Elk River Watershed Group Fish Passage Restoration Planning 2022

Prepared for
Nupqu Resource Limited Partnership

Prepared by
Al Irvine, B.Sc., R.P.Bio. and
Mateo Winterscheidt
New Graph Environment Ltd.

Version 0.0.1
2023-02-27

new graph environment
Research & Consulting

Table of Contents

Acknowledgement

Modern civilization has a long journey ahead to acknowledge and address the historic and ongoing impacts of colonialism that have resulted in harm to the cultures and livelihoods living interconnected with our ecosystems for many thousands of years.

1 Introduction

Since 2020, the Canadian Wildlife Federation (CWF) has been working on a watershed connectivity remediation plan for the Elk River watershed that incorporates the provincial Strategic Approach protocol (Fish Passage Assessment, Habitat Confirmation, Design and Remediation), evolution of the `bcfishpass` analysis tools (Norris [2020] 2023) and local knowledge of the watershed to prioritize barriers and restore connectivity for westslope cutthroat trout and other species in a strategic manner. Nupqu Resource Limited Partnership (Nupqu) was retained by the CWF in the summer of 2022 to conduct fish habitat and fish sampling assessments at sites related to road-stream crossings within the Elk River watershed group as part of this connectivity restoration planning. Subject streams included Brule Creek, Weigert Creek and an unnamed tributary to Bighorn Creek. New Graph Environment Ltd. was sub-contracted by Nupqu to assist with project delivery.

Assessments conducted in 2022 complement work completed in 2020 (72 fish passage assessments and 15 habitat confirmation assessments) and 2021 (92 fish passage assessments and 15 habitat confirmation assessments) which can be viewed interactively online at https://newgraphenvironment.github.io/fish_passage_elk_2020_reporting_cwf/ (Irvine 2021) and https://newgraphenvironment.github.io/fish_passage_elk_2021_reporting/ (Irvine 2022). This report is available as pdf and as an online interactive report at https://newgraphenvironment.github.io/fish_passage_elk_2022_reporting/. Viewing online is recommended as the web-hosted version contains more features and is more easily navigable.

The health and viability of freshwater fish populations can depend on access to tributary and off channel areas which provide refuge during high flows, opportunities for foraging, overwintering habitat, spawning habitat and summer rearing habitat (Bramblett et al. 2002; Swales and Levings 1989; Diebel et al. 2015). Culverts can present barriers to fish migration due to low water depth, increased water velocity, turbulence, a vertical drop at the culvert outlet and/or maintenance issues (Slaney, Zaldokas, and Watershed Restoration Program (B.C.) 1997; Cote et al. 2005).

As the costs of works for remediation of fish passage issues through the replacement of road/stream crossings can be significant, acquisition of detailed habitat and fish sampling data can be helpful for understanding the value of associated habitats to target fish species, attempting to understand the extent of the issues potentially created by subject culverts as well as providing baseline data for assessing the benefits of remedial work post-fish passage remediation.

2 Background

Study areas are tributary streams within the Elk River watershed group and eventually flow into the Elk River (Figure 2.1). The Elk River has a mean annual discharge of 26 m^3/s at station 08NK016 near Sparwood and 47.3 m^3/s at station 08NK016 near Fernie with flow patterns typical of high elevation watersheds on the west side of the Rocky Mountains which receive large amounts of precipitation as snow leading to peak levels of discharge during snowmelt, typically from May to July (Figures 2.2 - 2.4) (Environment and Canada 2020).

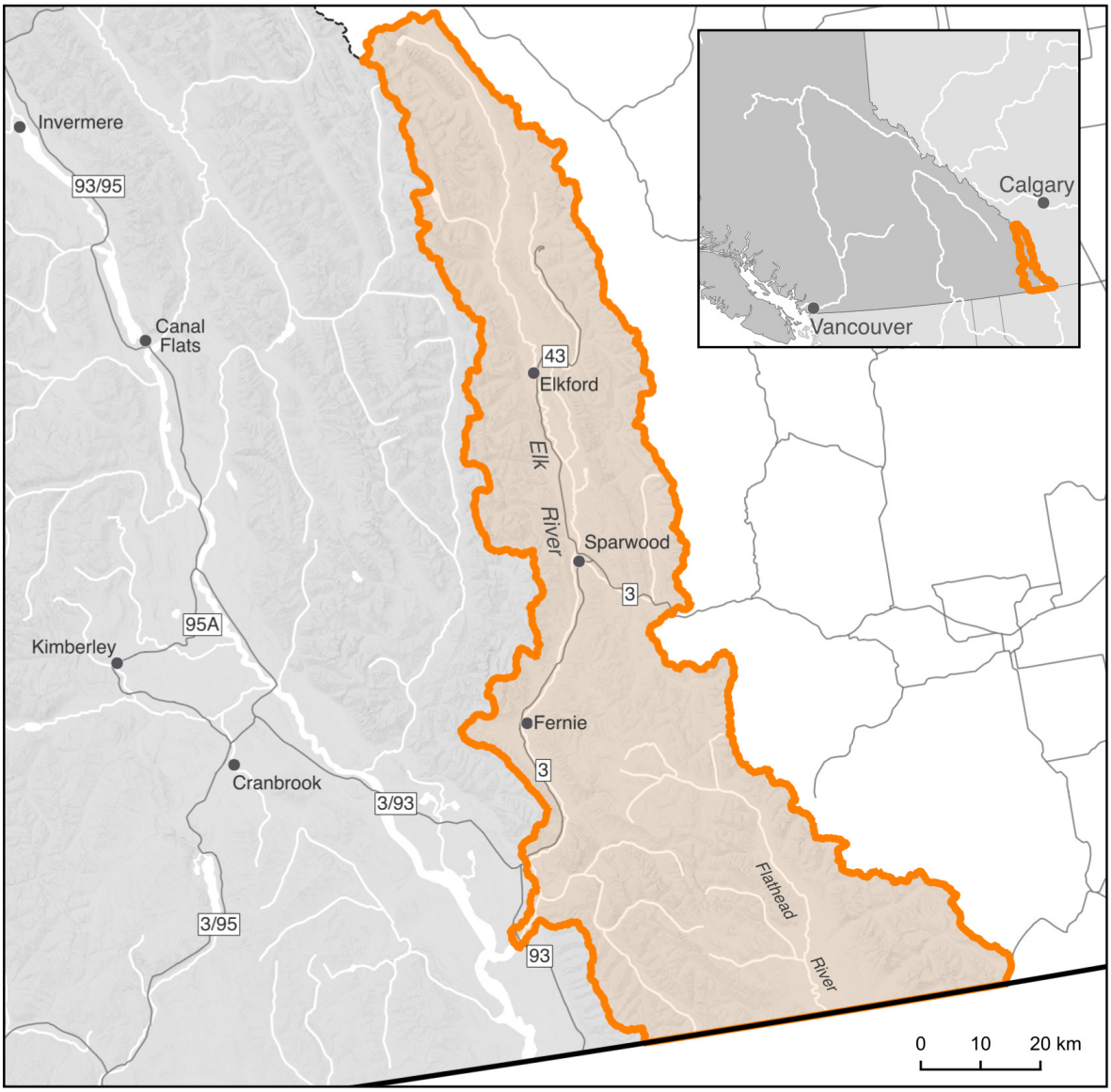

Figure 2.1: Overview map of Study Area

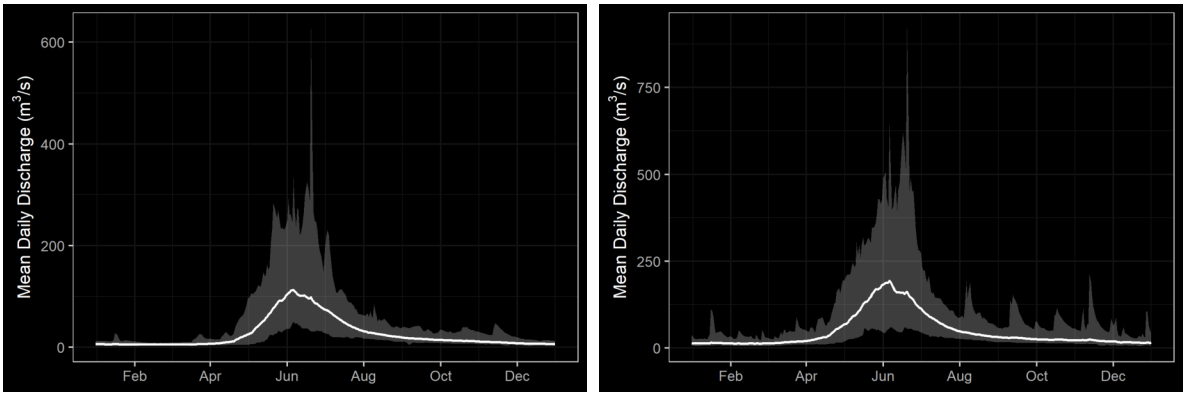

Figure 2.2: Hydrograph for Elk River near Sparwood (Station #08NK016) and near Fernie (Station #08NK002).

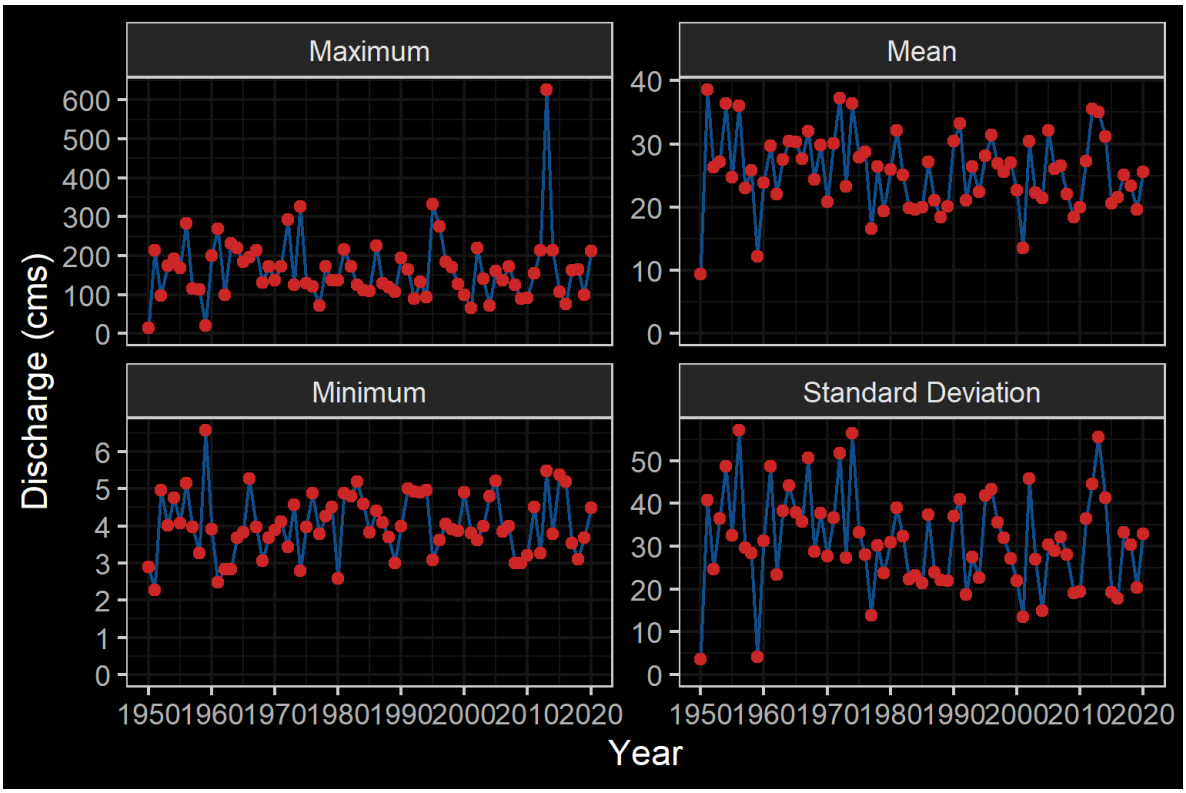

Figure 2.3: Elk River Near Sparwood (Station #08NK016 - Lat 49.86562 Lon -114.86868). Available daily discharge data from 1950 to 2020.

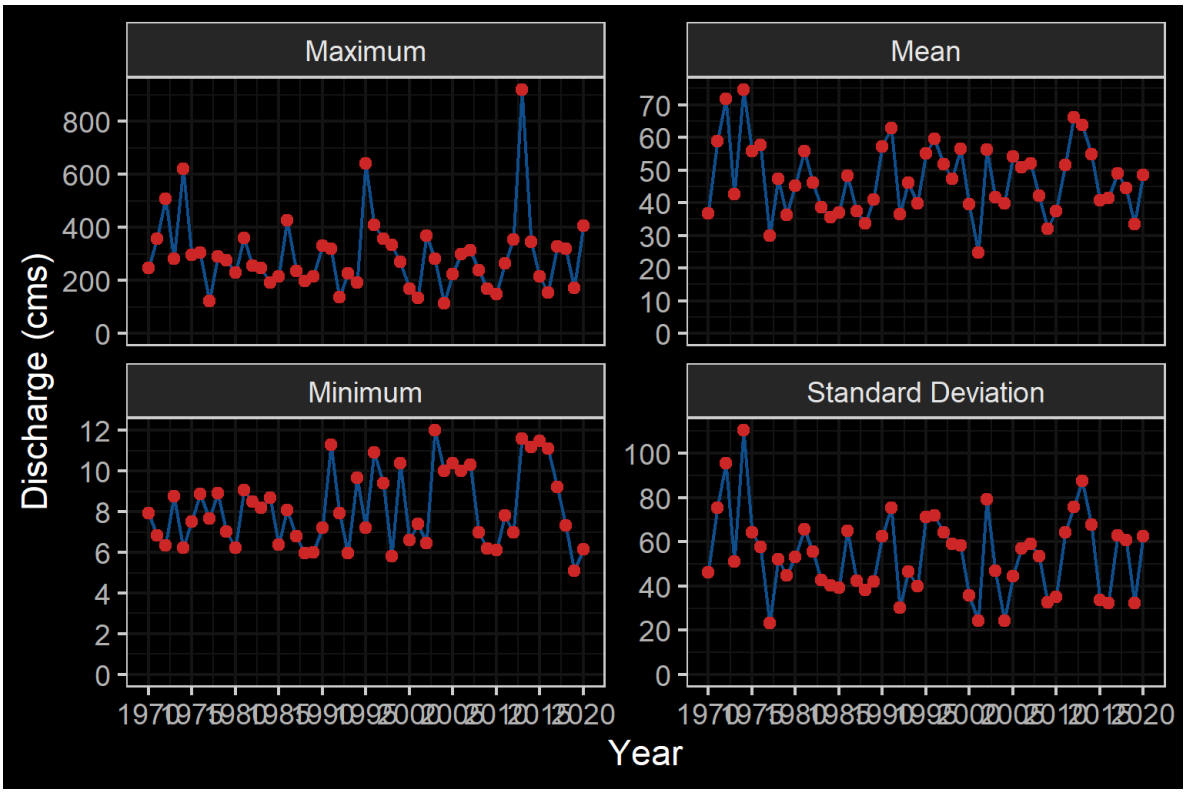

Figure 2.4: Elk River At Fernie (Station #08NK002 - Lat 49.50347 Lon -115.07013). Available daily discharge data from 1970 to 2020.

2.0.1 Ktunaxa Nation

The project location is within the traditional territory of the Ktunaxa Nation ("Ktunaxa Nation" 2020) with Elk River components within an area known as Qukin ʔamakʔis, or Raven's Land (Ministry of Forests 2020). When Europeans settled in the Kootenay Region around 200 hundred years ago, the Indian Reserves were created which lead to the seven Indian Bands:

- ʔakisq̓nuk- Columbia Lake Band (Windermere, BC);
- ʔaq̓am- St. Mary's Band (Cranbrook, BC);
- ʔakink̓um‡asnuq‡iʔit- Tobacco Plains Band (Grasmere, BC);
- yaqan nuʔkiy- Lower Kootenay Band (Creston, BC);
- kyaknuq‡iʔit- Shuswap Band (Invermere, BC);
- ʔaq̓anqmi- Kootenai Tribe of Idaho (Bonners Ferry, Idaho);
- k̓upawic̓q̓nuk- Ksanka Band (Elmo, Montana)

“Ktunaxa Nation” (2020) report the vision statement of the Ktunaxa as:

“K¢maǩqa ksukɬuɬa·k kuǩqani ¢ ǩitqakiɬ haqa ksi?ɬ ¢xa ?a·kɬukqa?is ksukiɬq̓uka?mi·k ki?in Ktunaxa na?s ?amaǩ?is. Qus piǩaks¢ na?s ¢xaɬ yaqanakiɬ haqa?ki. Ǩitqawi¢mu kakiɬwi¢kiɬ ?amak?is ǩisnik¢ik k¢xaɬ qa kiɬkǩaxuxami·k ǩitqakiɬ haqa ¢ ǩis?in ?aknumu¢tiɬ?is.”

The vision statement has been translated to english as:

“Strong, healthy citizens and communities, speaking our languages and celebrating who we are and our history in our ancestral homelands, working together, managing our lands and resources, within a self-sufficient, self-governing Nation.”

2.0.2 Elk Valley Cumulative Effects Management Framework

First Nations, stakeholders, proponents and provincial and municipal governments have recognized that the region has been impacted by historic and current coal operations as well as other stresses such as forestry operations, wildfire, residential development, recreational activities and transportation. To assess the historic, current and potential future conditions of valued ecosystem components and to support resource management decisions within the region, the Provincial Cumulative Effects Framework and the Elk Valley Cumulative Effects Management Framework (EV-CEMF) have been formed under joint management between the Ktunaxa Nation Council and the B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD). A working group consisting of the Ktunaxa Nation Council, industry, community, organizations, and provincial government ministries has been formed to provide guidance and oversight for EV-CEMF activities. Valued component technical reports for Grizzly Bear, Riparian and westslope cutthroat trout (Davidson et al. 2018), bighorn sheep, and old and mature forest have been drafted, integrated into an overarching Cumulative Effects Assessment and Management Report (Elk Valley Cumulative Effects Management Framework Working Group 2018) and endorsed by the Working Group. These reports describe the historical, current, and future assessment of cumulative effects in the Elk Valley and provide management and mitigation recommendations. Next steps for the framework include the development of an Implementation Plan to identify priority actions and spatial locations to focus management and mitigation of cumulative effects in the valley which may include actions to address aquatic habitat connectivity issues (Ministry of Forests 2020).

2.1 Fisheries

Fish species recorded in the upper Elk River watershed group (streams that drain into the Elk River) are detailed in Table 2.1 (MoE 2020a). Bull trout and westslope cutthrout trout are considered of special concern (blue-listed) provincially and westslope cutthrout trout (Pacific populations) are are

listed under the *Species at Risk Act* by the Committee on the Status of Endangered Wildlife in Canada as a species of special concern (BC Species & Ecosystem Explorer 2020b, 2020a; Schweigert et al. 2017).

Table 2.1: Fish species recorded in the study area (FISS 2020).

Scientific Name	Species Name	Species Code	BC List	Provincial FRPA	COSEWIC	SARA
Catostomus catostomus	Longnose Sucker	LSU	Yellow	–	–	–
Catostomus columbianus	Bridgelip Sucker	BSU	Yellow	–	–	–
Catostomus commersonii	White Sucker	WSU	Yellow	–	–	–
Oncorhynchus clarkii	Cutthroat Trout	CT	No Status	–	–	–
Oncorhynchus clarkii lewisi	Westslope Cutthroat Trout	WCT	Blue	Y (Jun 2006)	SC (Nov 2016)	1-SC (Feb 2010)
Oncorhynchus mykiss	Rainbow Trout	RB	Yellow	–	–	–
Oncorhynchus nerka	Kokanee	KO	Yellow	–	–	–
Prosopium williamsoni	Mountain Whitefish	MW	Yellow	–	–	–
Rhinichthys cataractae	Longnose Dace	LNC	Yellow	–	–	–
Richardsonius balteatus	Redside Shiner	RSC	Yellow	–	–	–
Salvelinus confluentus pop. 26	Bull Trout	BT	Blue	–	–	–
Salvelinus fontinalis	Brook Trout	EB	Exotic	–	–	–
–	Cutthroat/Rainbow cross	CRS	–	–	–	–
–	Sucker (General)	SU	–	–	–	–

2.1.1 Westslope Cutthrout Trout

There are multiple life history strategies for westslope cutthrout trout including stream-resident, fluvial and adfluvial. All have habitat requirements during life history stages that include cold clean water and varied forms of cover (undercut banks, pool-riffle habitat and riparian vegetation). Stream-resident fish inhabitat headwater streams above barriers, complete their life cycle within a relatively small range and typically remain relatively small (i.e. <200mm in length). Fluvial fish are migratory subpopulations that migrate between small spawning/rearing tributaries and larger adult rearing rivers. Lengths of fluvial fish generally reach more than 400mm. Finally, adfluvial

subpopulations rear in lakes and migrate to spawning/rearing tributaries with lengths often exceeding 500mm (Schweigert et al. 2017).

Spawning habitat for resident and fluvial subpopulations are documented as within the tailouts of deep pools at moderate to high-flow events within small, low-gradient streams with cold well-oxygenated water and clean unsilted gravels (Schmetterling 2001). Proximity to large woody debris, boulder or bedrock cover is important for spawning fish while residing in spawning tributaries as high mortality may result when suitable cover is lacking. The dominant substrate used for spawning is gravel (1.8 - 3.3cm diameter) with spawning occurring in late May and June towards the end of the spring freshet with rising water temperatures between 7-11°C. Nine of 11 westslope cutthrout trout radio-tagged in the Blackfoot River drainage, Montana by Schmetterling (2001) made movements to tributaries presumable for spawning. While in tributaries, fish movements to spawning sites averaged 12.5km where they stayed within an approximately 100m reach during the spawning period for between 15 and 63 days.

Small perennial streams with a diversity of cover are important for juvenile rearing with young-of-year fish inhabiting low energy lateral habitats (i.e. shallow riffle or backwatered areas) with cover available. Larger juveniles move into pools with social dominance behaviors prevalent and based on fish size. Availability of pool habitat is important and limiting for parr which have large territories (Schweigert et al. 2017; Schmetterling 2001). The suitability of overwintering habitat is determined by groundwater influx and the absence of anchor ice with fluvial adults congregating in slow deep pools in the winter. Boulders and other large in-stream structures or off-channel habitat (beaver bonds and sloughs) provide cover for juveniles with adfluvial fish overwintering in lakes (Schweigert et al. 2017; Brown and Mackay 1995; S. Cope, Schwarz, and Prince 2017).

In a swimming performance study conducted in an open-channel flume Blank et al. (2020) estimated the overall average swim speeds of westlope cutthrout trout (150mm - 290mm in length) at 0.84m/s with a maximum observed swim speed of 3.55m/s.

The greatest threats to westslope cutthrout trout are hybridization with non-native rainbow trout and degradation of the environment due to forestry, hydroelectric development, mining, urbanization and agriculture (Schweigert et al. 2017). Lamson (2020) sampled over 2000 trout in the Upper Kootenay watershed from 2014 to 2019 with results of genotyping indicating consistently high levels of westslope cutthrout trout allele purity (i.e. very low levels of rainbow trout, yellowstone cutthrout trout or coastal cutthrout trout genetic introgression) throughout the Elk River watershed areas upstream of the Elko Dam. Boyer, Muhlfeld, and Allendorf (2008) sampled 31 sites in the upper Flathead River system within the United States (27 sites) and Canada (4 sites). Genetic introgression declined with latitude with no evidence of rainbow trout allelles within any westslope cutthrout trout sampled within the Canadian portion of the upper Flathead River.

Gradient of streams is an important determinant of habitat suitability for salmonids with lower gradient habitats often providing the most productive environments for both rearing and spawning while high gradient sections typically present upstream migration barriers and less available habitat. A summary of historic westslope cutthrout trout observations in the Elk River watershed group delineated by average gradient category of associated stream segments where they were captured is provided in Figure 2.5. Of 4003 observations, 93% were within stream segments with average gradients ranging from 0 - 8%. A total of 73% of historic observations were within stream segments with gradients between 0 - 3%, 12% were within stream segments with gradients ranging from 3 - 5% and 8% were within stream segments with gradients between 5 - 8% (MoE 2020a; Norris 2020).

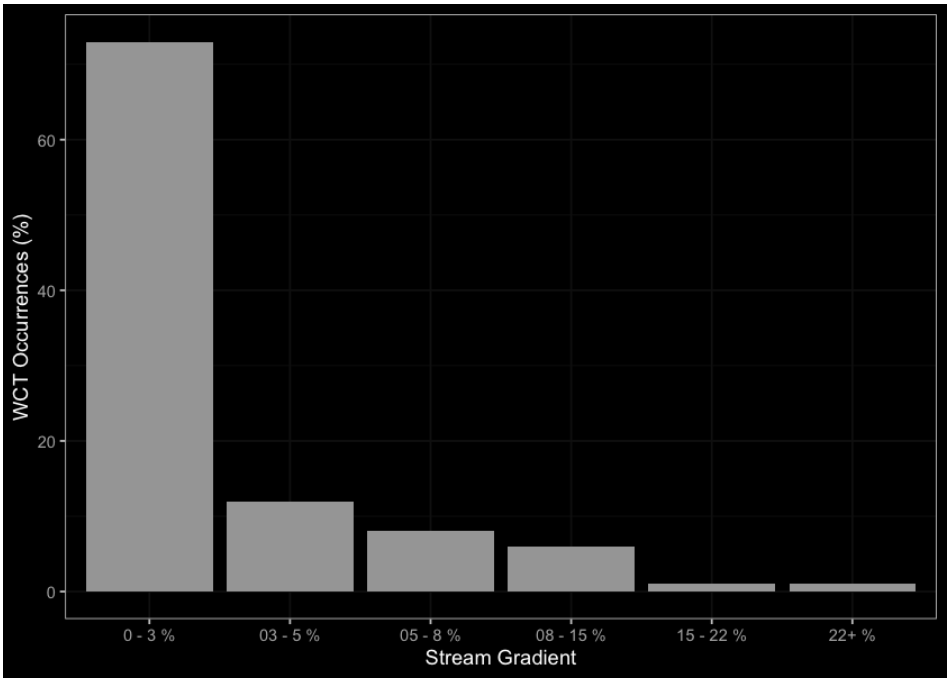

Figure 2.5: Summary of historic westslope cutthrout trout observations vs. stream gradient category.

3 Methods

3.1 Fish Sampling

Electrofishing was utilized for fish sampling according to stream inventory standards and procedures found in the Reconnaissance (1:20 000) Fish and Fish Habitat Inventory Manual (Resources Inventory Committee 2001). Individual captured fish were GPS'd, measured for fork length and released. A Fish Data Submission Spreadsheet Template - V 2.0, January 20, 2020 was populated for all sites and will be submitted to the provincial government under scientific fish collection permit CB22-755885. Habitat characteristics measured included water temperature, pH, conductivity, channel/wetted widths, pool depths, gradient, bankfull channel depth, stage, cover, large woody debris presence/abundance, channel bank characteristics, riparian vegetation type/structural stage, substrate and channel morphology. Downstream and upstream photographs were taken at each site and relevant features were recorded.

Habitat data associated with electrofishing sites was collated on "Site Cards" with habitat characteristics recorded included channel widths, wetted widths, residual pool depths, gradients, bankfull depths, stage, temperature, conductivity, pH, cover by type, substrate and channel morphology (among others). Any potential obstacles to fish passage were inventoried with photos, physical descriptions and locations recorded on site cards. Surveyed routes were recorded with time-signatures on handheld GPS units.

3.2 Fish Habitat Assessment

The Fish Habitat Assessment Procedures were developed by Johnston and Slaney (1996) to provide a standard framework for identifying needs and opportunities for fish habitat restoration. Field assessments in 2022 included Level 1 assessments - which are standardized protocols for characterizing average fish habitat conditions within stream reaches with the intent to identify scenarios that may limit fish production. Sample sites were divided into distinct geomorphic habitat units based on gradient, water flow characteristics, depth and size/position of the habitat unit relative to the main channel (habitat unit category). Habitat unit categories consisted of primary (occupy more than 50% of the wetted width of the main channel), secondary (side channels) and tertiary units (less than . These habitat units consisted of pools, glides, riffles and cascades which are described in more detail below:

- Pools - areas of slower, deeper water created by impoundment of water or scour (often associated with large woody debris) with a concave bottom profile and a water surface gradient near 0%. Minimum dimensions for the size of pools (miniumum area and associated minimum residual depth) are defined in Johnston and Slaney (1996) and based on the bankfull channel width of the stream.
- Glides were defined as areas of flat bottomed, fast-flowing and non-turbulent (laminar) flow.
- Riffles included areas of turbulent, fast flowing water usually consisting of shallow moderate-gradient areas with gravel or cobble bed material projecting above the water surface and

obvious surface turbulence.

- Cascades included steeper, stepped “riffles” of bedrock or emergent substrates in channels with gradient greater than ~4%. The water surface is usually very turbulent and frothy and white in appearance.

Sites were surveyed using a hip chain to track distance with the following attributes recorded for each habitat unit - gradient, mean water depth, mean wetted width, mean bankfull channel width, mean bankfull depth, pool characteristics (max depth, crest depth, residual depth), pool type (scour pool or impoundment), dominant/subdominant bed material type, large woody debris (total of all pieces >10cm in diameter as well as total number of “functional” pieces broken out into multiple size categories), cover (% by type), disturbance indicators, riparian vegetation type, riparian structural stage, overstream canopy closure and spawning gravel amount/type.

A clinometer was used to estimate gradient, channel measurements were taken using a tape measure and water depths measured using a measuring stick. Photographs were taken of representative habitats throughout the surveyed reaches. All field measurements were recorded on Level 1 Habitat Survey Data Form templates ((**slaney_etal1997Fishhabitat?**)). GPS waypoints were collected at the beginning and end of all Primary habitat units to allow georeferenceing of field data.

4 Results

4.1 Fish Sampling

A total of 14 sites were electrofished within 4 streams.

Table 4.1:

gazetted_name	alias_local_name	utm_easting	utm_northing	comments
Weigert Creek	197534_ds_ef1	651130	5532330	Started electrofishing at el where Weigert redirects to the south. Very fast flowing in parts. Wide channel but not too much cover. Some LWD providing functionality and some cover. 12:50
Weigert Creek	197534_ds_ef2	650627	5532190	0.5
Weigert Creek	197534_us_ef2	649387	5531718	High value habitat. Wide channel with fast flowing water. Many larger fish were caught (>200mm). Some deep pools spotted that could be suitable for overwintering. Cobbles and boulders in stream ptoviding cover . 12:26:06
Weigert Creek	197534_us_ef1	650134	5532055	0.5254861111111111
Bighorn Creek	197844_ds_ef1	657699	5452910	Mainstem of Bighorn Creek. Very wide channel but not a lot of cover from overhanging veg or crown closure. Mostly cobbles and boulders in stream. Some deep pools with fish found. All bull trout except one which was WCT. Only trace amounts of woody debris. good flow with abundant boulder cover throughout. Rare pockets of gravels at pool outlets only. High value habitat. 12:12:56
Weigert Creek	197534_us_ef3	648699	5532036	High value habitat. Good flow with lots of boulder cover and LWD. Some deep pools with abundant gravels suitable for spawning. Good habitat but no fish were caught. 11:20
Weigert Creek	197534_us4	648701	5532025	Medium value habitat. Frequent large Woody debris jams between 40 and 70 cm in height. Frequent small cascade sections of to 10% and up to 3 to 5 m long. Numerous sections with Apple quantity of travels suitable for resident and fluvial WCT. Surveyed in a downstream direction with the bottom end of the site at the first ford. 14:32:07
Weigert Creek	197534_us5	648699	5532036	Medium habitat quality. Fast flowing water with rapids and a few cascades that are about 0.6-0.7m in height. Could block passage of smaller fish. Lots of large woody debris changing the stream course and leading to small cascades. Wide channel with cover from boulders and cobbles. Deep pools in outlet to cascades. Some areas with gravels suitable for spawning. Good amount of cover from overhanging veg. 14:06:36
Tributary to Bighorn Creek	197844_ds_ef2	657824	5452765	Bottom approximately 50 m of the site also functions as a side channel of the Big Horn Creek main stem. Some of the flows in the low section may have been influenced by ground water from the main stem. First 2 widths and 1 gradient in high water side channel of main stem. Dewaters until just below culvert in outlet pool. All fish were caught in pool. Gravels present in lowest section of trib where overlaps with side channel. 10:33:46
Tributary to	197844_us_ef1	657923	5452805	Medium habitat value. Steep gradient with some cascades less than a meter in height. A few deep pools that could be ideal for resident fish. No fish caught

Table 4.2:

gazetted_name	local_name	ef_length_m	ef_width_m	ef_seconds	count_fish	test	CPUE
Weigert Creek	197534_ds_ef1	520	3.480000	4459	11	4.459	2.5
Weigert Creek	197534_ds_ef2	–	–	2995	7	2.995	2.3
Weigert Creek	197534_us_ef1	–	4.400000	–	1	–	–
Weigert Creek	197534_us_ef2	300	4.960000	2120	13	2.120	6.1
Weigert Creek	197534_us_ef3	–	4.440000	1466	1	1.466	0.7
Weigert Creek	197534_us_ef4	330	2.040000	1495	1	1.495	0.7
Weigert Creek	197534_us_ef5	300	1.525000	–	1	–	–
Weigert Creek	197534_us_ef6	550	4.900000	1521	4	1.521	2.6
Brule Creek	197559_us_ef1	600	3.500000	–	1	–	–
Brule Creek	197559_us_ef2	310	3.960000	1626	1	1.626	0.6
Bighorn Creek	197844_ds_ef1	265	6.533333	3846	25	3.846	6.5
Tributary to Bighorn Creek	197844_ds_ef2	95	5.666667	293	5	0.293	17.1
Tributary to Bighorn Creek	197844_us_ef1	300	4.820000	987	1	0.987	1.0
Tributary to Bighorn Creek	197844_us_ef2	225	2.033333	726	1	0.726	1.4

4.2 Fish Habitat Assessment

Fish habitat was assessed at four sites within three reaches of Weigert Creek.

Table 4.3:

location_site	location_reach_number	location_utm_easting	location_utm_northing	general_comments
2	1	649996	5531958	Started at ford crossing (PSCIS 197820) located at downstream route measure 1248m.
3	2	649409	5531694	Discharge Estimated
1	1	650985	5532436	Start approximately Elk River
4	3	647948	5532684	–

Table 4.4:

location_site	site_length	avg_chan_width	area_total_m2	lwd_func	lwd_func_bw	C	G	P	R
1	688	6.1	83457	173	1.5	44	14	5	37
2	311	6.5	17931	37	0.8	46	1	4	49
3	356	6.3	17262	119	2.1	60	5	3	32

4.2 Fish Habitat Assessment

location_site	site_length	avg_chan_width	area_total_m2	lwd_func	lwd_func_bw	C	G	P	R
4	266	5.9	15395	168	3.7	42	17	8	33

5 Recommendations

Recommendations for potential incorporation into collaborative watershed connectivity planning for the Elk River watershed group include:

- Continue to acquire background information and leverage ongoing research initiatives in the region to collaboratively clarify current conditions and identify limiting factors to inform prioritization and effectiveness monitoring programs.
- Develop strategies to explore cost and fisheries production benefits of stream crossing structure upgrades alongside alternative/additional restoration and enhancement investments such as land conservation/procurement/covenant, cattle exclusion, riparian restoration, habitat complexing, water conservation, commercial/recreational fishing management, water treatment and research. Look for opportunities to collaborate and leverage initiatives together for maximum likely restoration benefits.
- Refine barrier thresholds for road-stream crossing structures to explore metrics specific to life stage and life history types of species of interest. This will further focus efforts of potential remediation actions based on biological attributes (ex. timing of migration, size/direction of fish migrating, population dynamics, etc.) and could result in the consideration of interim "stop-gap" physical works to alter crossing characteristics that can address key connectivity issues yet be significantly less costly than structure replacements (ex. building up of downstream area with rock riffles to decrease the outlet drop size and/or increasing water depth within pipe with baffles and substrate additions).
- Model fish densities (fish/m^2) vs. habitat/water quality characteristics (i.e. gradient, discharge, alkalinity, elevation, riparian health, distance from high order streams, etc.) using historically gathered electrofishing and remotely sensed geodata to inform crossing prioritization, future data acquisition needs and the monitoring of restoration actions.
- Continue to develop `bcfishpass`,`bcfishobs`, `fwapg`, `bcdata`, `fpr` and share data analysis and presentation tools that are open source, scaleable and facilitate continual improvement. Tools should continue to be flexible and well documented to allow the future incorporation of alternative fragmentation indicators, habitat gain/value metrics and watershed sensitivity indicators.
- Continue to collaborate with potential partners to build relationships, explore perspectives and develop "road maps" for aquatic restoration in different situations (MoT roads, rail lines, permit roads of different usages, FSRs, etc.) – documenting the people involved, discussions and processes that are undertaken, funding options, synergies, measures of success, etc.

Weigert Creek - 197534 - Appendix

Site Location

PSCIS crossing 197534 is located on Highway 43, approximately 23.5km north of the town of Sparwood. The culvert is located approximately 1.3km upstream from the confluence with the Elk River and is the responsibility of the Ministry of Transportation and Infrastructure.

Background

At crossing 197534, Weigert Creek is a fourth order stream with a watershed area upstream of the crossing of approximately 43.3km^2. The elevation of the watershed ranges from a maximum of 2938m to 1253m at the crossing (Table 5.1). Although multiple upstream survey sites are recorded within provincial databases, there have been no fish recorded upstream (MoE 2020b).

Table 5.1: Summary of derived upstream watershed statistics for PSCIS crossing 197534.

Site	Area Km	Elev Site	Elev Min	Elev Max	Elev Median	Elev P60	Aspect
197534	43.3	1253	1319	2938	2019	1929	SE

* Elev P60 = Elevation at which 60% of the watershed area is above

PSCIS crossing 197534 was assessed in 2020 by (Irvine 2021) and ranked as a barrier for upstream fish migration. The site was noted as having a significantly sized outlet drop (1.2m) and good flow with a location very close to the mainstem of Bighorn Creek which contains confirmed spawning habitat for westslope cutthrout trout. There was 0.8km of steep but viable juvenile rearing habitat surveyed upstream of crossing 197844 in 2021. Bighorn Creek has been noted as contributing significantly to habitat suitable for bull trout spawning in the Wigwam River system with spawning been noted just upstream of the confluence with the Wigwam River. The Wigwam River has been characterized as the most important spawning system in the East Kootenay region, supporting some of the largest westslope cutthrout trout in the Kootenay Region and is located ~11.5km downstream of the subject culvert (Strong and K. D. 2015; R. S. Cope and Morris 2001). A detailed write up of habitat details and stream characteristics can be found in the 2021 report memo linked here.

A summary of habitat modelling outputs is presented in Table 5.2 and a map of the watershed is provided in map attachment 082G.123.

Table 5.2: Summary of fish habitat modelling for PSCIS crossing 197534.

Habitat	Potential	Remediation Gain	Remediation Gain (%)
WCT Spawning (km)	8.2	3.3	40
WCT Rearing (km)	11.1	4.6	41
WCT Stream (km)	20.3	5.4	27
WCT Network (km)	20.3	5.4	27
WCT Lake Reservoir (ha)	–	0.0	–
WCT Wetland (ha)	–	0.0	–
WCT Slopeclass03 Waterbodies (km)	0.0	0.0	–
WCT Slopeclass03 (km)	3.0	2.1	70
WCT Slopeclass05 (km)	6.0	1.2	20
WCT Slopeclass08 (km)	3.6	1.5	42
WCT Slopeclass15 (km)	5.9	0.3	5
WCT Slopeclass22 (km)	1.9	0.3	16

* Model data is preliminary and subject to adjustments.

Fish Sampling

Electrofishing was conducted with results summarised in Tables 5.4 - 5.5 and Figure 5.1. Habitat details are summarised in Table 5.3.

Results

Table 5.3: Summary of habitat details for electrofishing sites upstream and downstream of PSCIS crossing 197534.

Site	Length Surveyed (m)	Channel Width (m)	Wetted Width (m)	Pool Depth (m)	Gradient (%)	Total Cover	Habitat Value
197534_ds_ef1	520	4.4	3.5	0.8	3.1	moderate	Medium
197534_ds_ef2	1240	–	–	–	–	–	–
197534_us_ef2	300	5.6	5.0	0.5	5.2	moderate	High
197534_us_ef1	–	6.2	4.4	–	6.6	–	–
197534_us_ef3	–	6.4	4.4	0.6	3.8	–	High
197534_us4	440	6.8	5.7	0.6	5.5	moderate	Medium
197534_us5	450	6.7	4.8	0.6	3.5	moderate	Medium
197534_us_ef4	330	5.0	4.0	0.7	6.7	moderate	Medium
197534_us_ef5	300	4.9	–	–	–	abundant	–
197534_us_ef6	550	7.0	4.9	0.4	4.0	abundant	–

Table 5.4: Fish sampling site summary for 197534.

site	passes	ef_length_m	ef_width_m	area_m2	enclosure
197534_ds_ef1	1	520	3.480	1809.6	open
197534_ds_ef2	1	–	–	–	open
197534_us_ef1	1	–	4.400	–	open
197534_us_ef2	1	300	4.960	1488.0	open
197534_us_ef3	1	–	4.440	–	open
197534_us_ef4	1	330	2.040	673.2	open
197534_us_ef5	1	300	1.525	457.5	open
197534_us_ef6	1	550	4.900	2695.0	open

Table 5.5: Fish sampling density results summary for 197534.

local_name	species_code	life_stage	catch	density_100m2	nfc_pass
197534_ds_ef1	BT	adult	1	0.1	FALSE
197534_ds_ef1	EB	fry	1	0.1	FALSE
197534_ds_ef1	EB	parr	1	0.1	FALSE
197534_ds_ef1	EB	juvenile	1	0.1	FALSE
197534_ds_ef1	MW	juvenile	1	0.1	FALSE
197534_ds_ef1	WCT	parr	3	0.2	FALSE
197534_ds_ef1	WCT	juvenile	2	0.1	FALSE
197534_ds_ef2	WCT	adult	1	–	FALSE
197534_us_ef1	NFC	–	0	–	TRUE
197534_us_ef2	WCT	juvenile	1	0.1	FALSE
197534_us_ef2	WCT	adult	6	0.4	FALSE
197534_us_ef3	NFC	–	0	–	TRUE

local_name	species_code	life_stage	catch	density_100m2	nfc_pass
197534_us_ef5	NFC	–	0	0.0	TRUE
197534_us_ef6	WCT	juvenile	1	0.0	FALSE
197534_us_ef6	WCT	adult	1	0.0	FALSE

* nfc_pass FALSE means fish were captured in final pass indicating more fish of this species/lifestage may have remained in site. Mark-recaptured required to reduce uncertainties.

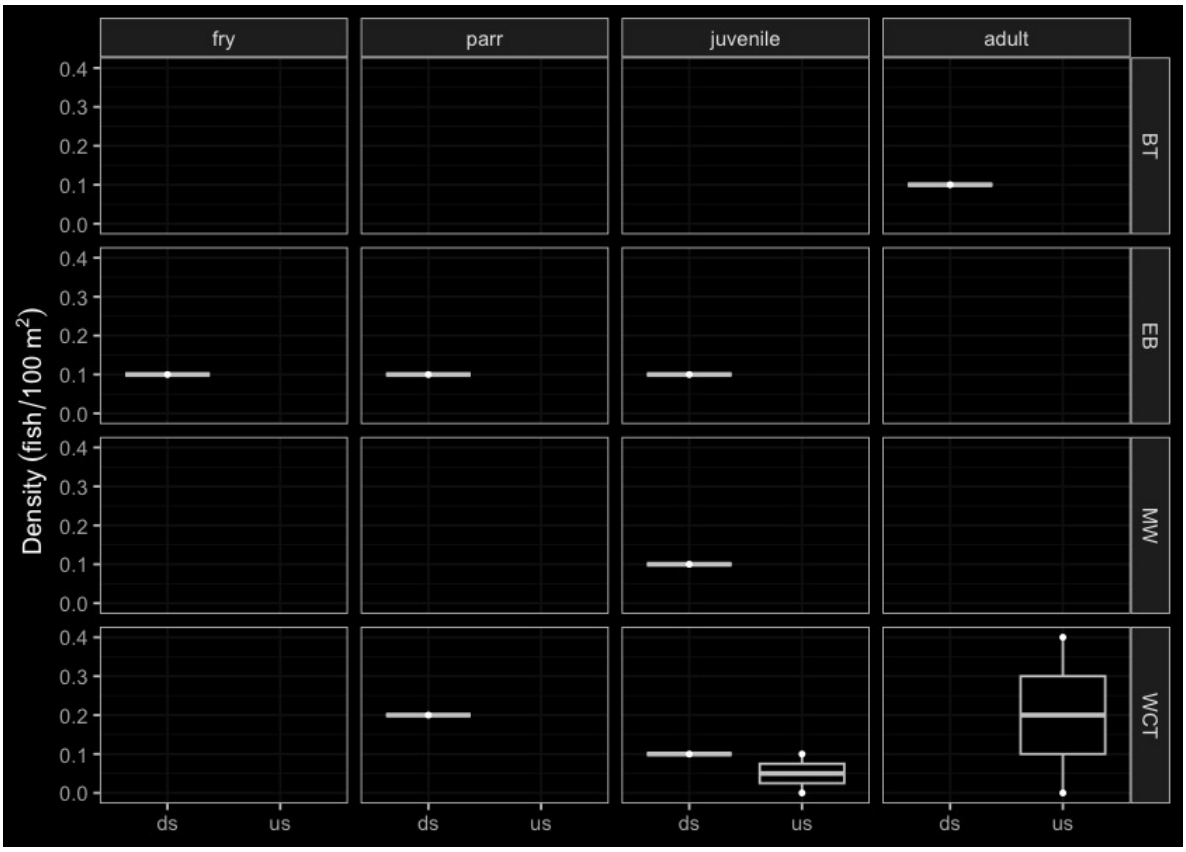

Figure 5.1: Densites of fish (fish/100m2) captured upstream and downstream of PSCIS crossing 197534.

Brule Creek - 197559 - Appendix

Site Location

PSCIS crossing 197559 is located on Highway 43 approximately 20km north of the town of Sparwood, 0.7km upstream from the confluence with the Elk River. This crossing is the responsibility of the Ministry of Transportation and Infrastructure. This stream was assessed in 2020 by (Irvine 2021). Two fords (PSCIS 197535 and 197536) were documented 700m and 2km upstream of crossing 197559 respectively.

5.1 Background

At the highway, Brule Creek is a 5th order stream with watershed characteristics detailed in Table 5.6. Brule Creek is known to contain westslope cutthrout trout, rainbow trout and bull trout downstream of the subject culverts and westslope cutthrout trout and rainbow trout above (MoE 2020b). On the south side of the upper watershed, at an elevation of 2000m, is the 5ha Josephine Lake (also known as Big Lake). The lake was stocked with westslope cutthrout trout from 1983 - 2000 (MoE 2020b; “Fish Inventories Data Queries” 2020). PSCIS stream crossing 197559 was ranked as a high priority for follow up with new structure designs following habitat confirmations by Irvine (2021) due to the large size of the stream network upstream of the highway and because Brule Creek is a 5th order stream. Detailed reporting can be found here.

Table 5.6: Summary of derived upstream watershed statistics for PSCIS crossing 197559.

Site	Area Km	Elev Site	Elev Min	Elev Max	Elev Median	Elev P60	Aspect
197559	82.1	1229	1225	2938	1966	1872	SSE

* Elev P60 = Elevation at which 60% of the watershed area is above

A summary of habitat modelling outputs is presented in Table 5.7 and a map of the watershed is provided in map attachment 082G.123.

Table 5.7: Summary of fish habitat modelling for PSCIS crossing 197559.

Habitat	Potential	Remediation Gain	Remediation Gain (%)
WCT Spawning (km)	18.8	18.8	100
WCT Rearing (km)	21.6	21.6	100
WCT Stream (km)	36.7	34.6	94
WCT Network (km)	37.4	35.2	94
WCT Lake Reservoir (ha)	1.9	1.9	100
WCT Wetland (ha)	0.6	0.6	100
WCT Slopeclass03 Waterbodies (km)	0.7	0.0	0
WCT Slopeclass03 (km)	15.2	15.2	100
WCT Slopeclass05 (km)	5.7	5.7	100
WCT Slopeclass08 (km)	2.2	2.2	100
WCT Slopeclass15 (km)	10.5	8.5	81
WCT Slopeclass22 (km)	2.7	2.5	93

* Model data is preliminary and subject to adjustments.

Stream Characteristics Upstream

The stream was surveyed at two different sites upstream of crossing 197559. The first site was located approximately 1km from the culvert. This section was surveyed for 600m (Figure **??**). The second site was located approximately 1km upstream of modelled crossing 197536. This section was surveyed for 310m to the location of a waterfall (Figure **??**). This waterfall was approximately 5m in height, and blocks the upstream migration of all fish. This obstacle is listed in the Canadian Aquatic Barrier Database, as well as `bcfishpass` (Canadian Wildlife Federation 2023). Stream habitat quality is shown in Figures **??** - **??**.

Fish Sampling

Electrofishing was conducted at two sites upstream of the highway with no fish captured at either site (Tables 5.9 - 5.10). Habitat details are summarised in Table 5.8.

Table 5.8: Summary of habitat details for electrofishing sites upstream of PSCIS crossing 197559.

Site	Length Surveyed (m)	Channel Width (m)	Wetted Width (m)	Pool Depth (m)	Gradient (%)	Total Cover	Habitat Value
197559_us_ef2	310	7.5	4.9	0.6	2.1	moderate	High
197559_us_ef1	600	6.0	3.5	0.6	2.8	abundant	–

Table 5.9: Fish sampling site summary for 197559.

site	passes	ef_length_m	ef_width_m	area_m2	enclosure
197559_us_ef1	1	600	3.50	2100.0	open
197559_us_ef2	1	310	3.96	1227.6	open

Table 5.10: Fish sampling density results summary for 197559.

local_name	species_code	life_stage	catch	density_100m2	nfc_pass
197559_us_ef1	NFC	–	0	0	TRUE
197559_us_ef2	NFC	–	0	0	TRUE

* nfc_pass FALSE means fish were captured in final pass indicating more fish of this species/lifestage may have remained in site. Mark-recaptured required to reduce uncertainties.

Figure 5.2: Left: Typical habitat upstream of PSCIS crossing 197559, on first electrofishing survey. Right: Typical habitat upstream of PSCIS crossing 197559 , on second electrofishing survey.

Figure 5.3: Left: Habitat immediately downstream of waterfall. Right: Waterfall at end of second electrofishing survey, upstream of PSCIS crossing 197559.

Bighorn Creek - 197844 - Appendix

Site Location

PSCIS crossing 197844 is located on a tributary to Bighorn Creek on the Cabin FSR approximately 11km west of the junction with the Wigwam FSR at a point approximately 30k south of Morrissey. Cabin FSR (forest file ID 5466) is ultimately the responsibility of the Ministry of Forests. Although unconfirmed, Canfor may have a road use permit for this section of FSR.

Background

At crossing 197844, Bighorn Creek is a fourth order stream with a watershed area upstream of the crossing of approximately 13.5km^2. The elevation of the watershed ranges from a maximum of 2585m to 1315m at the crossing (Table 5.11).

Table 5.11: Summary of derived upstream watershed statistics for PSCIS crossing 197844.

Site	Area Km	Elev Site	Elev Max	Elev Median	Elev P60	Aspect
197844	13.5	1315	2585	1976	1927	SSW

* Elev P60 = Elevation at which 60% of the watershed area is above

PSCIS crossing 197844 was assessed in 2021 by (Irvine 2022) and ranked as a barrier for upstream fish migration. The site was noted as having a significantly sized outlet drop (1.2m) and good flow with a location very close to the mainstem of Bighorn Creek which contains confirmed spawning habitat for westslope cutthrout trout. There was 0.8km of steep but viable juvenile rearing habitat surveyed upstream of crossing 197844 in 2021. Bighorn Creek has been noted as contributing significantly to habitat suitable for bull trout spawning in the Wigwam River system with spawning been noted just upstream of the confluence with the Wigwam River. The Wigwam River has been characterized as the most important spawning system in the East Kootenay region, supporting some of the largest westslope cutthrout trout in the Kootenay Region and is located ~11.5km downstream of the subject culvert (Strong and K. D. 2015; R. S. Cope and Morris 2001). A detailed write up of habitat details and stream characteristics can be found in the 2021 report memo linked here. A summary of habitat modelling outputs is presented in Table 5.12 and a map of the watershed is provided in map attachment 082G.108.

Table 5.12: Summary of fish habitat modelling for PSCIS crossing 197844.

Habitat	Potential	Remediation Gain	Remediation Gain (%)
WCT Spawning (km)	0.1	0.1	100
WCT Rearing (km)	0.3	0.3	100
WCT Stream (km)	3.1	3.0	97
WCT Network (km)	3.1	3.0	97
WCT Lake Reservoir (ha)	–	0.0	–
WCT Wetland (ha)	–	0.0	–
WCT Slopeclass03 Waterbodies (km)	0.0	0.0	–
WCT Slopeclass03 (km)	0.0	0.0	–
WCT Slopeclass05 (km)	0.1	0.1	100
WCT Slopeclass08 (km)	0.5	0.5	100
WCT Slopeclass15 (km)	2.3	2.3	100
WCT Slopeclass22 (km)	0.2	0.1	50

* Model data is preliminary and subject to adjustments.

Fish Sampling

Electrofishing was conducted with results summarised in Tables 5.14 - 5.15 and Figure 5.4. Habitat details are summarised in Table 5.13. Note that the first site (197844_ds_ef1) was located on the mainstem of Bighorn Creek, while all other sites were located on a tributary to Bighorn Creek.

Table 5.13: Summary of habitat details for electrofishing sites upstream and downstream of PSCIS crossing 197844.

Site	Length Surveyed (m)	Channel Width (m)	Wetted Width (m)	Pool Depth (m)	Gradient (%)	Total Cover	Habitat Value
197844_ds_ef1	265	11.0	6.5	0.7	–	moderate	High
197844_ds_ef2	–	5.0	2.0	–	3.2	–	Medium
197844_us_ef1	300	2.3	2.0	0.4	9.3	moderate	Medium
197844_us_ef2	225	2.1	1.5	0.4	8.7	moderate	Medium

Table 5.14: Fish sampling site summary for 197844.

site	passes	ef_length_m	ef_width_m	area_m2	enclosure
197844_ds_ef1	1	265	6.533333	1731.3	open
197844_ds_ef2	1	95	5.666667	538.3	open
197844_us_ef1	1	300	4.820000	1446.0	open
197844_us_ef2	1	225	2.033333	457.5	open

Table 5.15: Fish sampling density results summary for 197844.

local_name	species_code	life_stage	catch	density_100m2	nfc_pass
197844_ds_ef1	BT	parr	5	0.3	FALSE
197844_ds_ef1	BT	juvenile	6	0.3	FALSE
197844_ds_ef1	BT	adult	10	0.6	FALSE
197844_ds_ef1	NFC	juvenile	0	0.0	TRUE
197844_ds_ef1	WCT	adult	1	0.1	FALSE
197844_ds_ef2	BT	adult	5	0.9	FALSE
197844_us_ef1	NFC	–	0	0.0	TRUE
197844_us_ef2	NFC	–	0	0.0	TRUE

* nfc_pass FALSE means fish were captured in final pass indicating more fish of this species/lifestage may have remained in site. Mark-recaptured required to reduce uncertainties.

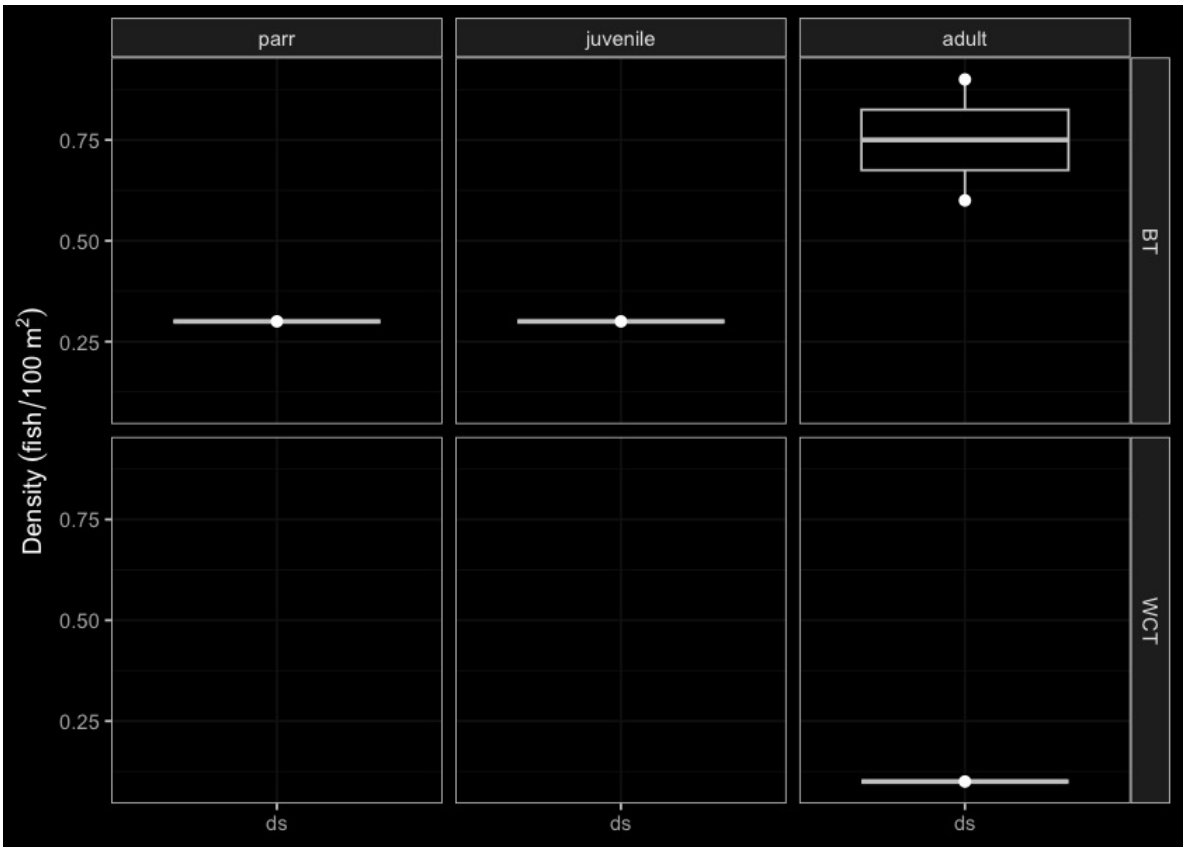

Figure 5.4: Densites of fish (fish/100m2) captured downstream of PSCIS crossing 197844.

References

BC Species & Ecosystem Explorer. 2020a. “Oncorhynchus Clarkii Lewisi (Cutthroat Trout, Lewisi Subspecies).” 2020. https://a100.gov.bc.ca/pub/eswp/reports.do?elcode=AFCHA02088.

———. 2020b. “Salvelinus Confluentus (Bull Trout).” 2020. https://a100.gov.bc.ca/pub/eswp/reports.do?elcode=AFCHA05020.

Blank, Matt D., Kevin M. Kappenman, Kathryn Plymesser, Katharine Banner, and Joel Cahoon. 2020. “Swimming Performance of Rainbow Trout and Westslope Cutthroat Trout in an Open-Channel Flume.”*Journal of Fish and Wildlife Management* 11 (1): 217–25. https://doi.org/10.3996/052019-JFWM-040.

Boyer, Matthew C, Clint C Muhlfeld, and Fred W Allendorf. 2008. “Rainbow Trout (*Oncorhynchus Mykiss*) Invasion and the Spread of Hybridization with Native Westslope Cutthroat Trout (*Oncorhynchus Clarkii Lewisi*).”*Canadian Journal of Fisheries and Aquatic Sciences* 65 (4): 658–69. https://doi.org/10.1139/f08-001.

Bramblett, Robert, Mason Bryant, Brenda Wright, and Robert White. 2002. “Seasonal Use of Small Tributary and Main-Stem Habitats by Juvenile Steelhead, Coho Salmon, and Dolly Varden in a Southeastern Alaska Drainage Basin.”*Transactions of the American Fisheries Society* 131: 498–506. https://doi.org/10.1577/1548-8659(2002)131<0498:SUOSTA>2.0.CO;2.

Brown, Richard S., and William C. Mackay. 1995. “Spawning Ecology of Cutthroat Trout (*Oncorhynchus Clarki*) in the Ram River, Alberta.”*Canadian Journal of Fisheries and Aquatic Sciences* 52 (5): 983–92. https://doi.org/10.1139/f95-097.

Canadian Wildlife Federation. 2023. “Canadian Aquatic Barrier Database.”https://github.com/Canadian-Wildlife-Federation/CABD.

Cope, R S, and K J Morris. 2001. “Wigwam River Juvenile Bull Trout and Fish Habitat Monitoring Program: 2000 Data Report.”https://digital.library.unt.edu/ark:/67531/metadc718003/m2/1/high_res_d/786475.pdf.

Cope, Scott, C. J Schwarz, and A Prince. 2017. “Upper Fording River Westslope Cutthrout Trout Population Monitoring Project: 2017.”https://www.teck.com/media/Upper-Fording-River-Westslope-Cutthroat-Trout-Population-Monitoring-Project,-2012-2017-(December-2017).pdf.

Cote, David, P Frampton, M Langdon, and R Collier. 2005. *Fish Passage and Stream Habitat Restoration in Terra Nova National Park Highway Culverts*.

Davidson, A, H Tepper, J Bisset, K Anderson, P. J Tschaplinski, A Chirico, A Waterhouse, et al. 2018. “Aquatic Ecosystems Cumulative Effects Assessment Report.”https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/cumulative-effects/final_ev_cemf_aquatic_ecosystems_cea_report_24072018.pdf.

Diebel, M. W., M. Fedora, S. Cogswell, and J. R. O’Hanley. 2015. “Effects of Road Crossings on Habitat Connectivity for Stream-Resident Fish: STREAM-RESIDENT FISH HABITAT CONNECTIVITY.”*River Research and Applications* 31 (10): 1251–61. https://doi.org/10.1002/rra.2822.

Elk Valley Cumulative Effects Management Framework Working Group. 2018. “Elk Valley Cumulative Effects Assessment and Management Report.”https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/cumulative-effects/final_elk_valley_ceam_12122018.pdf.

Environment, and Climate Change Canada. 2020. “National Water Data Archive: HYDAT.” Service description. aem. 2020. https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/monitoring/survey/data-products-services/national-archive-hydat.html.

Irvine, A. 2021. “Upper Elk River and Flathead River Fish Passage Restoration Planning.”https://newgraphenvironment.github.io/fish_passage_elk_2020_reporting_cwf/.
———. 2022. “Elk River Watershed Group Fish Passage Restoration Planning 2021.”https://newgraphenvironment.github.io/fish_passage_elk_2021_reporting/.
Johnston, N. T., and P. A. Slaney. 1996. “Fish Habitat Assessment Procedures.”
“Ktunaxa Nation.” 2020. 2020. https://www.ktunaxa.org/.
Lamson, Heather. 2020. “Evaluation of Current Westslope Cutthroat Trout Hybridization Levels in the Upper Kootenay Drainage.”http://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=58888.
Ministry of Forests, Lands. 2020. “Elk Valley Cumulative Effects Management Framework - Province of British Columbia.”Province of British Columbia. 2020. https://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/cumulative-effects-framework/regional-assessments/kootenay-boundary/elk-valley-cemf.
MoE. 2020a. “Known BC Fish Observations and BC Fish Distributions.” Ministry of Environment and Climate Change Strategy - Knowledge Management. 2020. https://catalogue.data.gov.bc.ca/dataset/known-bc-fish-observations-and-bc-fish-distributions.
———. 2020b. “Known BC Fish Observations and BC Fish Distributions.” Ministry of Environment and Climate Change Strategy - Knowledge Management. 2020. https://catalogue.data.gov.bc.ca/dataset/known-bc-fish-observations-and-bc-fish-distributions.
Norris, Simon. 2020. “Bcfishobs.”Hillcrest Geographics. https://github.com/smnorris/bcfishpass.
———. (2020) 2023. “Smnorris/Bcfishpass.”https://github.com/smnorris/bcfishpass.
Resources Inventory Committee. 2001. “Reconnaissance (1:20 000) Fish and Fish Habitat Inventory: Standards and Procedures. Version 2.0.”Resources Inventory Committee; Prepared by BC Fisheries Information Services Branch. https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/recce2c.pdf.
Schmetterling, David. 2001. “Seasonal Movements of Fluvial Westslope Cutthroat Trout in the Blackfoot River Drainage, Montana.”*North American Journal of Fisheries Management* 21: 507–20. https://doi.org/10.1577/1548-8675(2001)021<0507:SMOFWC>2.0.CO;2.
Schweigert, J. F, John Robert Post, Canada, Environment, limate Change Canada, Canadian Wildlife Service, and Committee on the Status of Endangered Wildlife in Canada. 2017. *COSEWIC Assessment and Status Report on the Westslope Cutthroat Trout, Oncorhynchus Clarkii Lewisi, Saskatchewan-Nelson River Populations, Pacific Populations, in Canada.*Ottawa: Environment and Climate Change Canada. http://publications.gc.ca/collections/collection_2017/eccc/CW69-14-506-2017-eng.pdf.
Slaney, P. A, Daiva O Zaldokas, and Watershed Restoration Program (B.C.). 1997. *Fish Habitat Rehabilitation Procedures*. Vancouver, B.C.: Watershed Restoration Program. https://www.for.gov.bc.ca/hfd/library/FFIP/Slaney_PA1997_A.pdf.
Strong, J. S., and Heidt K. D. 2015. “McNeil Substrate Sampling Program 2015 Summary Report.”https://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=49787.
Swales, Stephen, and C. Levings. 1989. “Role of Off-Channel Ponds in the Life Cycle of Coho Salmon (Oncorhynchus Kisutch) and Other Juvenile Salmonids in the Coldwater River, British Columbia.”*Canadian Journal of Fisheries and Aquatic Sciences - CAN J FISHERIES AQUAT SCI* 46: 232–42. https://doi.org/10.1139/f89-032.

Session Info

```
R version 4.2.2 (2022-10-31)
Platform: aarch64-apple-darwin20 (64-bit)
Running under: , RStudio 2022.12.0.353

Locale: en_US.UTF-8 / en_US.UTF-8 / en_US.UTF-8 / C / en_US.UTF-8 /
en_US.UTF-8

Package version:
  AsioHeaders_1.22.1.2     askpass_1.1              assertthat_0.2.1
backports_1.4.1          base64enc_0.1-3
  bcdata_0.4.0             BH_1.81.0.1              bibtex_0.5.1
bit_4.0.5                bit64_4.0.5
  bitops_1.0-7             blob_1.2.3               bookdown_0.32
boot_1.3.28.1            broom_1.0.3
  bslib_0.4.2              cachem_1.0.7             callr_3.7.3
cellranger_1.1.0         chk_0.8.1.9002
  chron_2.3-59             citr_0.3.2               class_7.3-21
classInt_0.4-8           cli_3.6.0
  clipr_0.8.0              codetools_0.2-19         colorspace_2.1-0
commonmark_1.8.1         compiler_4.2.2
  conflicted_1.2.0         cpp11_0.4.3              crayon_1.5.2
crosstalk_1.2.0          crul_1.3
  curl_5.0.0               data.table_1.14.8        datapasta_3.1.0
DBI_1.1.3                dbplyr_2.3.0
  digest_0.6.31            doParallel_1.0.17        dplyr_1.1.0
dtplyr_1.3.0             e1071_1.7-13
  elevatr_0.4.2            ellipsis_0.3.2           english_1.2-6
evaluate_0.20            exifr_0.3.2
  fansi_1.0.4              farver_2.1.1             fasstr_0.5.0
fastmap_1.1.0            fishbc_0.2.1.9000
  fitdistrplus_1.1.8       fontawesome_0.5.0        forcats_1.0.0
foreach_1.5.2            foreign_0.8-84
  fpr_1.0.2.9000           fs_1.6.1                 furrr_0.3.1
future_1.31.0            fwapgr_0.1.0.9013
  gargle_1.3.0             generics_0.1.3           geojson_0.3.4
geojsonio_0.10.0         geojsonsf_2.0.3
  geometries_0.2.1         ggdark_0.2.1             ggmap_3.0.1.900
ggplot2_3.4.1            globals_0.16.2
  glue_1.6.2               googledrive_2.0.0
googlePolylines_0.8.2    googlesheets4_1.0.1      googleway_2.7.6
  graphics_4.2.2           grDevices_4.2.2          grid_4.2.2
gridExtra_2.3            gtable_0.3.1
  haven_2.5.1              highr_0.10               hms_1.1.2
```

```
httpcode_0.3.0           httpuv_1.6.9             httr_1.4.5
ids_1.0.1                isoband_0.2.7
  iterators_1.0.14         janitor_2.2.0            jpeg_0.1-10
jqr_1.2.3                jquerylib_0.1.4
  jsonify_1.2.2            jsonlite_1.8.4           kableExtra_1.3.4
Kendall_2.2.1            KernSmooth_2.23-20
  knitr_1.42               labeling_0.4.2           later_1.3.0
lattice_0.20-45          lazyeval_0.2.2
  leafem_0.2.0             leaflet_2.1.1
leaflet.extras_1.0.0     leaflet.providers_1.9.0  lifecycle_1.0.3
  listenv_0.9.0            lubridate_1.9.2          magick_2.7.3
magrittr_2.0.3           maptools_1.1-6
  markdown_1.5             MASS_7.3.58.2            Matrix_1.5.3
memoise_2.0.1            methods_4.2.2
  mgcv_1.8.41              mime_0.12                miniUI_0.1.1.1
modelr_0.1.10            munsell_0.5.0
  nabor_0.5.0              nlme_3.1.162             openssl_2.0.5
openxlsx_4.2.5.2         pacman_0.5.1
  pagedown_0.20.1          parallel_4.2.2           parallelly_1.34.0
pdftools_3.3.3           PearsonDS_1.2.3
  pgfeatureserv_0.0.0.9003 pillar_1.8.1             pkgconfig_2.0.3
plogr_0.2.0              plyr_1.8.8
  png_0.1-8                poisspatial_0.1.0.9000
poisutils_0.0.0.9010     prettyunits_1.1.1        processx_3.8.0
  progress_1.2.2           progressr_0.13.0         promises_1.2.0.1
protolite_2.2.0          proxy_0.4-27
  ps_1.7.2                 purrr_1.0.1              qpdf_1.3.0
R6_2.5.1                 ragg_1.2.5
  rapidjsonr_1.2.0         rappdirs_0.3.3           raster_3.6-14
rayimage_0.9.1           rayshader_0.24.10
  rbbt_0.0.0.9000          RColorBrewer_1.1.3       Rcpp_1.0.10
RcppArmadillo_0.12.0.1.0 RcppEigen_0.3.3.9.3
  RcppRoll_0.3.0           readr_2.1.4
readwritesqlite_0.2.0    readxl_1.4.2             RefManageR_1.4.0
  rematch_1.0.1            rematch2_2.1.2           remotes_2.4.2
reprex_2.0.2             rgdal_1.6-4
  rgeos_0.6-1              rgl_1.0.1
RgoogleMaps_1.4.5.3      rlang_1.0.6              rmarkdown_2.20
  RPostgres_1.4.5          RPostgreSQL_0.7-5        RSQLite_2.3.0
rstudioapi_0.14          rvest_1.0.3
  s2_1.1.2                 sass_0.4.5               scales_1.2.1
selectr_0.4.2            servr_0.25
  sf_1.0-9                 sfheaders_0.4.0          shiny_1.7.4
shinyjs_2.1.0            slippymath_0.3.1
  snakecase_0.11.0         sourcetools_0.1.7.1      sp_1.6-0
splines_4.2.2            stats_4.2.2
  stringi_1.7.12           stringr_1.5.0            survival_3.5.3
```

```
svglite_2.1.1           sys_3.4.1
  systemfonts_1.0.4       terra_1.7-3           terrainmeshr_0.1.0
textshaping_0.3.6       tibble_3.1.8
  tidyhydat_0.5.9         tidyr_1.3.0           tidyselect_1.2.0
tidyverse_2.0.0         timechange_0.2.0
  tinytex_0.44            tools_4.2.2           triebeard_0.3.0
tzdb_0.3.0              units_0.8-1
  urltools_1.7.3          utf8_1.2.3            utils_4.2.2
uuid_1.1.0              V8_4.2.2
  vctrs_0.5.2             viridis_0.6.2         viridisLite_0.4.1
vroom_1.6.1             webshot_0.5.4
  websocket_1.4.1         withr_2.5.0           wk_0.7.1
xfun_0.37               XML_3.99.0.13
  xml2_1.3.3              xtable_1.8-4          yaml_2.3.7
yesno_0.1.2             zip_2.2.2
  zyp_0.11
```