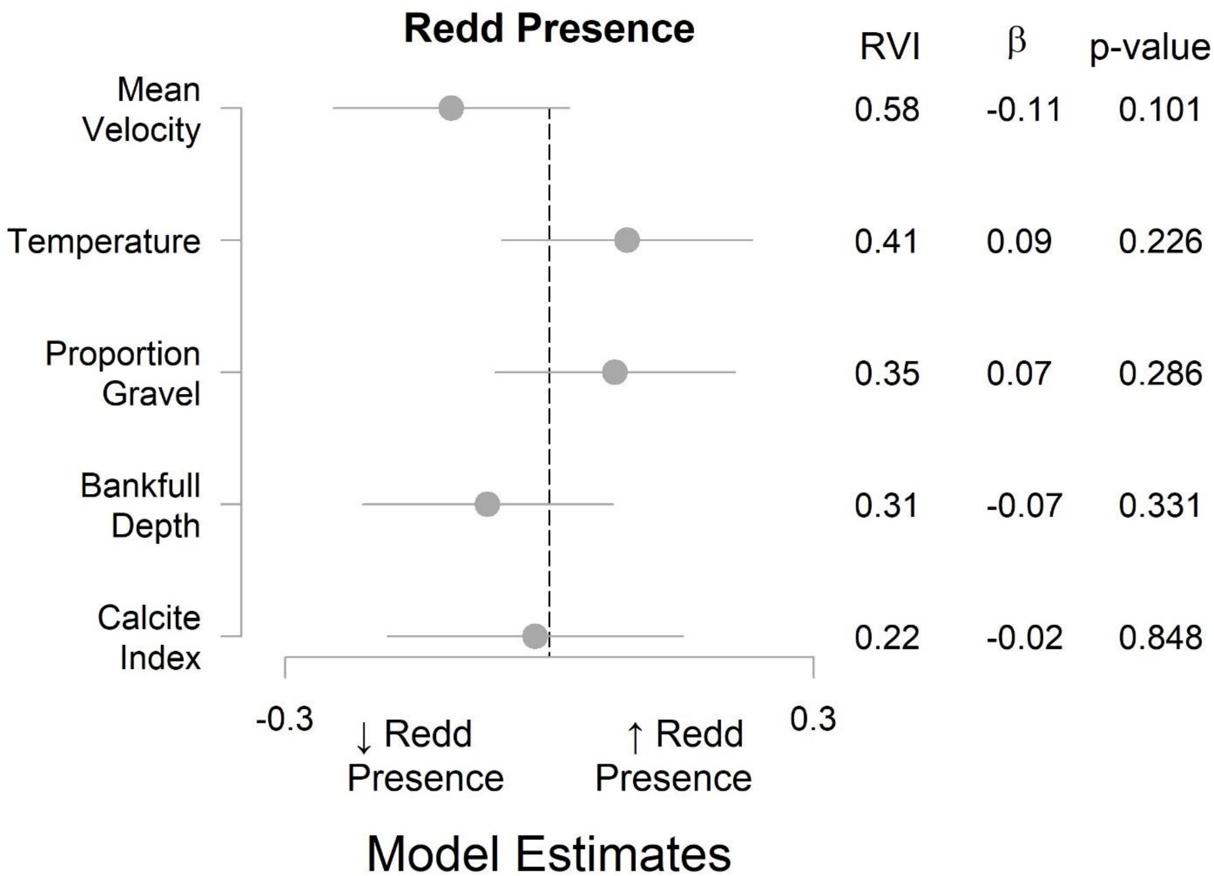


Figure 15. **Model averaged coefficients (with 95% confidence intervals) indicating the most important variables predicting redd presence. Values in the x-axis are estimates of model parameters. RVI = Relative Variable Importance scores, where a score of 1 indicates that a predictor variable occurs in all top models with ΔAICc < 4. β represents the values of the model averaged coefficients. p-values represent probability that the coefficient is equal to 0.**

Table 6. Top models that best predict Westslope Cutthroat Trout redd presence in the upper Fording River watershed. 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 ~ Mean Velocity	0.00	0.10
Redd Presence ~ Mean Velocity + Bankfull Depth	0.33	0.08
Redd Presence ~ 1 (Null Model)	0.66	0.07
Redd Presence ~ Mean Velocity + Temperature	0.84	0.06
Redd Presence ~ Mean Velocity + Proportion Gravel	0.97	0.06
Redd Presence ~ Temperature	1.02	0.06
Redd Presence ~ Proportion Gravel	1.35	0.05
Redd Presence ~ Proportion Gravel + Temperature	1.58	0.04
Redd Presence ~ Proportion Gravel + Mean Velocity + Temperature	1.70	0.04
Redd Presence ~ Bankfull Depth + Mean Velocity + Temperature	1.77	0.04

3.4. Redd Density

3.4.1. Beta Regression Model

Variability in the density of redds in the streams surveyed was not strongly explained by the measured CI scores nor any of the stream habitat variables (Figure 16). All explanatory variables, including CI, had coefficients with confidence intervals that overlapped with zero (*i.e.*, not statistically different from zero, p-values > 0.05 in Figure 16). The top models explaining redd density all received relatively similar empirical support (model weights were all 0.16 or less). Model selection statistics for the top 10 models is presented in Table 7. The model with the highest weight included only bankfull depth. CI was included in the second ranked model.

The relative variable importance of each explanatory variable is shown in Figure 16. Bankfull depth had the highest relative variable importance among the explanatory variables (RVI = 0.60). The effect of bankfull depth was negative, which suggests that redds are less common in deep water. CI was the second most important variable to explain redd density, and its effect was negative, i.e. there are lower redd densities in mesohabitats with higher CI scores (Figure 16).

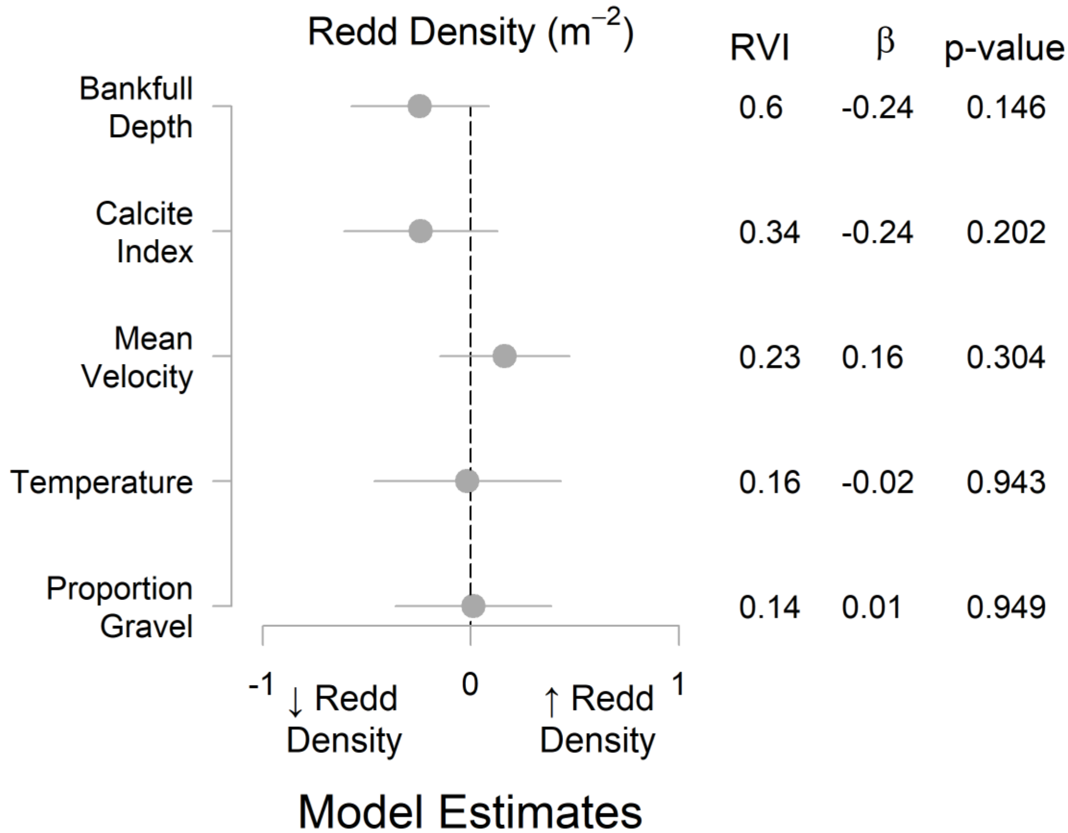


Figure 16. **Model averaged coefficients (with 95% confidence intervals) indicating the most important variables describing redd density, modelled using beta regression models. Values in the x-axis are estimates of model parameters. RVI = Relative Variable Importance scores, where a score of 1 indicates that a predictor variable occurs in all top models with ΔAICc < 4. β represents the values of the model averaged coefficients. p-values represent probability that the coefficient is equal to 0.**

Table 7. Top models that best predict Westslope Cutthroat Trout redd density in the upper Fording River watershed, modelled using beta regression models. Models are ranked by 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. Values of pseudo R2 (Ferrari and Cribari-Neto (2004)) are also presented.

Model		ΔAICc	Weight	Pseudo R^2
Redd Density ~	Bankfull Depth	0	0.2	0.23
Redd Density ~	Bankfull Depth + Calcite Index	0.89	0.13	0.25
Redd Density ~	1 (Null Model)	1.08	0.11	
Redd Density ~	Mean Velocity	2.02	0.07	0.06
Redd Density ~	Calcite Index	2.41	0.06	0.05
Redd Density ~	Bankfull Depth + Temperature	2.45	0.06	0.24
Redd Density ~	Bankfull Depth + Mean Velocity	2.5	0.06	0.24
Redd Density ~	Bankfull Depth + Proportion Gravel	2.76	0.05	0.23
Redd Density ~	Proportion Gravel	2.79	0.05	0.03
Redd Density ~	Calcite Index + Mean Velocity	2.98	0.04	0.12

3.4.2. Quantile Regression Model

The wedge shape of the relationship between calcite and redd density is illustrated in Figure 17. A species' abundance may 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. In the current data set redds occur throughout the range of CI scores observed. However, high redd densities are only found at low levels of CI (Figure 17). The quantile regression slopes of the 50^{th} quantile has a slope close or equal to zero, while the 90^{th} quantile regression line has a negative slope.

The relative variable importance of each explanatory variable in predicting the 90^{th} quantile of redd density is shown in Figure 18. Bankfull depth, proportion gravel and CI score had relative variable importance scores of 0.96, 0.78 and 0.73, respectively, providing evidence for an effect of these habitat variables in predicting redd density. The proportion of each mesohabitat area covered by spawning gravel has a positive effect on redd density, while bankfull depth and CI have a negative effect on redd density. However, due to the large variance at the edges of the data (i.e., the 90^{th} quantile), all explanatory variables, including CI, had coefficients with confidence intervals that overlapped with zero (p-values > 0.05 in Figure 18).

Similar to the beta regression models for mean redd density, several quantile regression models for the 90^{th} quantile of redd density received similar empirical support (Table 8). However, counter to the results for redd presence and mean redd density, none of the top models in the 90^{th} quantile regression included the null intercept-only model. The model with the highest weight included a combination of bankfull depth, proportion gravel and CI score. Based on the current data, there was little support for temperature or water velocity affecting redd density.

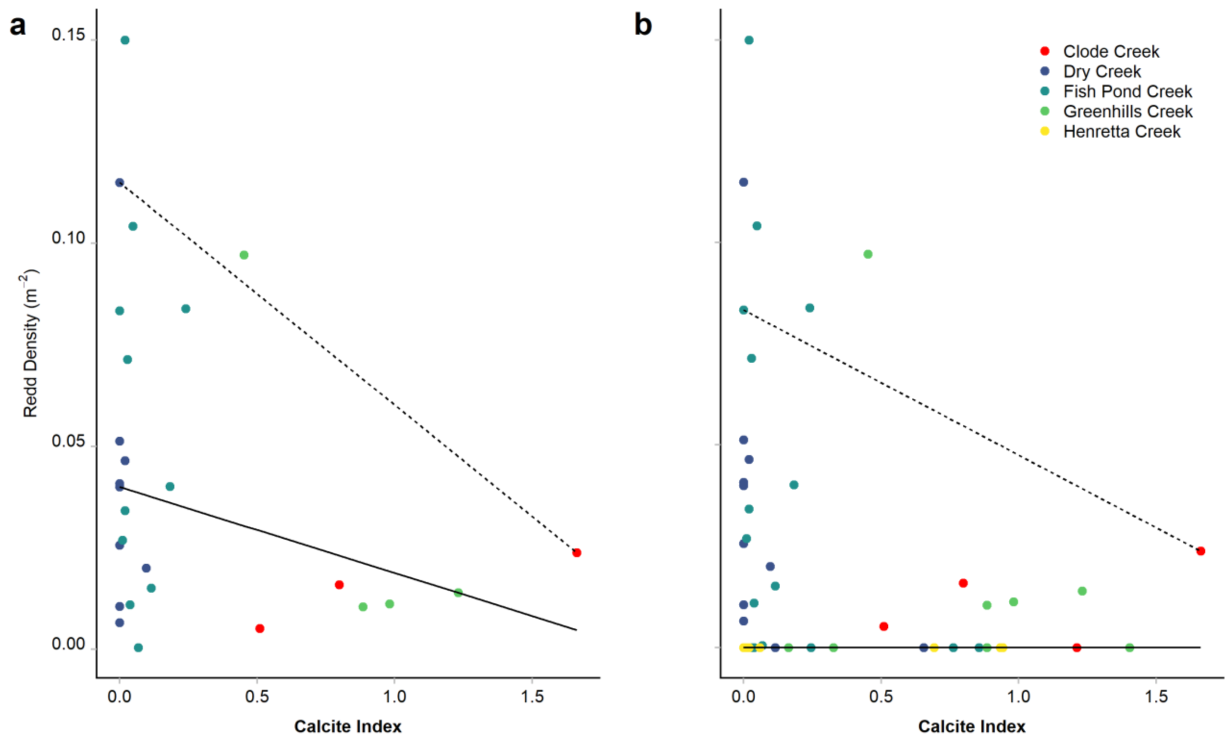


Figure 17. **Westslope Cutthroat Trout redd density as a function of CI and the 50th and 90th quantile regression fits to the data. (a) Plot only shows mesohabitats where redds were observed (null sites excluded). (b) Plot shows all of the data, including both spawning sites and null sites.**

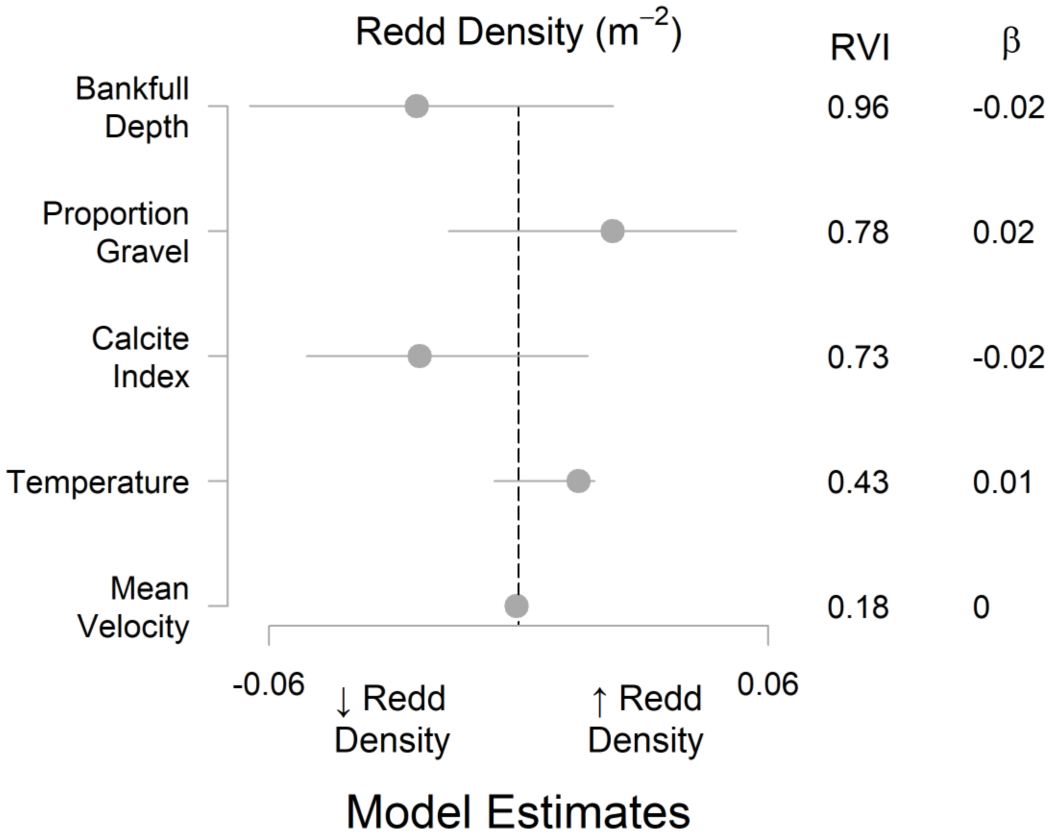


Figure 18. **Model averaged coefficients (with 95% confidence intervals) indicating the most important variables describing redd density, modelled using quantile regression models. Values in the x-axis are estimates of model parameters. RVI = Relative Variable Importance scores, where a score of 1 indicates that a predictor variable occurs in all top models with ΔAICc < 4. β represents the values of the model averaged coefficients.**

Table 8. Top models that best predict Westslope Cutthroat Trout redd density in the upper Fording River watershed, modelled using quantile regression. Models are ranked by ΔAkaike 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. Values of $R^1_{(\tau)}$ (Koenker and Machado (1999)) are also presented.

Model	ΔAICc	Weight	$R^1_{(\tau)}$
Redd Density ~ Bankfull Depth + Calcite Index + Proportion Gravel	0	0.21	0.26
Redd Density ~ Bankfull Depth + Proportion Gravel	0.35	0.17	0.22
Redd Density ~ Bankfull Depth + Calcite Index + Proportion Gravel + Temperature	0.42	0.17	0.29
Redd Density ~ Bankfull Depth + Calcite Index + Temperature	1.12	0.12	0.24
Redd Density ~ Bankfull Depth + Calcite Index	2.27	0.07	0.19
Redd Density ~ Bankfull Depth + Proportion Gravel + Temperature	2.62	0.06	0.22
Redd Density ~ Bankfull Depth + Calcite Index + Proportion Gravel + Mean Velocity + Temperature	2.68	0.05	0.31
Redd Density ~ Bankfull Depth + Proportion Gravel + Mean Velocity	2.99	0.05	0.22
Redd Density ~ Bankfull Depth + Calcite Index + Proportion Gravel + Mean Velocity	3.02	0.05	0.26
Redd Density ~ Calcite Index + Proportion Gravel	3.44	0.04	0.17

4. DISCUSSION

4.1. Testing the Research Hypothesis H2

Data collected in 2018 came from redd surveys, calcite surveys, fish habitat assessments and assessment of water quality from 62 mesohabitat units in five tributary streams of the upper Fording River watershed. These data were used to test the research hypothesis H2:

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

H_A2 (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. The five tributary streams included in the 2018 study were observed to support Westslope Cutthroat Trout spawning in previous years (Cope *et al.* 2016; Wright *et al.* 2018).

The study design in 2018 built on the outcomes 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 with varying levels of calcite (Wright *et al.* 2017; 2018). These 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 Westslope Cutthroat Trout 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, sites with relatively 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 (Figure 1).

Three different modelling approaches were used to test the relationship between spawning substrate suitability and calcite condition: a redd presence absence model, a beta regression model, and a quantile regression model. The beta regression and quantile regression models used redd density (redds/m^2) as the response variable.

Variability in the presence of redds in the streams surveyed was not explained by the measured CI scores nor any of the stream habitat variables. Mean CI scores were similar between spawning sites and null sites and did not show a calcite response as conceptualized in Section 2.2 (Figure 14).

Variability in density of redds in the streams surveyed was modeled using beta regression, and was also not strongly explained by the measured CI scores. CI was found to be the second most important variable to explain redd density, and its effect was negative, which is consistent with the predicted direction of effect. However, all explanatory variables, including CI, had coefficients with confidence intervals that overlapped with zero (p-values > 0.05 in Figure 16). The relative variable importance of

CI in explaining redd density was 0.34, which means that CI occurred in only roughly one third of the top models that were competed against one another to best explain patterns in redd density.

The clearest result of the three modelling approaches was observed with quantile regression applied to the redd density data. This approach models the outer bounds of the wedge-shaped relationship between calcite and redd density (Figure 17). Quantile regression is a useful analytical method to examine 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). For example, the 90th quantile is a robust model to describe the upper bounds of wedge-shaped relationships (Scharf *et al.* 1998, Armstrong *et al.* 2010, Hocking *et al.* 2013).

Redds were found throughout the range of CI observed. However, high redd densities were only found at low levels of CI. Conversely, above a CI score of ~0.5, redd densities were low and did not exceed 0.025 redds/m^2 of habitat. In the quantile regression models, CI had a relative variable importance score equal to 0.73, which means that CI occurred in roughly three quarters of the top models explaining redd density. This result provides evidence for an effect of calcite on spawning substrate conditions. Further, the CI threshold of 0.5 aligns with the 2029 SPO for calcite of CI ≤ 0.5 as defined in Permit 107517. However, we caution that there is not enough data to currently confirm that CI = 0.5 represents a true threshold for spawning habitat suitability due to the limited dataset.

Overall, the results suggest there may be two different habitat suitability response curves between calcite and spawning habitat; one response curve that describes a relationship for the presence of redds, and a second relationship for the density of redds. Preliminary conceptual response curves for redd presence and redd density are visualized in Figure 19.

Calcite is one of many influences on fish and fish habitat, and these other influences (e.g., substrate, cover, water depth, velocity, water quality, etc.) need to be considered as potential covariates when developing the spawning substrate suitability versus calcite response curve. Therefore, a number of habitat variables were included in the modelling to account for variable 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 included in model selection were CI, mean water velocity, proportion spawning gravel, bankfull depth, and water temperature. All of these habitat variables were hypothesized to affect spawning suitability.

Some habitat variables were found to predict Westslope Cutthroat Trout spawning. Water velocity was found to be weakly negatively related to redd presence, which suggests that redds occur less frequently in slow water habitats such as pools. Mean water velocity had the highest relative variable importance (RVI = 0.58) compared to other habitat variables, and was present in four of the first five top models explaining redd presence. Bankfull depth had the highest relative variable importance (RVI = 0.60) among the explanatory variables explaining redd density in the beta regression model. The effect of bankfull depth was negative, which suggests that redds are less common in deep water. In the quantile regression model, bankfull depth and proportion spawning gravel were the most important predictors of redd density with relative variable importance scores of 0.96 and 0.78, respectively. The proportion of each mesohabitat area covered by spawning gravel has a positive effect on redd density (e.g., Magee *et al.* 1996), while deeper water sites such as pools support lower redd density.

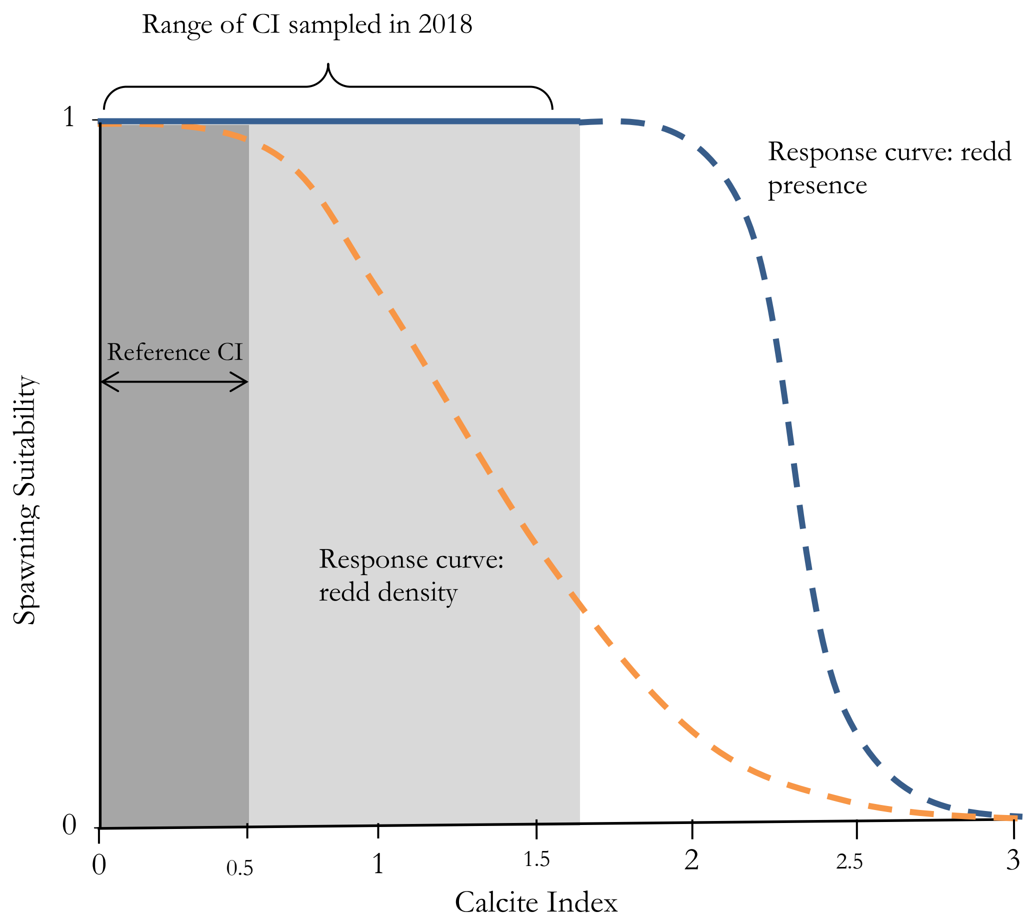


Figure 19. **Conceptual response curves for redd presence and redd density across the range of sampled CIs in 2018. The dashed lines represent that these are conceptual curves and that there is uncertainty in the data based on the limited dataset. The dark grey rectangle represents the range of naturally occurring calcite indices in reference streams (0-0.5). The light grey rectangle represents the range of calcites indexes at sites sampled in 2018 (0-1.66).**

4.2. Uncertainties and potential next steps

A key limitation of the present study was that most of the mesohabitat locations measured had relatively low to moderate calcite scores. The highest average CI score occurred in Clode Creek (mean CI = 1.00, maximum CI = 1.66). CI can range from 0 to a maximum of 3, but we were not able to test the relationship between CI and redd presence and density across the full range of possible calcite conditions. It is likely that a stronger effect of calcite on redd density would be observed if we included sites with higher levels of CI. More than 90% of the mesohabitats surveyed so far for this study had CI scores <1. In addition, there seems to be a threshold of ~75% calcite presence (CI_{Pr}) before concretion (CI_{Conc}) occurs (Figure 3), and therefore CI_{Conc} was higher than zero in only a few sites. We suggest that future effort focus on streams and mesohabitats with higher levels of calcite, especially CI scores between 2 and 3. This will also allow a more thorough exploration of how components of CI (CI_{Pr} and CI_{Conc}) may differentially affect the presence and density of Westslope Cutthroat Trout redds.

We suggest that Teck consider extending this study for at least one additional year of data collection. One consideration is whether to resample some of the same streams or to sample entirely new locations. In the present analysis, tributary stream was used as a random effect because there is a strong correlation in the calcite and stream habitat data collected across different mesohabitats on the same stream compared to other sampled streams. In that sense, although the unit of replication is the mesohabitat unit (62 sampled), only five different tributary streams were sampled, which inherently limits the level of inference that can be drawn from the data. Evidence for this limitation is observed in the high variability in effect sizes for each of the explanatory variables (e.g., wide confidence intervals in Figure 15, Figure 16, Figure 18). We therefore suggest that as many new streams (or reaches) as possible be sampled to increase the sample size and the diversity of stream habitats measured.

Streams that show significant changes (both increases or decreases) in calcite conditions from one year to the next could also be monitored. Shifts in calcite conditions within a single stream over time present a natural experiment to detect potential effects to spawning conditions. Although increasing the number of streams surveyed, including sites with high CI scores, is the primary recommendation, we suggest that Teck consider monitoring any streams that have calcite conditions that have changed considerably through time. An example would be to monitor effects to Westslope Cutthroat Trout response to the calcite prevention activities occuring on Lower Greenhills Creek (Teck 2019).

Another consideration is to include some reference streams that support Westslope Cutthroat Trout spawning but do not have mining influence. This will allow comparison of the natural range in redd presence and redd densities to streams influenced by mining. Adding reference streams will also increase our ability to test for other measured fish habitat variables and their influence on spawning suitability.

A final consideration is that some habitats may have been under-represented in sampling and could receive more effort during an additional year of data collection. For example, pool habitats are scarce in our samples from 2018. We suggest that the selection of null sites be adjusted to better represent all mesohabitat types in sampling. In some of the smaller streams (e.g., Clode Creek) this is not possible as all or most mesohabitats were sampled. In the larger streams with more mesohabitat units, null sites should better sample units in proportion to their availability in the stream.

It also is possible to expand the data analysis approach if a second year of data collection occurs. A larger dataset across a broader range of sites, including some with high CI scores (CI = 2 to 3) would likely reduce the variability in the response and increase the level of inference (i.e., prediction) that could be drawn. This would also enable more work on the components of CI (CI_{Pr} and CI_{Conc}) and their influence on redd presence and redd density. One challenge during analysis of the redd density data was how to include the null sites with zero redds in the model selection for redd density. If all of the null sites are included then a zero inflated mixed-effects model needs to be used, which can be complicated and challenging to fit. An extension to the current analysis could be to subsample the null sites at random so that some null sites (i.e., zeros) could be included in a general linear model or quantile regression model of redd density. This additional effort could be warranted if the overall sample size was increased.

5. CONCLUSION

A redd presence absence model and two different redd density models were developed to test if calcite conditions influence spawning habitat suitability for Westslope Cutthroat Trout in the upper Fording River watershed. Overall, based on the streams sampled in 2018, we conclude that redds may be present at stream sites across the full range of CI scores sampled (up to ~1.7) and there was no apparent decline in suitability for redd presence over this range of CI. However, there is evidence for an influence of CI on redd density. The highest redd densities were only found at low levels of CI. Above a CI score of ~0.5, redd densities were low and did not exceed 0.025 redds/m^2 of habitat. Our conclusions should be considered preliminary, as the results are based on a fairly low sample size and therefore have broad confidence intervals. Nevertheless, the results suggest there may be two different response curves between calcite and spawning habitat; one response curve that describes a relationship for the presence of redds, and a second relationship for density of redds. The occurrence of two different relationships may be due to habitat heterogeneity within mesohabitat units, particularly at moderate levels of calcite, such that spawning may be possible, but at a lower spawning intensity (i.e., a small number of redds may occur but not more than this). Additional field work and analysis are required to reduce uncertainties in the results presented here and to improve the predictive ability of the spawning habitat response curves. At this time, a study design for 2019 work is advancing, which will incorporate recommendations from this 2018 study.

REFERENCES

Armstrong, D.S., T.A. Richards, and S.L. Brandt. 2010. Preliminary assessment of factors influencing riverine fish communities in Massachusetts. U.S. Geological Survey Open-File Report 2010-1139, 43 p.

Barton, K. 2018. MuMIn: Multi-Model Inference. R package version 1.42.1. Available online at: https://CRAN.R-project.org/package=MuMIn. Accessed on November 16, 2018.

Beswick, S.M. 2007. Greenhills Creek fish stream identification. Report prepared for Elk Valley Coal Corporation, Elkford, B.C. Prepared by Kootenay Natural Resource Consulting. 14 p.

Buchanan, S., S. Faulkner, and K. Akaoka. 2016. Dry Creek Fish Habitat Assessment Report. Consultant's report prepared for Teck Coal Limited by Ecofish Research Ltd., December 9, 2016.

Burnham, K.P., and D.R. Anderson. 2002. Model selection and multimodel inference. A practical Information-theoretic approach. Springer, New York, USA.

Burnham, K. P., Anderson, D. R., and Huyvaert, K. P. 2011. AIC model selection and multimodel inference in behavioral ecology: Some background, observations, and comparisons. Behavioral Ecology and Sociobiology, 65: 23–35.

Cade, B.S., and B.R. Noon. 2003. A gentle introduction to quantile regression for ecologists. Frontiers in Ecology and the Environment. 1: 412-420.

Cade, B.S., J.W. Terrell, and R.L. Schroeder. 1999. Estimating effects of limiting factors with regression quantiles. Ecology 80: 311-323.

Cade, B.S., B.R. Noon, and C.H. Flather. 2005. Quantile regression reveals hidden bias and uncertainty in habitat models. Ecology 86: 786-800.

Clark, M.J.R.E. 2013. British Columbia Field Sampling Manual: Part E Water and Wastewater Sampling, Ambient Freshwater and Effluent Sampling. Water, Air and Climate Change Branch, Ministry of Water, Land and Air Protection, Victoria, BC, Canada. Available online at: https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/monitoring/emre/bc_field_sampling_manual_part_e.pdf. Accessed on December 12, 2017.

Cope, S., C.J. Schwarz, A. Prince and J. Bisset. 2016. Upper Fording River Westslope Cutthroat Trout Population Assessment and Telemetry Project: Final Report. Report Prepared for Teck Coal Limited, Sparwood, BC. Report Prepared by Westslope Fisheries Ltd., Cranbrook, BC. 259 p.

Cribari-Neto, F, and A. Zeileis. 2010. Beta Regression in R. Journal of Statistical Software 34(2), 1-24. Available online at: http://www.jstatsoft.org/v34/i02/. Accessed on November 16, 2018.

Faulkner, S., N. Swain, I. Girard, J. Ellenor, and T. Hatfield. 2018. Dry Creek Fish and Fish Habitat Monitoring Program Year 2 Baseline Summary Report. Consultant's report prepared for Teck Coal Limited by Ecofish Research Ltd, Draft V1.

Ferrari, S.L.P., and F. Cribari-Neto. 2004. Beta regression for modelling rates and proportions. Journal of Applied Statistics 31: 799-815.

Grueber, C.E., S. Nakagawa, R.J. Laws and I.G. Jamieson. 2011. Multimodel inference in ecology and evolution: challenges and solutions. Journal of Evolutionary Biology, 24: 699-711.

Hocking, M.D., N.K. Dulvy, J.D. Reynolds, R.A. Ring, and T.E. Reimchen. 2013. Salmon subsidize an escape from a size spectrum. Proceedings of the Royal Society of London – Biological Sciences 280: 20122433.

Huang, Q., H. Zhang, J. Chen, and M. He. 2017. Quantile regression models and their applications: a review. Journal of Biometrics and Biostatistics, 8(3). DOI: 10.4172/2155-6180.1000354.

Hurlbert, S.H. 1984. Pseudoreplication and the Design of Ecological Field Experiments. Ecological Monographs 54: 187-211. doi:10.2307/1942661

Johnston, N.T. and P.A. Slaney. 1996. Fish habitat assessment procedures. Watershed Restoration Technical Circular No. 8 (revised April 1996). Watershed Restoration Program. Ministry of Environment, Lands and Parks and Ministry of Forests, Victoria BC.

Koenker, R. 2018. quantreg: Quantile Regression. R package version 5.36. Available online at: https://CRAN.R-project.org/package=quantreg. Accessed on November 16, 2018.

Koenker, R., and Machado, J.A. 1999. Goodness of Fit and Related Inference Processes for Quantile Regression, Journal of the American Statistical Association, 94(448): 1296-1310

Magee, J.P., T.E. McMahon, and R.F. Thurow. 1996. Spatial Variation in Spawning Habitat of Cutthroat Trout in a Sediment-Rich Stream Basin. American Fisheries Society 125:768-779.

McCullagh, P., and J.A. Nelder. 1989. Generalized linear models, Second Edition. Chapman and Hall, London – New York.

Minnow Environmental (Minnow Environmental Inc). 2016. Evaluation of calcite effects on aquatic biota in the Elk Valley (2014 and 2015). Prepared for Teck Coal Ltd. 44 pp + appendices.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available online at: https://www.R-project.org.

Robinson, M.D. and R.J. MacDonald. 2014. Teck Coal Ltd 2013 Calcite Monitoring Program - Elk Valley Operations Summary Report. Prepared by Lotic Environmental Ltd. Available online at: http://www2.gov.bc.ca/assets/gov/environment/waste-management/industrial-waste/industrial-waste/mining-smelt-energy/area-based-man-plan/annexes/j3_2013_calcite_monitoring_program.pdf. Accessed on October 28, 2016.

Robinson, M.D., M. Chernos, K. Baranowska and R.J. MacDonald. 2016. Teck Coal Ltd. – Elk Valley 2015 Calcite Monitoring Program Annual Report and Program Assessment. Prepared for Teck Coal Ltd. by Lotic Environmental Ltd. 17 pp. + appendices.

Scharf, F.S., F. Juanes, and M. Sutherland. 1998. Inferring ecological relationships from the edges of scatter diagrams: comparison of regression techniques. Ecology 79:448-460.

Smithson, J., Robinson, M.D. and K. Baranowska. 2018. Teck Coal Ltd – Elk Valley 2017 Calcite Monitoring Program Annual Report and Program Assessment. Prepared for Teck Coal Ltd. by Lotic Environmental Ltd. 27 pp + appendices.

Teck Resources Limited. 2014. Elk Valley Water Quality Plan. Sparwood, BC. Available online at: http://www.teck.com/media/2015-Water-elk_valley_water_quality_plan_T3.2.3.2.pdf. Accessed on November 16, 2018.

Teck Resources Limited. 2016. Fish and Fish Habitat Offsetting and Effectiveness Monitoring Plan. Line Creek Operations Phase 2. DFO File No. 09-HPAC-PA7-0038. Submitted by Lindsay Watson, Teck Coal Ltd. May 12, 2016.

Teck Resources Limited. 2018. Water Quality Adaptive Management Plan for Teck Coal Operations in the Elk Valley. Sparwood, B.C.

Teck Resources Limited. 2019. Lower Greenhills Creek Calcite Management - 2018 Operations Report. Teck Coal Ltd. 61pp.

Wright, N., D. West, T. Jensma, S. Cope, M. Hocking, and T. Hatfield. 2017. Calcite Effects to Fish Incubation Conditions. Consultant's report prepared for Teck Coal by Ecofish Research Ltd, and Westslope Fisheries Ltd. May 15, 2017.

Wright, N., T. Jensma, H. Wright, K. Akaoka, M. Hocking, and T. Hatfield. 2018. 2017 Calcite Effects to Fish Spawning and Incubation. Draft V1. Consultant's report prepared for Teck Coal by Ecofish Research Ltd. February 19, 2018.

Zuur, A.F., E. N. Ieno, N.J. Walker, A.A. Saveliev and G.M. Smith. 2009. Mixed effects models and extensions in ecology with R. Springer, New York.

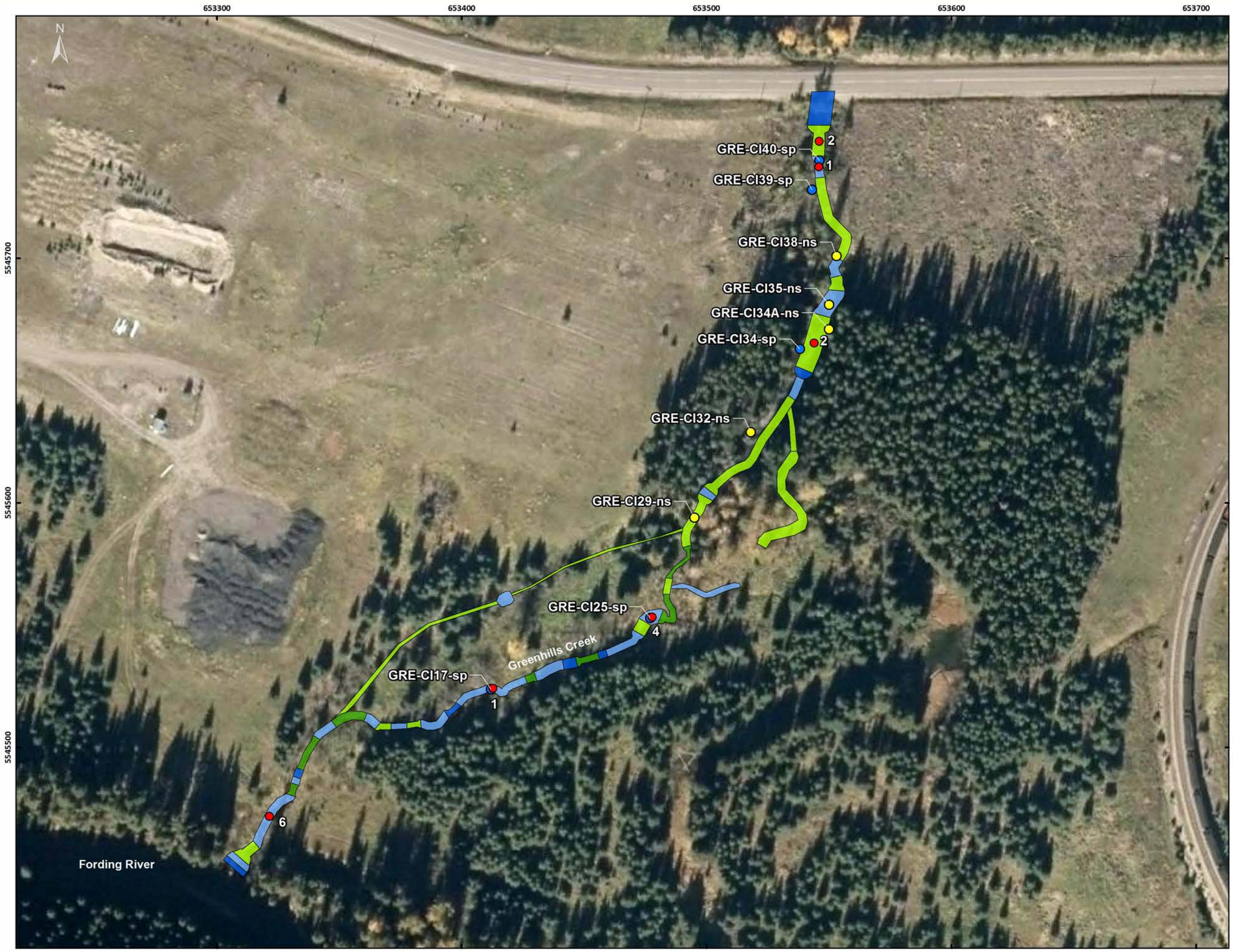
Zuur, A.F., E.N. Ieno, and C.S. Elphick. 2010. A protocol for data exploration to avoiding common statistical problems. Methods in Ecology and Evolution, 1: 3−14.

APPENDICES

Appendix A. Summary Maps of FHAP, Redd and Calcite Surveys Completed in Tributaries of the Fording River, 2018

LIST OF MAPS

TECK COAL LTD.
Greenhills Creek FHAP, Redd Survey and Calcite Sample Sites (2018)



Legend

Calcite Monitoring Site
- Spawn Site
- Null Site
- Number of Redds Observed

FHAP Type
- 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
1	15/02/2019	1229_GRE_FHAPReddCalcite_2018Nov05	CGA
2			
3			
4			
5			

Date Saved: 15/02/2019
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 1

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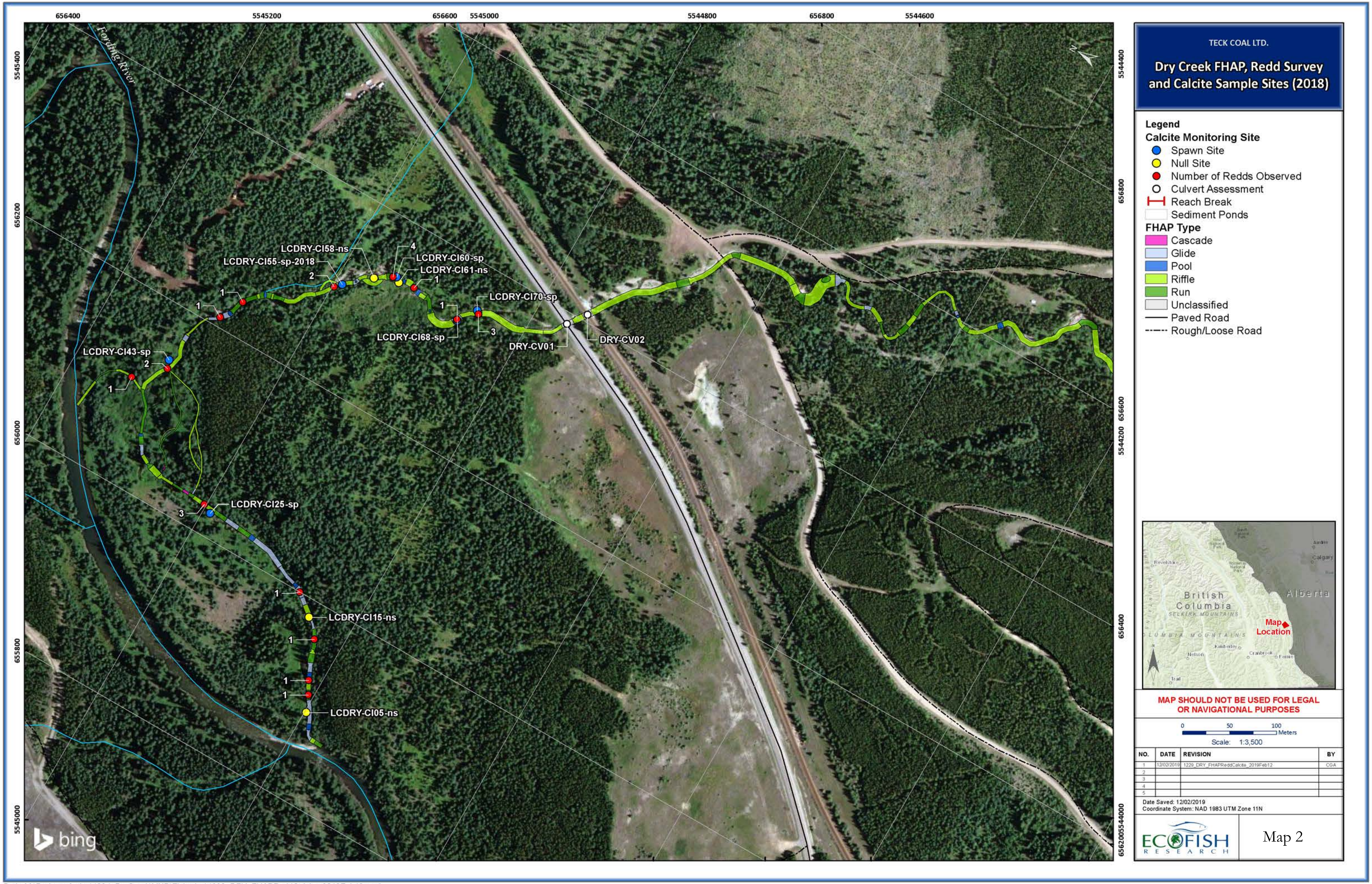

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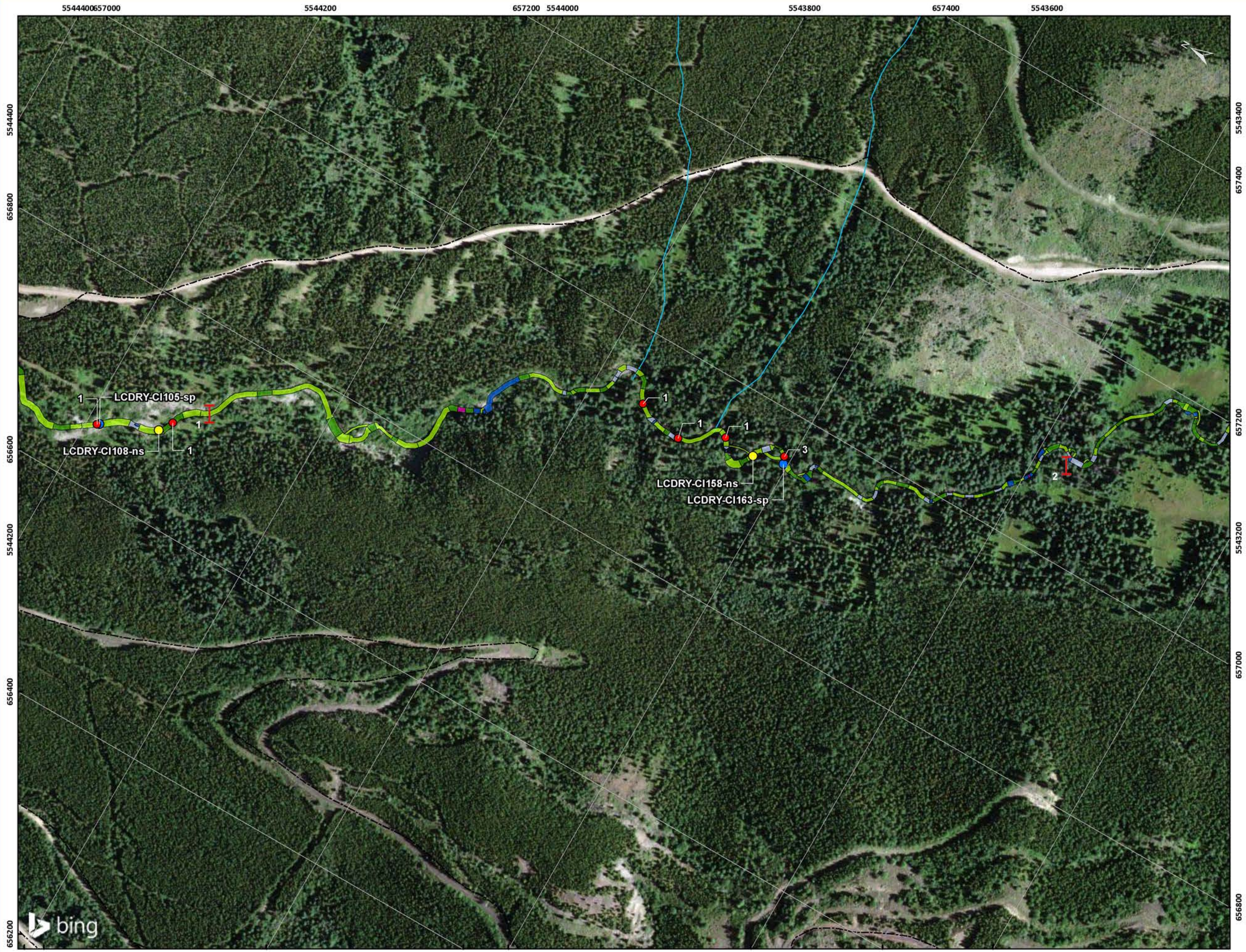


TECK COAL LTD.

Dry Creek FHAP, Redd Survey and Calcite Sample Sites (2018)

Legend

Calcite Monitoring Site
- Spawn Site
- Null Site
- Number of Redds Observed
- Culvert Assessment
- Reach Break
- Sediment Ponds

FHAP Type
- Cascade
- Glide
- Pool
- Riffle
- Run
- Unclassified
- Rough/Loose Road

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 50 100 Meters

Scale: 1:3,500

NO.	DATE	REVISION	BY
1	12/02/2019	1229_DRY_FHAPReddCalcite_2019Feb12	CGA
2			
3			
4			
5			

Date Saved: 12/02/2019
Coordinate System: NAD 1983 UTM Zone 11N

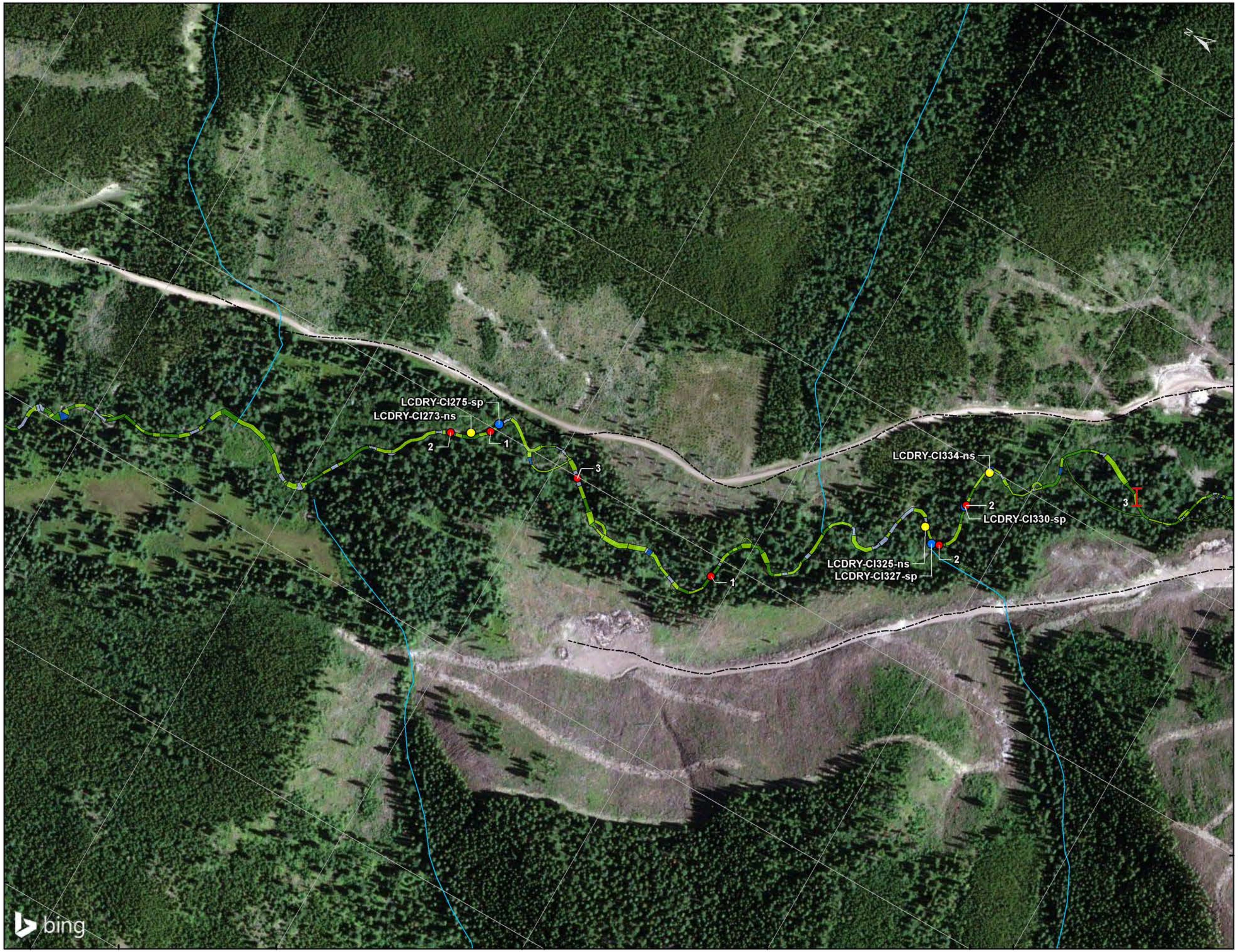
ECOFISH RESEARCH

Map 3

Path: M:\Projects-Active\1224_DryCreek\MXD\Fisheries\1229_DRY_FHAPReddCalcite_2019Feb12.mxd

TECK COAL LTD.

Dry Creek FHAP, Redd Survey and Calcite Sample Sites (2018)



Legend

Calcite Monitoring Site
- Spawn Site
- Null Site
- Number of Redds Observed
- Culvert Assessment
- Reach Break
- Sediment Ponds

FHAP Type
- Cascade
- Glide
- Pool
- Riffle
- Run
- Unclassified
- Rough/Loose Road

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 50 100 Meters

Scale: 1:3,500

NO.	DATE	REVISION	BY
1	12/02/2019	1229_DRY_FHAPReddCalcite_2019Feb12	CGA
2			
3			
4			
5			

Date Saved: 12/02/2019
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 4

Path: M:\Projects-Active\1224_DryCreek\MXD\Fisheries\1229_DRY_FHAPReddCalcite_2019Feb12.mxd

TECK COAL LTD.

Dry Creek FHAP, Redd Survey and Calcite Sample Sites (2018)

Legend

Calcite Monitoring Site
- Spawn Site
- Null Site
- Number of Redds Observed
- Culvert Assessment
- Reach Break
- Sediment Ponds

FHAP Type
- Cascade
- Glide
- Pool
- Riffle
- Run
- Unclassified
- Rough/Loose Road

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 50 100 Meters

Scale: 1:3,500

NO.	DATE	REVISION	BY
1	12/02/2019	1229_DRY_FHAPReddCalcite_2019Feb12	CGA
2			
3			
4			
5			

Date Saved: 12/02/2019
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 5

Path: M:\Projects-Active\1224_DryCreek\MXD\Fisheries\1229_DRY_FHAPReddCalcite_2019Feb12.mxd

TECK COAL LTD.

Clode Creek FHAP, Redd Survey and Calcite Sample Sites (2018)

Legend

Calcite Monitoring Site
- Spawn Site
- Null Site
- Number of Redds Observed

FHAP Type
- Glide
- Pool
- Riffle
- Run

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 10 20 m

Scale: 1:400

NO.	DATE	REVISION	BY
1	15/02/2019	1229_CLO_FHAPReddCalcite_2018Nov02	CGA
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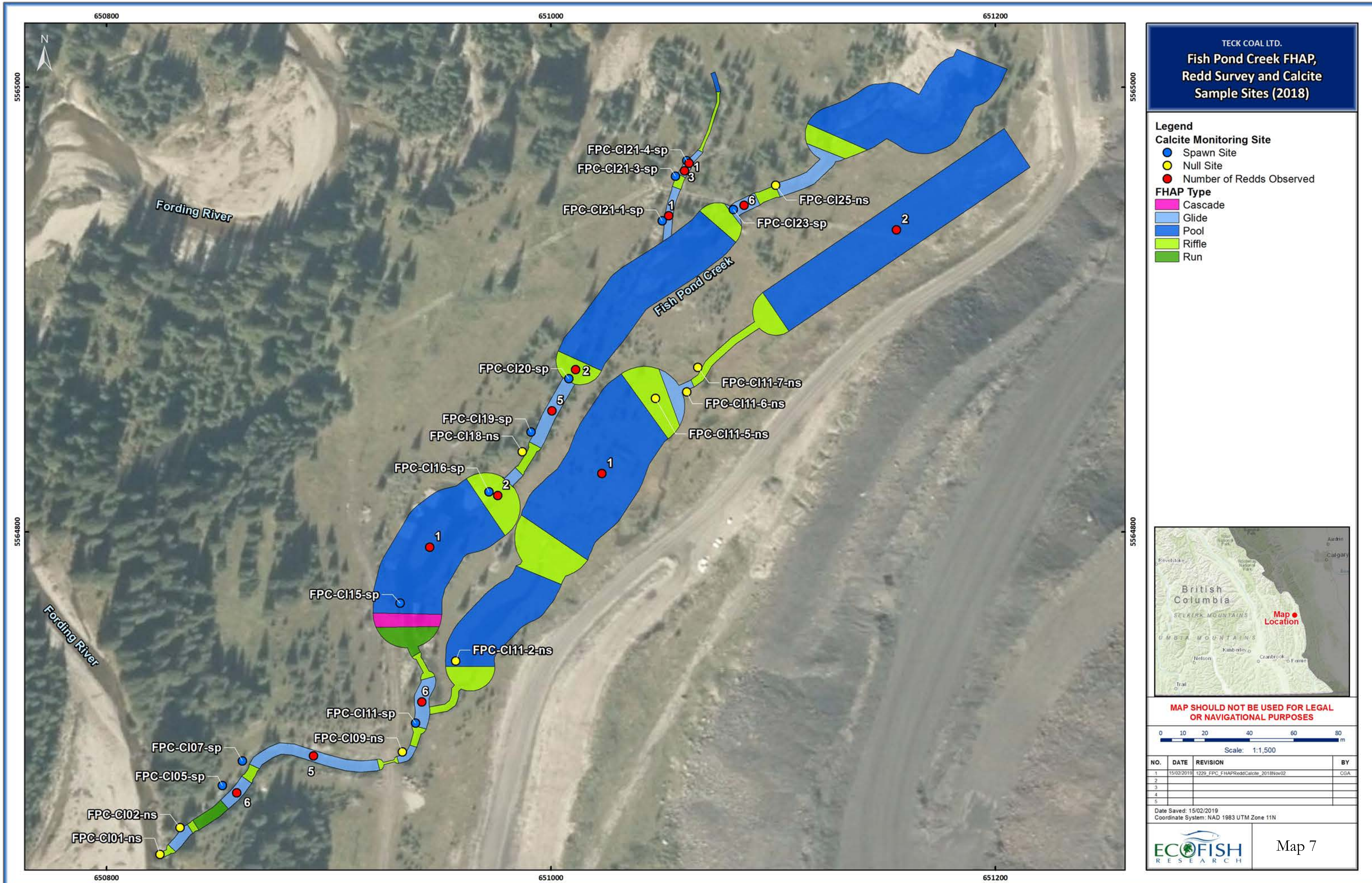
Date Saved: 15/02/2019
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 6

Path: M:\Projects-Active\1229_EVWQP\MXD\Fisheries\1229_CLO_FHAPReddCalcite_2018Nov02.mxd



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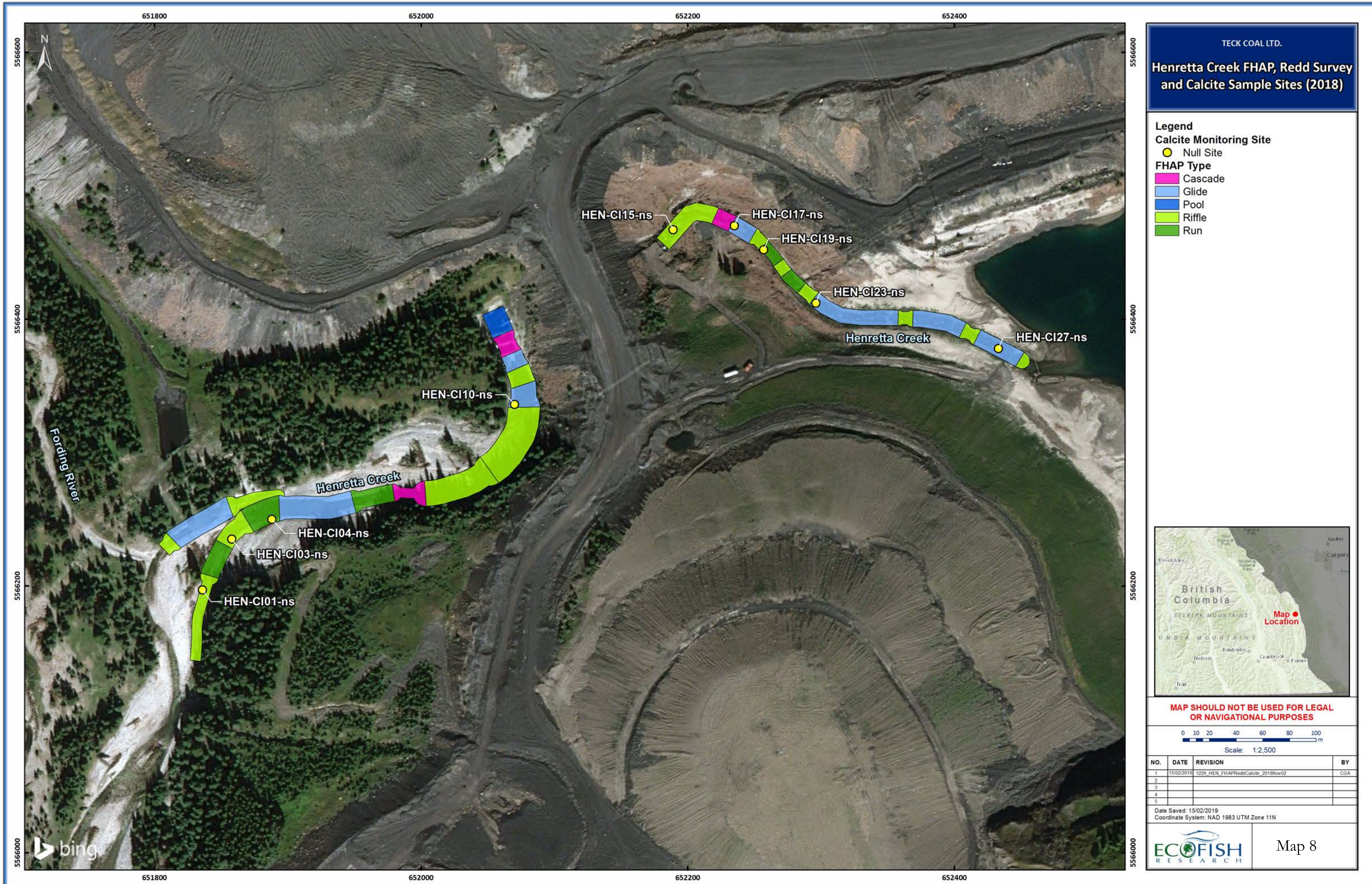

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Appendix B. Summary of Habitat, Water Quality, and Spawning Data Collected in Tributaries of the Fording River, 2018

LIST OF TABLES

Table 1. Summary of habitat, water quality, and spawning data collected in Greenhills Creek in July, 2018

Waterbody	Site	Date	Habitat Type	Unit Length (m)	Unit Area (m^2)	Water Depth (m)		Bankfull Width (m)	Mean Velocity (m/s)	Mean Flow (cms)	Calcite Measures			Mean Pebble Size (mm)	Gravel Prop. (%)	Water Temp. (°C)	DO (mg/L)	Spec. Cond. (µS/cm)	pH	Total Redds	Redd Density (#/m^2)
						Wetted	Bankfull				CI	CC	CP								
Greenhills Creek	GRE-CI17-sp	11-Jul-18	Glide	32	96	0.29	0.75	3.0	0.20	0.09	0.89	0.05	0.84	47.0	1.13	15.1	10.0	1479.7	8.4	1	0.010
	GRE-CI25-sp	10-Jul-18	Glide	7	41	0.22	0.58	5.8	0.30	0.07	0.45	0.01	0.44	16.6	0.00	15.4	9.9	1474.0	8.2	4	0.097
	GRE-CI29-ns	10-Jul-18	Riffle	22	81	0.15	0.28	3.6	0.23	0.08	0.16	0.00	0.16	40.9	5.63	15.7	10.1	1472.0	8.1	0	0.000
	GRE-CI32-ns	11-Jul-18	Glide	9	30	0.21	0.70	3.4	0.35	0.09	0.33	0.05	0.28	76.3	0.00	15.6	10.3	1476.0	8.2	0	0.000
	GRE-CI34-sp	10-Jul-18	Riffle	23	178	0.12	0.60	7.6	0.31	0.08	0.98	0.24	0.74	58.0	0.00	16.6	10.1	1478.3	8.6	2	0.011
	GRE-CI35-ns	10-Jul-18	Glide	12	80	0.17	0.75	6.7	0.24	0.08	0.89	0.19	0.69	73.3	0.00	16.2	10.0	1478.7	8.4	0	0.000
	GRE-CI38-ns	10-Jul-18	Riffle	37	153	0.16	0.65	4.1	0.34	0.10	1.40	0.50	0.90	70.8	0.00	15.8	10.1	1476.7	8.1	0	0.000
	GRE-CI39-sp	10-Jul-18	Glide	9	32	0.19	0.60	3.6	0.31	0.13	0.90	0.09	0.82	72.7	3.98	n/c	10.1	1473.3	8.2	1	0.032
	GRE-CI40-sp	10-Jul-18	Riffle	27	144	0.13	0.50	5.3	0.25	0.10	1.23	0.38	0.86	71.9	0.00	16.1	10.2	1476.7	8.2	2	0.014

Table 2. Summary of habitat, water quality, and spawning data collected in LCO Dry Creek in July, 2018.

Waterbody	Site	Date	Habitat Type	Unit Length (m)	Unit Area (m^2)	Water Depth (m)		Bankfull Width (m)	Mean Velocity (m/s)	Mean Flow (cms)	Calcite Measures			Mean Pebble Size (mm)	Gravel Prop. (%)	Water Temp. (°C)	DO (mg/L)	Spec. Cond. (µS/cm)	pH	Total Redds	Redd Density (#/m^2)
						Wetted	Bankfull				CI	CC	CP								
Dry Creek	LCDRY-CI05-ns	19-Jul-18	Glide	20	90	0.48	0.76	4.5	0.28	0.08	0.65	0.04	0.62	34.6	1.70	6.7	10.0	414.7	8.3	0	0.000
	LCDRY-CI105-sp	20-Jul-18	Run	5	25	0.45	0.80	5.0	0.37	0.14	0.00	0.00	0.00	39.6	12.00	7.3	10.1	412.9	8.6	1	0.040
	LCDRY-CI108-ns	20-Jul-18	Riffle	22	143	0.27	0.70	6.5	0.23	0.10	0.01	0.00	0.01	50.0	0.00	7.3	9.9	413.0	8.7	0	0.000
	LCDRY-CI158-ns	20-Jul-18	Riffle	20	86	0.31	0.45	4.3	0.25	0.09	0.00	0.00	0.00	53.3	69.77	9.3	8.9	412.2	8.4	0	0.000
	LCDRY-CI15-ns	19-Jul-18	Riffle	14	77	0.54	0.70	5.5	0.23	0.07	0.12	0.00	0.12	25.8	0.00	7.2	9.3	412.8	8.4	0	0.000
	LCDRY-CI163-sp	20-Jul-18	Riffle	17	65	0.37	0.50	3.8	0.23	0.10	0.02	0.00	0.02	45.3	61.92	8.9	8.6	412.3	8.4	3	0.046
	LCDRY-CI25-sp	19-Jul-18	Riffle	26	117	0.34	0.60	4.5	0.20	0.05	0.00	0.00	0.00	16.6	0.26	8.8	9.1	408.7	8.7	3	0.026
	LCDRY-CI273-ns	19-Jul-18	Run	17	65	0.29	0.40	3.8	0.17	0.08	0.00	0.00	0.00	37.1	51.08	11.3	8.7	419.5	8.6	0	0.000
	LCDRY-CI275-sp	20-Jul-18	Glide	14	38	0.33	0.60	2.7	0.23	0.07	0.00	0.00	0.00	35.9	38.10	11.8	7.9	420.5	8.3	0	0.000
	LCDRY-CI325-ns	21-Jul-18	Glide	12	34	0.27	0.50	2.8	0.10	0.04	0.00	0.00	0.00	50.3	75.00	12.8	8.1	447.1	8.5	0	0.000
	LCDRY-CI327-sp	21-Jul-18	Run	15	39	0.25	0.36	2.6	0.20	0.06	0.00	0.00	0.00	46.4	71.79	12.8	9.2	446.3	8.5	2	0.051
	LCDRY-CI330-sp	21-Jul-18	Glide	6	17	0.36	0.60	2.9	0.27	0.05	0.00	0.00	0.00	44.5	28.74	13.3	8.3	447.7	8.4	2	0.115
	LCDRY-CI334-ns	21-Jul-18	Pool	7	25	0.42	0.70	3.5	0.13	0.05	0.00	0.00	0.00	48.8	40.82	13.1	7.4	447.7	8.4	0	0.000
	LCDRY-CI43-sp	19-Jul-18	Riffle	66	304	0.35	0.37	4.6	0.14	0.11	0.00	0.00	0.00	42.5	81.52	10.0	9.2	407.1	8.7	2	0.007
	LCDRY-CI55-sp	19-Jul-18	Riffle	42	189	0.29	0.43	4.5	0.29	0.10	0.00	0.00	0.00	34.6	59.63	11.8	8.7	390.6	8.9	2	0.011
	LCDRY-CI58-ns	19-Jul-18	Run	12	43	0.31	0.49	3.6	0.41	0.10	0.00	0.00	0.00	37.0	55.56	11.6	8.5	399.4	8.9	0	0.000
	LCDRY-CI60-sp	19-Jul-18	Run	14	98	0.25	0.41	7.0	0.23	0.10	0.00	0.00	0.00	31.2	28.57	11.7	8.5	373.5	8.8	4	0.041
	LCDRY-CI61-ns	19-Jul-18	Glide	8	40	0.29	1.00	5.0	0.27	0.10	0.00	0.00	0.00	48.0	44.00	11.4	8.3	403.1	8.8	0	0.000
	LCDRY-CI68-sp	19-Jul-18	Glide	10	50	0.38	0.61	5.0	0.19	0.10	0.10	0.05	0.05	34.3	46.20	10.9	8.3	406.2	8.8	1	0.020
	LCDRY-CI70-sp	19-Jul-18	Glide	7	36	0.44	0.96	5.1	0.18	0.09	0.00	0.00	0.00	33.1	0.00	10.7	8.3	407.4	8.7	3	0.084

Table 3. Summary of habitat, water quality, and spawning data collected in Clode Creek in July, 2018.

Waterbody	Site	Date	Habitat Type	Unit Length (m)	Unit Area (m^2)	Water Depth (m)		Bankfull Width (m)	Mean Velocity (m/s)	Mean Flow (cms)	Calcite Measures			Mean Pebble Size (mm)	Gravel Prop. (%)	Water Temp. (°C)	DO (mg/L)	Spec. Cond. (µS/cm)	pH	Total Redds	Redd Density (#/m^2)
						Wetted	Bankfull				CI	CC	CP								
Clode Creek	CLO-CI02-1-sp	13-Jul-18	Glide	32	192	0.18	0.40	6.0	0.10	0.02	0.51	0.04	0.47	34.3	3.90	9.2	8.5	398.3	8.9	1	0.005
	CLO-CI02-sp	13-Jul-18	Glide	42	189	0.41	0.65	4.5	0.29	0.07	0.80	0.09	0.71	37.4	0.38	15.8	9.9	1473.0	8.2	3	0.016
	CLO-CI04-sp	13-Jul-18	Run	42	84	0.28	0.70	2.0	0.18	0.06	1.66	0.66	1.00	75.8	0.00	17.7	9.5	1632.8	9.5	2	0.024
	CLO-CI05-ns	13-Jul-18	Glide	11	50	0.23	0.50	4.5	0.07	0.06	1.21	0.22	0.99	57.0	14.22	17.7	9.4	163.3	9.5	0	0.000

Table 4. Summary of habitat, water quality, and spawning data collected in Fish Pond Creek in July, 2018.

Waterbody	Site	Date	Habitat Type	Unit Length (m)	Unit Area (m^2)	Water Depth (m)		Bankfull Width (m)	Mean Velocity (m/s)	Mean Flow (cms)	Calcite Measures			Mean Pebble Size (mm)	Gravel Prop. (%)	Water Temp. (°C)	DO (mg/L)	Spec. Cond. (µS/cm)	pH	Total Redds	Redd Density (#/m^2)
						Wetted	Bankfull				CI	CC	CP								
Fish Pond Creek	FPC-CI01-ns	13-Jul-18	Riffle	7	18	0.17	0.30	2.5	0.95	0.26	0.86	0.01	0.85	66.1	12.57	7.7	10.5	346.9	8.7	0	0.000
	FPC-CI02-ns	13-Jul-18	Glide	12	58	0.43	1.20	4.8	0.13	0.21	0.76	0.05	0.71	36.2	1.22	7.8	10.4	347.0	8.6	0	0.000
	FPC-CI05-sp	13-Jul-18	Glide	13	72	0.29	0.65	5.5	0.40	0.23	0.24	0.00	0.24	29.5	5.79	11.4	9.2	360.3	8.1	6	0.084
	FPC-CI07-sp	14-Jul-18	Glide	66	330	0.67	1.00	5.0	0.23	0.24	0.12	0.00	0.12	39.0	5.11	11.5	9.1	360.0	8.1	5	0.015
	FPC-CI09-ns	14-Jul-18	Glide	10	32	0.43	0.80	3.2	0.16	0.26	0.25	0.01	0.24	35.3	1.13	11.5	9.1	360.1	8.1	0	0.000
	FPC-CI11-2-ns	14-Jul-18	Pool	54	1188	0.77	1.10	22.0	0.04	0.10	0.04	0.00	0.04	52.7	0.00	9.1	8.9	364.7	8.0	0	0.000
	FPC-CI11-5-ns	14-Jul-18	Riffle	12	18	0.25	0.40	1.5	0.49	0.07	0.00	0.00	0.00	50.1	1.56	8.8	8.8	359.5	7.9	0	0.000
	FPC-CI11-6-ns	14-Jul-18	Glide	12	40	0.35	0.35	3.3	0.40	0.08	0.00	0.00	0.00	39.1	0.00	8.8	8.5	360.2	7.9	0	0.000
	FPC-CI11-7-ns	14-Jul-18	Riffle	50	175	0.34	0.55	3.5	0.27	0.06	0.03	0.00	0.03	52.3	4.02	8.8	8.4	357.9	7.9	0	0.000
	FPC-CI11-sp	14-Jul-18	Glide	23	150	0.76	1.20	6.5	0.23	0.23	0.18	0.04	0.14	30.0	12.17	11.5	9.0	360.2	8.1	6	0.040
	FPC-CI15-sp	14-Jul-18	Pool	67	2077	1.10	2.00	31.0	0.06	0.11	0.07	0.00	0.07	31.2	0.17	11.3	8.8	357.6	8.1	1	0.000
	FPC-CI16-sp	14-Jul-18	Riffle	15	59	0.13	0.25	3.9	0.40	0.10	0.02	0.00	0.02	36.9	66.67	8.8	8.9	364.4	8.1	2	0.034
	FPC-CI18-ns	14-Jul-18	Riffle	14	53	0.24	0.40	3.8	0.28	0.11	0.03	0.00	0.03	42.9	0.00	9.5	8.7	353.8	8.1	0	0.000
	FPC-CI19-sp	14-Jul-18	Glide	31	186	0.62	1.30	6.0	0.09	0.10	0.01	0.00	0.01	35.4	13.31	8.9	8.6	354.6	8.0	5	0.027
	FPC-CI20-sp	14-Jul-18	Riffle	8	28	0.30	0.40	3.5	0.22	0.10	0.03	0.00	0.03	37.9	2.54	9.8	8.6	353.5	8.0	2	0.071
	FPC-CI21-1-sp	14-Jul-18	Glide	26	91	0.22	0.50	3.5	0.12	0.05	0.04	0.00	0.04	46.6	2.20	8.2	8.0	355.6	7.9	1	0.011
	FPC-CI21-3-sp	14-Jul-18	Glide	5	20	0.41	0.55	4.0	0.11	0.01	0.02	0.00	0.02	31.1	70.00	8.7	8.0	352.3	8.0	3	0.150
	FPC-CI21-4-sp	14-Jul-18	Riffle	3	10	0.17	0.45	3.2	0.06	0.01	0.05	0.00	0.05	40.4	5.00	9.6	8.2	348.5	8.0	1	0.104
	FPC-CI23-sp	14-Jul-18	Glide	12	72	0.39	0.60	6.0	0.07	0.07	0.00	0.00	0.00	36.5	29.17	9.5	8.0	348.7	8.0	6	0.083
	FPC-CI25-ns	14-Jul-18	Glide	28	176	0.62	1.00	6.3	0.02	0.04	0.00	0.00	0.00	34.9	5.40	9.2	7.9	353.2	8.0	0	0.000

Table 5. Summary of habitat, water quality, and spawning data collected in Henretta Creek in July, 2018.

Waterbody	Site	Date	Habitat Type	Unit Length (m)	Unit Area (m^2)	Water Depth (m)		Bankfull Width (m)	Mean Velocity (m/s)	Mean Flow (cms)	Calcite Measures			Mean Pebble Size (mm)	Gravel Prop. (%)	Water Temp. (°C)	DO (mg/L)	Spec. Cond. (µS/cm)	pH	Total Redds	Redd Density (#/m^2)
						Wetted	Bankfull				CI	CC	CP								
Henretta Creek	HEN-CI01-ns	12-Jul-18	Riffle	65	520	0.19	0.60	8.0	0.31	0.68	0.69	0.01	0.68	66.4	0.00	10.1	9.0	396.7	8.9	0	0.000
	HEN-CI03-ns	12-Jul-18	Riffle	25	350	0.44	0.80	14.0	0.29	0.70	0.94	0.03	0.91	66.0	0.10	9.6	8.9	398.5	8.6	0	0.000
	HEN-CI04-ns	12-Jul-18	Run	26	494	0.33	0.80	19.0	0.33	1.22	0.93	0.03	0.90	65.7	0.05	9.5	8.8	399.9	9.3	0	0.000
	HEN-CI10-ns	18-Jul-18	Glide	17	323	0.65	1.00	19.0	0.34	1.01	0.00	0.00	0.00	54.6	0.00	8.5	9.1	406.3	8.3	0	0.000
	HEN-CI15-ns	18-Jul-18	Riffle	50	650	0.42	0.85	13.0	0.44	0.97	0.06	0.01	0.05	45.3	51.69	8.6	8.7	405.1	8.3	0	0.000
	HEN-CI17-ns	18-Jul-18	Glide	18	234	0.93	1.60	13.0	0.29	0.96	0.00	0.00	0.00	56.1	0.00	8.6	8.8	403.4	8.3	0	0.000
	HEN-CI19-ns	18-Jul-18	Run	17	145	0.99	1.50	8.5	0.17	0.89	0.02	0.00	0.02	49.9	0.00	8.8	8.6	396.5	8.3	0	0.000
	HEN-CI23-ns	18-Jul-18	Glide	67	771	0.62	0.90	11.5	0.38	1.03	0.02	0.00	0.02	57.2	1.83	8.7	8.5	395.7	8.3	0	0.000
	HEN-CI27-ns	18-Jul-18	Glide	36	450	0.73	0.90	12.5	0.23	0.96	0.01	0.00	0.01	43.1	2.13	8.9	8.5	392.5	8.3	0	0.000