Study Design and Field Methods: Guidance on Coastal Tailed Frog Monitoring of Run-of-River Hydropower Projects

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1 Introduction

Coastal Tailed Frogs (*Ascaphus truei*) are listed as “Special Concern” under Schedule 1 of the federal Species at Risk Act (COSEWIC 2012), and provincially under the "Blue List" and the Conservation Framework (CDC 2013). Tailed frogs lay their eggs in perennial streams, where they remain as tadpoles for 2-4 years, after which they reside in riparian habitats post-metamorphosis (IWMS 2004). The specialized habitat requirements of tailed frogs cause them to be sensitive to changes in stream conditions and adjacent riparian areas (Welsh and Ollivier 1998, Dupuis and Steventon 1999, Stoddard and Hayes 2005). This sensitivity may be compounded by their unique life history, which includes an extended larval stage and a lengthy time to reach reproductive maturity (≤7 years). In Coastal B.C., hydropower development consistently overlaps with suitable terrestrial and aquatic habitat for tailed frogs, leading to concerns regarding cumulative population-level impacts. Potential operational impacts of reduced flow and altered ramping rates include: egg and tadpole stranding, reduced aquatic habitat availability, reduced suitable substrate availability, changes to sedimentation patterns, and reduced population connectivity. Construction of project infrastructure may cause additional impacts to terrestrial juveniles and adults, including loss and fragmentation of riparian habitat.

The Ministry of Forest, Lands, and Natural Resource Operations (FLNR) is currently in the process of implementing a collaborative study to monitor tailed frog tadpoles and habitat conditions at several facilities in the South Coast, using a Before-After-Control-Impact (BACI) design to assess if hydropower construction or operation affects tadpole survival, distribution, or abundance. This document summarizes the project study design and field sampling methods, as well as the first year of data collection in 2013. These are the most up-to-date FLNR tailed frog recommendations to Run-of-River Hydropower proponents regarding development of Long-Term Monitoring Plans, as per Water License conditions.

2 Study Design

Our study employs a Before-After-Control-Impact (BACI) design to assess the potential effects of project construction and operation on tailed frog tadpole abundance and distribution. If properly implemented, BACI designs are considered to be the most suitable approach for detecting and quantifying human-based environmental disturbances (Underwood 1994). Because BACI studies focus on the difference between control and impact sites compared before and after the impact occurs, natural population fluctuations can be separated from effects directly attributable to the project itself. This is particularly important for highly variable systems such as montane streams, where channel characteristics and tailed frog abundance can vary widely between years under natural conditions (Friele 2009, FREP 2010).

2.1 Mainstem Infrastructure

Our study design involves sampling tadpoles and habitat characteristics in the diversion reach between the intake and the tailrace ("Impact Treatment") and upstream of the intake beyond the effects of water diversion ("Control Treatment"; Figure 1). Results of a recent power analysis suggest that to detect a 50% difference in tadpole counts between control and impact treatments, and before and after construction, five survey locations per treatment ("sites"; Figure 1) are required, assuming 2 years of sampling pre-construction, and 5 years post-construction (Malt and Crockett 2013). This design also assumes that each site is surveyed 3 times per season (section 2.4). In 2013, we added a "Tailrace" treatment located below the powerhouse (Figure 1). This treatment is intended as a preliminary investigation of potential impacts of flow ramping downstream of the tailrace. Additional replication and/or refinement of the study design may be required in the future to study this impact mechanism in a more rigorous manner.

Survey sites in the mainstem are located a minimum of 100 m apart to ensure independence, but this requirement can be relaxed to 75 m if necessary due to logistical constraints (e.g. natural barriers or a limited amount of suitable habitat to "fit" sites into). In some cases, these constraints may also limit the number of sites per treatment (Table 1). Sites are preferentially located in reaches with low-gradient cross-sections and shallow margins, as we predict these sites will have the highest probability of being impacted by reductions in flow.

In smaller streams (e.g. Sakwi and Keenan creeks) sites can be located in reaches where it is possible to survey the entire width of the stream during a time-constrained search (TCS; section 4.1). However, this may not possible in larger streams with high flow levels. In this case, an area along the stream margin is selected, using natural channel features to delineate a suitable area (e.g. side channel or riffle). In 2013, sites were selected along stream margins (and did not span the width of streams) at all facilities except Sakwi.

2.2 Penstock Tributary Crossings

Our study design to assess impacts of tributary penstock crossings is similar to the BACI design described above. For each tributary, sampling is conducted at one site within reaches representing three treatments: upstream of the penstock crossing ("Control"), at the proposed penstock crossing ("Crossing Impact"), and downstream of the penstock crossing ("Downstream Impact"). Each site is surveyed 3 times per season (section 2.4). In 2013, we sampled two tributaries at each of three facilities (Table 1), but more replication at additional tributary crossings is possible at most facilities. Similar to the mainstem, each site within a tributary should be at least 100 meters apart.

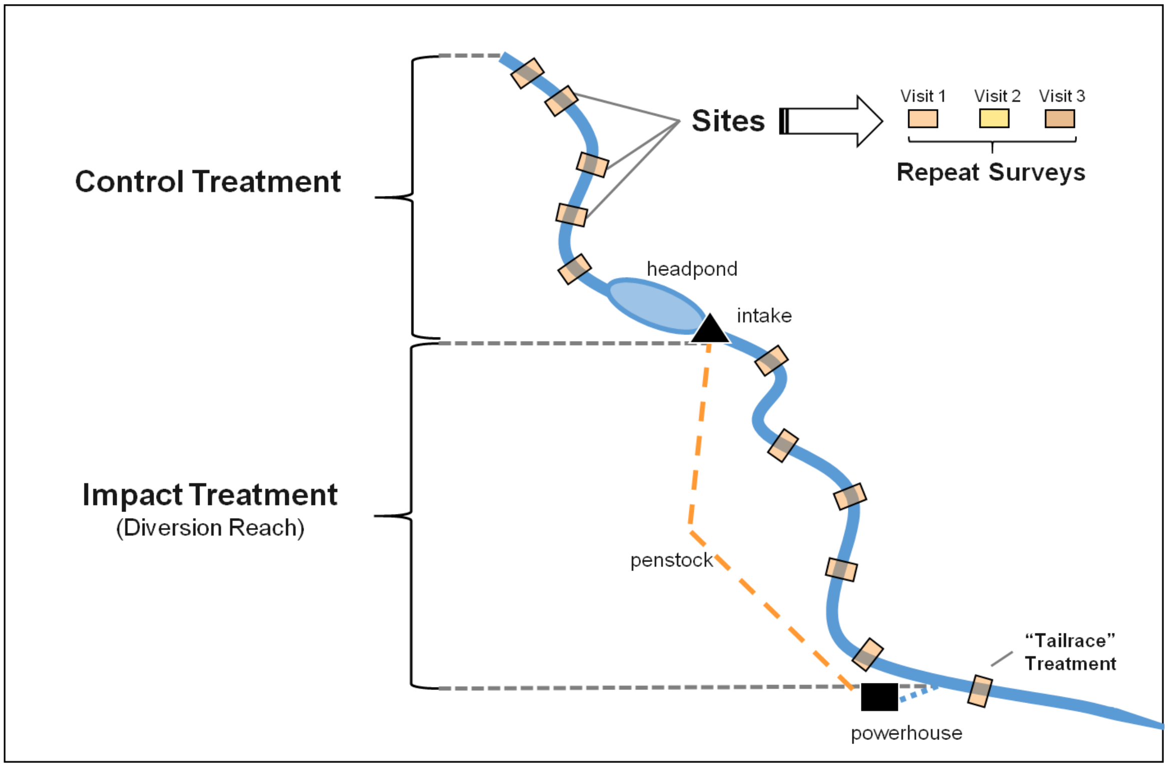

Figure 1: Schematic of the BACI study design on mainstem project infrastructure.

2.3 Facility Selection

Selection of facilities (watersheds) to conduct this study was based primarily on tailed frog habitat suitability, access, and timing. Habitat suitability or tailed frog presence was based on data from previous surveys and watershed-scale predictors (i.e. basin size 0.3-100 km^2; Dupuis and Friele 2006). A minimum of two years pre-construction sampling (i.e. prior to commencement of water diversion) is necessary to provide a sufficient baseline for comparison to post-construction conditions. Based on these criteria, we choose to initiate sampling at Sakwi, Hunter, Tamihi, and Wahleach in 2013 (Table 1, Figure 2).

Table 1. Sites per treatment sampled at each facility in 2013 (each site surveyed 3 times).

	Mainstem			**Penstock Crossings**			
Facility	**Mainstem**	**Control**	**Impact**	**Trib.**	**Upstream**	**Crossing**	**Downstream**
Hunter Cr.	Hunter East	4	5	X13	1	1	1
	Hunter West	5	5	X15	1	1	1
Sakwi Cr.	Sakwi	5	5				
	Keenan	5	4				
Tamihi Cr.	Tamihi	5	5	Trb05	1	1	1
				Trb06	1	1	1
Wahleach Cr.	Wahleach	5	5	DivTrb	1	1	1
				TrbA	1	1	1
Totals		**29**	**29**		**6**	**6**	**6**

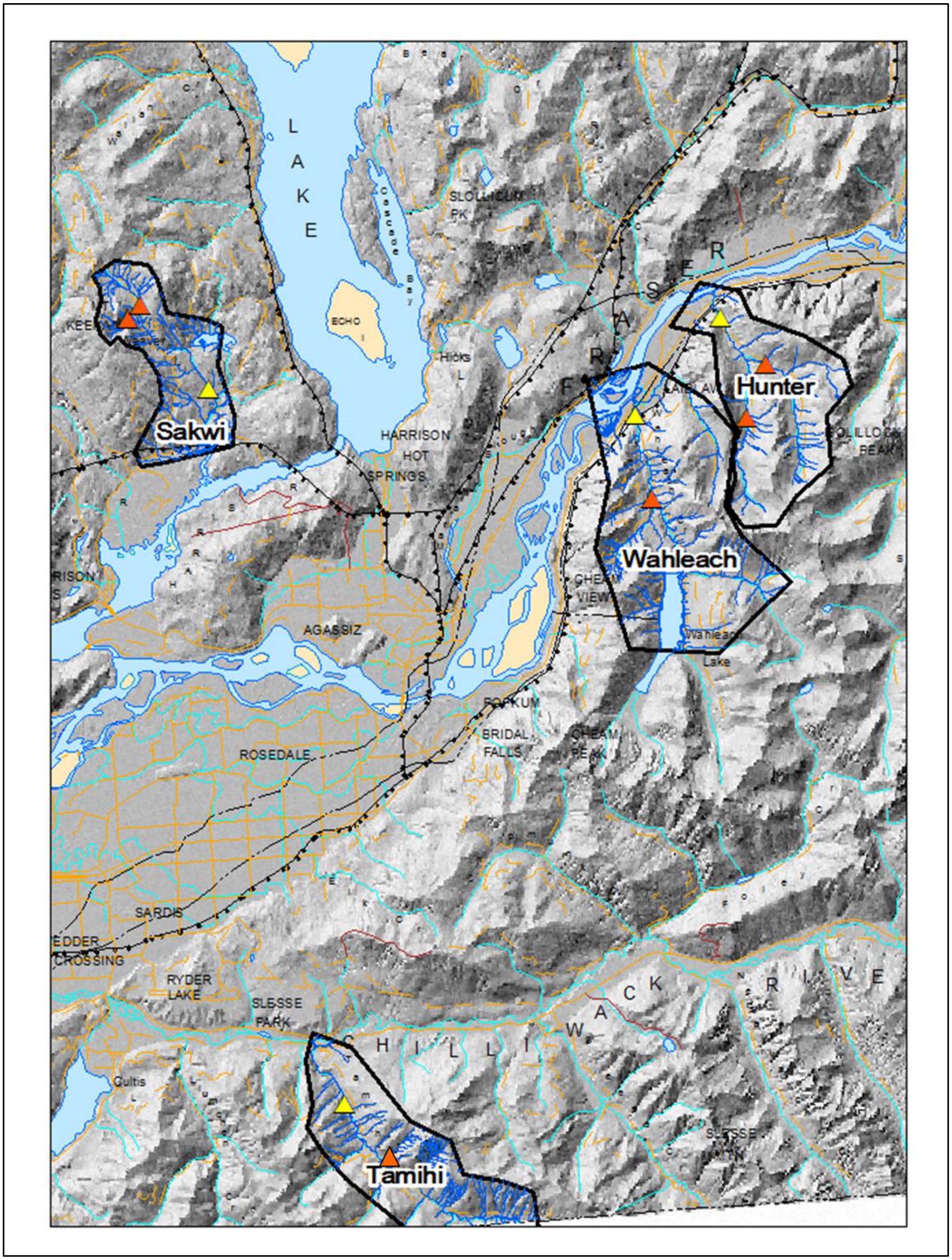

Figure 2. Selected Facilities (watersheds) for sampling under the BACI study design, which was initiated in 2013. Orange and yellow triangles indicate intake and powerhouse locations, respectively.

2.4 Adjusting for imperfect detectability

Our study design includes at least three repeat surveys per season of sampling. In addition to providing an acceptable level of power (Malt and Crockett 2013), this enables us to analyze the data using an occupancy framework, which accounts for variation in detection probability between surveys (MacKenzie et al. 2002, Tyre et al. 2003, Royle 2004). This is important, because unless exhaustive search such as depletion methods are conducted, observed abundance will always be subject to imperfect detection. This is especially true for elusive species such as tailed frogs, where the possibility of detection can vary both temporally (daily, seasonally) and with survey conditions (weather, habitat structure)[1]. Occupancy models account for detection probability when calculating estimates of 'true' abundance, thereby yielding estimates that are closer to the true population size. Adjusting tailed frog tadpole counts for variation in detectability will help to reduce measurement error, and thereby significantly improve our ability to detect project effects.

3 Scheduling

3.1 Mainstem

The first sampling visit to a mainstem infrastructure replicate[2] typically requires two days, as more habitat data needs to be collected on this visit relative to subsequent visits (section 5.1). Typically, one treatment is sampled per day, with the order of treatments and sites reversed on each subsequent visit. For example, during the first visit of Keenan Creek in 2013, the Impact treatment was surveyed on day 1 and the Control on day 2, both downstream to upstream. On the second visit, the Control was surveyed on day 1 and the Impact on day 2, both upstream to downstream. For some mainstem replicates (i.e. those with easy access), 2nd or 3rd sampling visits may be able to be completed in a single day. In those cases, the order of treatments and sites should still be reversed from the last visit. Scheduling in this manner should limit systemic bias due to factors such as weather conditions, time of day, or season.

Timing between visits should be approximately two weeks, to allow enough time for channel conditions and tadpoles to recover. This is sometimes not possible; for instance, high water levels shortened the sampling period to 1.5 weeks for Tamihi and Hunter in 2013. Sampling should also be conducted such that each round of visits is completed for all sites in a facility before the next round is initiated.

[1] Sampling of variables that may affect detectability are described in Section 4.

[2] A mainstem infrastructure replicate refers to a location within a stream where an intake is located or proposed, where Control and Impact (upstream and downstream) treatments are established. Because Hunter and Sakwi have 2 mainstem replicates each, these facilities would take four days each to sample on the first visit.

3.2 Penstock Tributary Crossings

As our design prescribes fewer sites per penstock tributary crossings relative to mainstem sites, 2 tributaries (6 sites) can typically be completed in one day. Similar to the mainstem, the order of tributaries and sites is reversed between visits. For example, for our first visit of Wahleach tributaries, “DivTrb” was surveyed downstream- upstream, followed by “TrbA” in the same direction. During the second visit, DivTrb and TrbA were both sampled upstream-downstream (although logistics precluded reversing tributary order; Appendix IV).

4 Data Collection- Larval Surveys

4.1 Time-Constrained Searches

Tadpole abundance is assessed with time-constrained searches (TCS) of each site, which are 15-minute surveys conducted simultaneously by two observers (RIC 2000). A method similar to the “light-touch” method is used, as recommended by Quinn et al. (2007). While less exhaustive compared to Area-Constrained surveys (which are closer to a census), TCS are quicker and easy to repeat, thereby allowing higher levels of both spatial and temporal replication. This in turn provides increased statistical power and the ability to adjust for imperfect detectability (Section 2.4).

TCS surveys for this study are modification of the methodology of Quinn et al. (2007), as per Todd et al. (2012). This method involves searching both the stream and the stream banks for individuals from any stage (tadpole, metamorph, juvenile or adult). At the beginning of the survey, observers scan the surface of substrates for basking individuals. Next, observers carefully move larger substrates (cobbles and boulders) to search for individuals while holding a dipnet downstream of the substrate to catch dislodged tadpoles. The undersides of rocks are checked for attached tadpoles before they are returned to the stream. Areas of gravel and/or fines are "rubble-roused" while holding a dipnet downstream to capture dislodged tadpoles. As much as possible, observers remain adjacent to each other so that turbidity from an upstream observer does not impede a downstream observer (Todd et al. 2012). In a narrow stream, observers can "leap-frog" each other, while keeping enough distance between themselves to allow sediment to settle. Table 4 includes a list of variables to be collected during and after a TCS (see Appendix I for datasheet).

Table 2. Description of variables to be recorded during each TCS survey of a site.

Category	Variable name	Description
Site Information	Facility	Name of facility and mainstem (e.g. "Hunter East").
	Reach/TCS	Unique name of individual survey sites (e.g. "SakM-CR-TCS3").
	Photo #	Filename of corresponding photo of the site.
	Date	Date on which data was collected.
	Visit #	Which of the three survey visits (1-3).
	Obs	Observers who collected the data.
Weather / Survey Conditions	Air T (C)	Air temperature.
	Water T (C)	Water Temperature .
	RH (%)	Relative humidity.
	Conductivity	Water conductivity taken after each survey.
	Precip	Level of precipitation at time of survey (N = nil, L = light, M = medium, H = heavy).
	Wind	Wind at time of survey (N = nil, L = low, M = medium, H = high).
	CldCvr	Cloud cover at time of survey (0%, < 50%, > 50%, and 100%).
	Shade	Percentage of survey area shaded (%, < 50%, > 50%, and 100%).
Survey Results	Recorder	Observer who recorded the data.
	Start time	Start time of survey (24hr clock).
	time to 1st	Time to first detection (min:sec) of any stage. Not necessarily captured.
	Length surv. (m)	Total length of stream surveyed during 15 min. TCS survey.
	# seen, not cap.	Total number of tadpoles seen during the survey but not captured.
	Cohort	Cohort to which tadpole belongs (0 – 4; see Table X for descriptions)
	Length (mm)	Total length of tadpole or metamorph. Snout-to-vent length for juveniles and adults.
	Wt (g)	Weight (g) of individual.
	Sex	Sex of individual, if applicable.
	Shank	Right shank length.
	Notes	Any notes of interest regarding individual characteristics. This may include disfigurements and abnormalities

4.2 Animal Care

This study will follow methods as described in MOE (2008). During surveys, tadpoles, metamorphs, juveniles and adults are placed into plastic containers filled with cool stream water. Observers keep their hands cool and wet and minimize handling of all life-stages to reduce heat stress (MOE 2008). Tadpoles and metamorphs are not be left in buckets for more than 30 minutes, and are only be handled for 15 to 30 seconds at a time. Adults and juveniles are left in buckets with solid, moist substrate to rest on, and covered to reduce stress from noise vibrations.

4.3 Measurement & Cohort Identification

Total tadpole length is measured in small transparent containers, with a ruler placed underneath. Tailed frogs are categorized as tadpole cohort 0 - 4, juveniles, or adults (Table 3). This classification system is based on Brown (1990), who studied a North Cascades population similar to those in our study area (average maximum stream temperatures of 10°C), where tadpoles take four years to reach metamorphosis. Because our study is conducted at a similar latitude and climate, we assume a similar development schedule. In areas with warmer summer temperatures, time to metamorphosis may take fewer years, and therefore streams will contain fewer cohorts (Bury and Adams 1999).

When categorizing tadpoles, it is important to be cognizant of the seasonal context, as the morphology and size of cohorts will vary throughout the field season. Tailed frog eggs typically hatch in August, so each August tadpoles have their "birthdays" and transition into the next cohort. As such, between birthdays, they grow and develop substantially, particularly in early summer, before they transition into the next cohort. For instance, when a tadpole has its' second birthday in August (becomes a cohort 2), it is ~36 mm, and the hind limb buds are well covered by the anal fold (Brown 1990). After overwintering and growing in early summer of the following year, it is now ~39 mm, the hind limb buds are larger, and are close to emerging from the anal fold (or protruding slightly; Figures 3a&b and Plate IIa in Brown 1990). By August, the tadpole has now transitioned into a cohort 3, and will have conspicuous hind limbs with five distinct toes; as well as knees *protruding out of* the anal fold (Figure 3c; M. Todd pers. comm.). These legs will become much larger and more developed by the following summer (Figure 3d). The criteria in Table 3 (adapted from Brown 1990 and Todd et al. 2012) should correctly categorize tadpoles to cohort, despite this variation in size and development. For instance, a cohort 3 will always have knees outside of the anal fold, though the size of the legs will vary depending on the season.

Table 3. Criteria used to determine cohort of tailed frogs, adapted from Brown 1990.

Cohort	Age Class	Total length	Description
0	Hatchling / Juvy tad.	1-3 cm	No legs, just hatched in late summer (August; 1-1.5cm); early summer of next year (June/July) will be ~2-2.7cm
1	1-year tad.	~ 3 cm	No visible hind limbs.
2	2-year tadpole	3.5- 4 cm	Recognizable hind limbs, either completely covered by, or protruding slightly from, the anal fold (Fig. 3a). "Knees" may be visible, but do not extend outside of the anal fold (Fig. 3b).
3	3-year tadpole	4-5 cm	Conspicuous hind limb with five distinct toes. Obvious knees that *extend out of* the anal fold (Fig 3c). Limbs can be seen extending from the body when viewed dorsally (Fig 3d).
4	Metamorph / Transformed frog	variable	Front legs appear. Oral disc still present in late summer when metamorphosing. By fall, has transformed, with terminal frog mouth and tadpole-width tail.
J	Juvenile	< 2cm SVL	Tadpole tail gone, very small (<2 g), frequently lighter and smaller than cohorts 4, no nuptial pads. Males can have small developing "tail", but not always visible.
A	Adult		Males have 'tails' (cloaca); nuptial pads present = breeding male; females have no tail; can be non-gravid or gravid (eggs visible under skin of abdomen; will weigh 2-3 grams heavier)

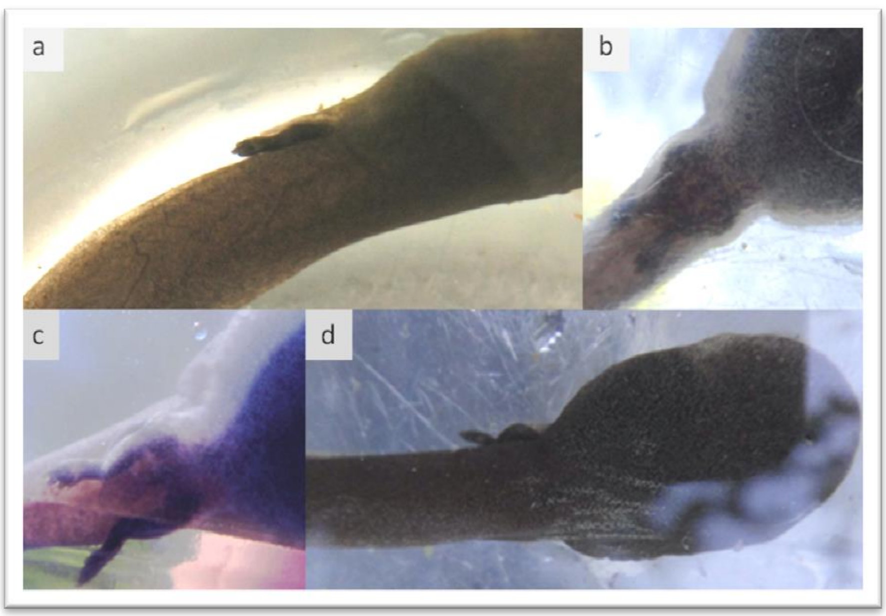

Figure 3. Morphological features used to determine tadpole cohorts. The tadpole in (a) is cohort 2 (note hind legs just protruding from anal fold; M. Todd photo credit), (b) is a well-developed cohort 2 (note knees developing inside the anal fold), (c) has just transitioned to cohort 3 (knees outside anal fold), and (d) is a more developed cohort 3 (note knees; limbs visible dorsally).

5 Data Collection- Habitat Data

5.1 Channel Morphology

Methods to measure channel morphology are modified from the provincial Fish Habitat Assessment Procedures (Johnston and Slaney 1996). For the purposes of the study, these variables are intended to a) estimate the 2-dimensional area of the TCS survey, b) estimate the volume of water within the survey area via multiple cross-sections, and c) track how these variables change during the field season. These are quantified through measurement of bankfull width (Bfw), bankfull depth (Bfd), wetted width (Ww), and wetted depth (Wd) (see Table 4 for definitions, and Appendix I for datasheet).

All channel morphology measurements are located in reference to "Bankfull", which refers to the elevation of a stream bank above which flooding begins (Johnston and Slaney 1996). Measurements are taken along 3 perpendicular transects ("Widths") placed at the beginning (TCS 0 m), mid-point, and end of the TCS survey area (Figure 4). The three measurement starting points for each Width are located at bankfull on the river right ("Bankfull width 0 m mark"; "Bfw 0 m"). The location of Bankfull can be determined by deposits of sand or silt at the active scour mark, a break in stream bank slope, the limit of perennial vegetation, rock discoloration, or root hair exposure.

On the <u>first visit of the season</u>, observers follow these directions:

1. Upon arriving at a site, place a measuring tape is along the center (thalweg) of the stream, starting at the downstream end of the TCS survey ("TCS 0 m"). After the TCS survey is completed (section 5), note the total survey length ("Total length Surv.").

2. Mark the start, mid-point, and end of the TCS survey on the streambank river right, at the location of bankfull, with non-toxic spray-paint. Unless the channel is severely disturbed, these should be permanent markers for the duration of the study (multiple years).

3. At the first Width transect, stretch another measuring tape perpendicular to the channel axis, starting at the bankfull 0 m mark. Measure Bfw as the horizontal distance perpendicular to the channel axis, between bankfull on either side of the streambank.

4. With the tape at Bankfull height, measure Bfd with a measuring stick at the deepest point along the transect. Bfd is measured as the vertical distance from bankfull height to the channel bottom. Note the distance from 0 m where Bfd was measured ("loc of Bfd"), which will be used as a reference point for sampling during subsequent visits (see below).

5. Measure Ww along the transect, as the horizontal distance perpendicular to the channel axis, from water's edge to water's edge on either side of the channel. This is done by noting the distance from the 0 m mark to the beginning and end of wetted area ("Ww [b-e]").

6. Measure Wd at 5-10 evenly spaced intervals (or 3-5 in tributaries), noting the distance from 0 m for each ("d fr Bfw 0m"). Also measure Wd at the deepest point along the transect ("Wd @ Bfd"), as determined in step 4.

7. Repeat steps 3-6 for Width transects 2 and 3.

On the second and third visits of the season, the observers all of these directions:

1. Measure Ww for all 3 transects, as per Step 5 above.
2. Using loc of Bfd from the first visit as a reference (step 4)[3], measure Wd @ Bfd for all 3 transects.

   Note:

   - If the new TCS endpoint is past the 1st (original) endpoint, establish a new Width transect, and record the new total survey length. Measure 5-10 Wd, Bfd, loc of Bfd, Wd @ Bfd, and Ww.
   - If the new TCS endpoint is before the original endpoint, measure only Ww at this transect, and measure Ww and Wd @ Bfd at the original endpoint as per usual.

[3] In 2013, relocating loc of Bfd after the first visit was very challenging, leading to inconsistency between surveys and likey negatively impacting the utility of these data. In future years, alternatives should be explored, such as installing permanent water-level gauges at each site.

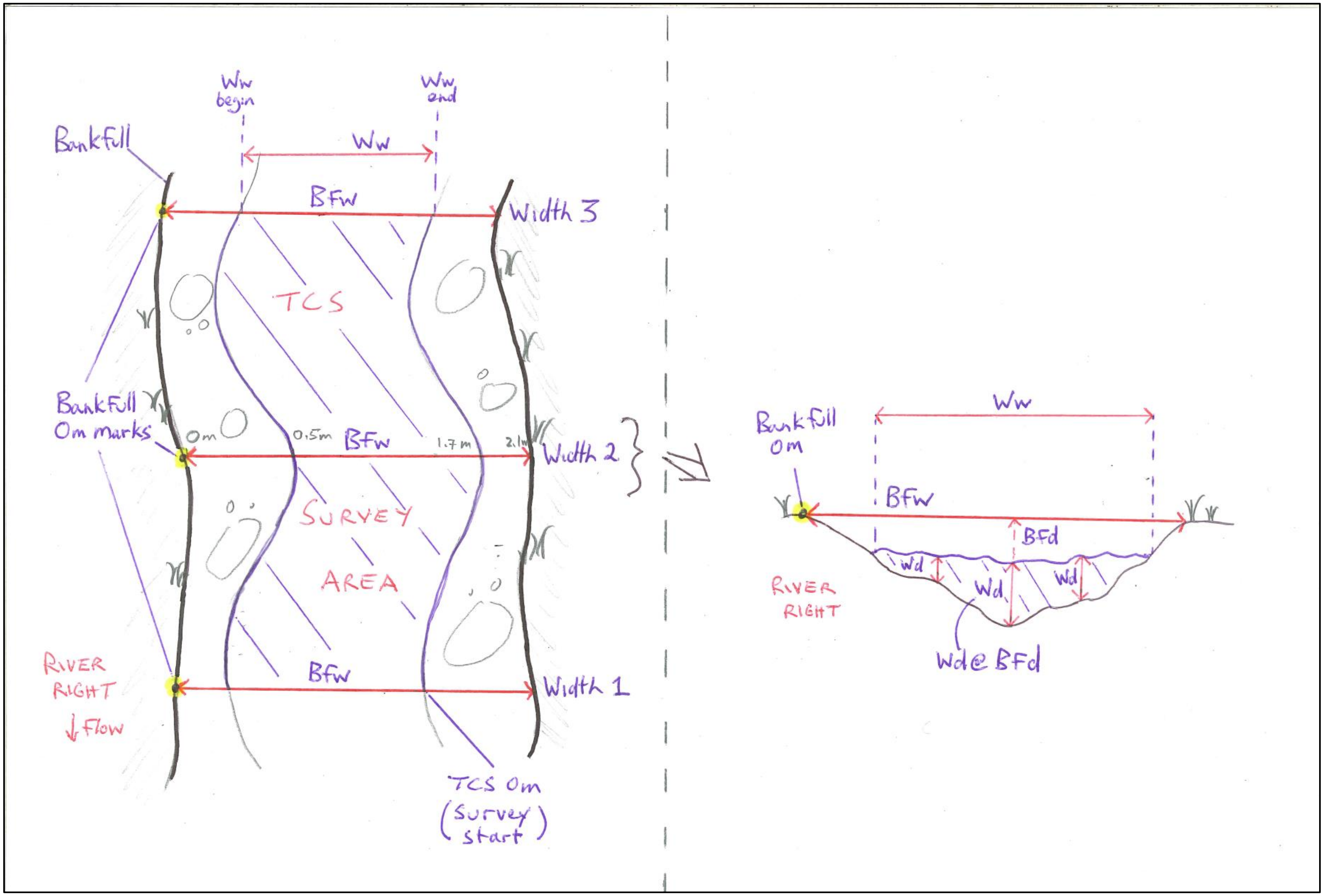

Figure 4. Diagram of channel morphology measurements and associated reference points.

Table 4. Description of variables to be recorded during habitat sampling of each site.

Variable name	Description	Measurement frequency
Facility	Name of facility and mainstem stream (e.g. "Hunter East").	Every visit
Reach/TCS	Unique name of individual survey sites (e.g. "SakM-CR-TCS3").	Every visit
Date	Date on which data was collected.	Every visit
Visit #	Which of the three survey visits (1-3).	Every visit
Obs	Observers who collected the data.	Every visit
Habitat	Type of habitat data within the TCS survey area (riffle, pool, glide, and cascade).	First visit
d fr TCS 0m	Distance from survey start point of habitat type listed above. When >1 habitat types in the survey area, fill multiple entries.	First visit or as required
Length (m)	Total length of habitat type.	First visit
Embedd.	Embeddedness of survey area measured as the degree to which fine sediments fill the pores around coarse substrate pieces [(nil (<5%), low (5 – 25%), med (25 – 75%), high (> 75%).]	First visit
% (Habitat Type)	Percent of each habitat type found within the survey area (%Pool, %Riffle, %Glide, %Cascade).	First visit
Total length Surv. (m)	Total length of area surveyed.	Every visit
ww [b-e] (m)	Wetted width beginning and end as measured from bankfull width 0 m mark.	Every visit
Bfw	Width of stream when at highest flow period (bankfull width).	First visit
loc of Bfd	Location of bankfull depth. Point along cross-sectional transect (which starts bankfull width 0 m mark) where water is deepest.	First visit or as required
wd @ Bfd	Wetted depth at same location as bankfull depth.	Every visit
d fr Bfw 0m	Distance from bankfull width 0 m mark.	First visit or as required
Wd(cm)	Wetted depth.	First visit or as required

5.2 Microhabitat Description

For the purposes of this study, microhabitat features are described in terms of Riffle-pool and cascade-pool morphology, which repeats regularly over stream lengths, as driven by changing sedimentation patterns (Hogan and Luzi 2010). The percent of each morphology type is estimated at each site. Pools are defined as areas with <10% turbulence (i.e. deep, slow water with an overall smooth surface). Riffles are defined as areas with 10-50% turbulence (i.e. shallows with fast, turbulent water running over rocks). Cascades are defined as areas with >50% turbulence, and are typically formed from drops caused by rock weirs and log jams. Glides are defined as deep water with visible turbulence at the surface.

Embeddedness of the survey is also recorded on the first visit (Table 4). It is defined as the degree to which fine sediments fill the pores around coarse substrate pieces (Todd et al. 2012).

5.3 Wolman Pebble Count

A modifies Wolman pebble count (Wolman 1954) of 30 particles is completed in each reach once per season (typically on the first visit), using methods adapted from Todd et al. (2012). Depending on the length and substrate composition of the TCS survey area, particles can either be sampled along one transect in the centre of the survey area, or along two parallel transects. If the survey area contains two different microhabitat types (e.g. riffle in the centre and fines on the margins), sample 2 parallel transects centered on each, to ensure sampling is representative of the survey area. Similarly, if the survey area is less than 3 m in length, use two transects, as this length will not allow the required 10 cm spacing between particles.

To conduct a pebble count, observers place a measuring tape along the transect parallel to the channel axis. One observer walks along the measuring tape collecting pebbles at regular intervals, while the other records data. Particles are sampled by dropping a metal rod at pre-determined intervals along the measuring tape, and measuring the "b-axis" of the first particle the rod touches. Particles are measured with a gravelometer, and classified according to the largest hole that it *cannot* pass through (see Appendix III for pebble size classification). For cobbles and boulders that are too large to measure with the gravelometer, the b-axis is measured manually with a measuring stick. Table 5 includes a description of all variables collected during the Wolman pebble count (see Appendix I for datasheet).

Table 5. Description of variables to be recorded on pebble count datasheets for each site. These variables will be collected only once per sampling season.

Variable name	Description
Facility	Name of facility and mainstem stream (e.g. “Hunter East”).
Reach/TCS	Unique name of individual survey sites (e.g. “SakM-CR-TCS3”).
Date	Date on which data was collected.
Visit #	Which of the three survey visits (1-3).
Obs	Observers who collected data.
d fr Bfw 0m	Distance from bankfull width 0 m mark
Habitat	Type of habitat where transect is located (riffle, pool, glide, and cascade).
d fr TCS 0m	Distance interval of habitat type from survey start point.
PS (mm)	Particle size as indicated by the gravelometer.

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Appendix I- Datasheet templates

ASTR Tadpole TCS

Facility			**Date**		
Reach / TCS			**Visit #**		
Photo #s	upstream:		**Obs.**		
	downstrm:				
	Air T (C)		**Precip**	N L M H	
	Water T (C)		**Wind**	N L M H	
	RH (%)		**Cloud Cvr**	0% <50% >50% 100%	
	Conductivity		**Shade**	0% <50% >50% 100%	
Recorder		**Start time**		**Length Surv. (m)**	
		t to 1st dxn.		**# seen, not cap.**	

	Cohort	Length (mm)	Wt (g)	Sex	Shank (mm)	Notes
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						

ASTR Channel Morphology

Facility		**Date**	
Reach / TCS		**Visit #**	
		Obs.	

Habitat ool, Riffle, Glide, Cascac	**d fr TCS 0m**	**Length (m)**	**Embedd.**	[Nil <5%
				Low 5-25%
				Med 25-75%
				High >75]

%Pool		**%Glide**		**Total Length Surv. (m)**	
%Riffle		**%Cascade**			

Width 1		**Width 2**		**Width 3**	
d fr TCS 0m (m)		d fr TCS 0m (m)		d fr TCS 0m (m)	
Ww [b-e] (m)		Ww [b-e] (m)		Ww [b-e] (m)	
Bfw (m)		Bfw (m)		Bfw (m)	
Bfd (cm)		Bfd (cm)		Bfd (cm)	
loc of Bfd (m)		loc of Bfd (m)		loc of Bfd (m)	
wd @ Bfd (cm)		wd @ Bfd (cm)		wd @ Bfd (cm)	

	d fr Bfw 0m	Wd (cm)		d fr Bfw 0m	Wd (cm)		d fr Bfw 0m	Wd (cm)
1			1			1		
2			2			2		
3			3			3		
4			4			4		
5			5			5		
6			6			6		
7			7			7		
8			8			8		
9			9			9		
10			10			10		

ASTR Pebble Count

Facility		Date	
Reach / TCS		Visit #	
		Obs.	

d fr Bfw 0m		Transect1	d fr Bfw 0m		Transect2
Habitat			Habitat		
	d fr TCS 0m	PS (mm)		d fr TCS 0m	PS (mm)
1			1		
2			2		
3			3		
4			4		
5			5		
6			6		
7			7		
8			8		
9			9		
10			10		
11			11		
12			12		
13			13		
14			14		
15			15		
16			16		
17			17		
18			18		
19			19		
20			20		
21			21		
22			22		
23			23		
24			24		
25			25		
26			26		
27			27		
28			28		
29			29		
30			30		

Appendix II- Equipment

- ☐ Field forms and /or iPad in waterproof case (ideally also with a lanyard to attach to field vests) for data entry
- ☐ Mechanical pencils and extra lead
- ☐ Sharpie
- ☐ GPS to mark and find reaches and survey starting points
- ☐ Spare batteries for the GPS
- ☐ Flagging tape
- ☐ Spray paint
- ☐ Dipnets with rubber tubing around the edges
- ☐ Small plastic containers with lid for collection during TCS or collapsible containers
- ☐ Small ruler to measure tadpoles
- ☐ Small clear container to measure tadpoles in
- ☐ Magnifying glass to help distinguish aging features
- ☐ Stopwatch with alarm
- ☐ Thermometer for air and water temperature
- ☐ 50 m tape
- ☐ 2 m collapsible ruler
- ☐ Gravelometer
- ☐ Metal rod for randomizing pebbles collected
- ☐ 4% bleach solution for decontaminating all equipment before moving to a new site
- ☐ Digital camera
- ☐ Chest waders
- ☐ Wading boots
- ☐ Polarized sunglasses

Appendix III- Substrate size categories for Wolman pebble count

Substrate size categories for Wolman pebble count, reproduced from Todd (et al. 2012).

Size Class	Size Range (mm)
Sand	<2
Very Fine Gravel	2-4
Fine Gravel	4-6
Fine Gravel	6-8
Medium Gravel	8-11
Medium Gravel	11-16
Coarse Gravel	16-22
Coarse Gravel	22-32
Very Coarse Gravel	32-45
Very Coarse Gravel	45-64
Small Cobble	64-90
Medium Cobble	90-128
Large Cobble	128-180
Very Large Cobble	180-256
Small Boulder	256-512
Medium Boulder	512-1024
Large Boulder	1024-2048
Very Large Boulder	2048-4096

Appendix IV- Order of visits of penstock tributary crossing sites at each facility.

Facility	Tributary	Visit 1	Visit 2	Visit 3
Hunter Creek	X13 - DS	1	3	1
	X13 - X	2	1	2
	X13 - US	3	2	3
	X15 - DS	4*	4	6
	X15 - X	5*	5	5
	X15 - US	6*	6	4
Tamihi Creek	Trb05 - DS	4*	dry	5*
	Trb05 - X	5*	dry	4*
	Trb05 - US	6*	4	6*
	Trb06 - DS	1	1	1
	Trb06 - X	3	2*	2
	Trb06 - US	2	3*	3
Wahleach Creek	DivTrb - DS	1	3	6
	DivTrb - X	2	2	5
	DivTrb - US	3	1	4
	TrbA - DS	4	6	1
	TrbA - X	5	5	2
	TrbA - US	6	4	3

*Asterisks indicate that the second tributary was surveyed on a different day than those sampled in the first tributary visited.