Coquitlam-Buntzen Project Water Use Plan

Lower Coquitlam River Fish Habitat Requirements Study

Implementation Year 4

Reference: COQMON-03

Study Period: 2008-2016

James Bruce
Creekside Aquatic Sciences
Jason Macnair
Living Resources Environmental Services

April 18, 2017

Development and Assessment of Habitat Suitability Index Curves for Coquitlam River Salmonids following Water Use Plan Implementation (COQMON#3)

Technical Report CAQ – 019

April 2017

James Bruce, MSc
Creekside Aquatic Sciences / 2754 Highway 101, Roberts Creek, BC, V0N 2W3

Jason Macnair
Living Resources /

Technical Report
CAS - 019

Development and Assessment of Habitat Suitability Index Curves for Coquitlam River Salmonids following Water Use Plan Implementation (COQMON#3)

April 2017

Prepared for

BC Hydro
Water License Requirements
6911 Southpoint Dr.,
Burnaby BC

by

James Bruce, MSc
Creekside Aquatic Sciences
2754 Hwy 101
Roberts Creek, BC, V0N 2W3
james@creeksideaq.com

and

Jason Macnair
Living Resources

Suggested Citation:

Bruce, J.A. and J. Macnair. 2017. Development and Assessment of Habitat Suitability Index Curves for Coquitlam River Salmonids following Water Use Plan Implementation (COQMON#3). Report Prepared for BC Hydro Water License Requirements, Burnaby, BC by Creekside Aquatic Sciences. Report No. CAQ-019: 51 p + App.

Acknowledgements

The following people are gratefully acknowledged for their contribution and assistance during this study:

Jeff Greenbank, Greenbank Environmental Ltd., for providing context and clarity regarding the data collected in re-WUP studies (1999).

Brent Wilson, BC Hydro, for facilitating our field studies and providing historical data.

Alf Leake, BC Hydro, for providing information regarding the HSI curves used during the WUP and the modelling process.

Teri Neighbor, BC Hydro, for providing funding support to the project.

Preface

BC Hydro initiated a water use planning process for the Coquitlam-Buntzen facilities in September 1999. The process was formally concluded in April 2002, but additional consultations were held for another year as newly gathered information became available. Thus, the consultative process did not conclude until March 2003. Results of this process were summarised in a consultative report, which included recommendations for facilities operations and the collection of additional information to resolve key uncertainties identified by the Consultative Committee (CC) (BC Hydro 2003). These recommendations were later incorporated into the Coquitlam-Buntzen Water Use Plan (WUP) which was completed in April 2005 (BC Hydro 2005). The WUP specifies targeted flow releases for the Coquitlam River downstream of the Coquitlam Dam, as well as the need for eight monitoring studies to help resolve the uncertainties identified by the WUP CC. The present report is concerned with the habitat requirements of lower Coquitlam River fish (described in terms of habitat suitability indices) and how these may be used to help refine the instream flow release targets described in the WUP. BC Hydro developed a terms of reference (TOR) for this monitoring study in December 2006, which laid out the general approach and study design for this study work (BC Hydro 2006). This monitoring study is referred to as study COQMON#3 in the TOR.

Executive Summary

The Coquitlam-Buntzen Water Use Planning Consultative Committee (CC) relied on flow-habitat models to develop minimum flow targets from Coquitlam Dam that would meet the minimum flow needs of salmonid target species and life stages. The flow-habitat model used habitat suitability index (HSI) function to weight the value of stream cells (sections of river along a transect line perpendicular to the stream bank) in terms of relative depth and velocity preference. Although empirical data were collected at the time to develop stream-specific HSI functions for this purpose, they were considered insufficient and generic HSI functions were used instead. The purpose of the study is to determine if further development of stream-specific HSI functions though the collection of additional data would alter the flow targets set by using the generic functions. This purpose is captured in the management question associated with this study and a set of null impact assessments that are to be evaluated. Two impact hypotheses were proposed by the CC, and another four were proposed as part of this study.

Habitat use and availability data collected at the time of the WUP were collated with data collected after WUP implementation in 2007 to create a database to test the impact hypotheses. In addition, data were collected in 2016 to address the specific impact hypotheses regarding the effects of day vs. night sampling in rearing juvenile salmonids and whether hyporheic flows at redds site confound spawning habitat selection among chum salmon.

Stream-specific HSI functions were compared between -pre-and post WUP surveys, as well as with the generic functions used during the WUP. Significant differences were found which could impact the optimum flows that maximize habitat for the species and life stage of interest. These are summarised in Table A.

Table A. Summary of likely optimum flow changes resulting from use of stream-specific HSI function in PUW calculations instead of the generic function used in during the WUP process.

Species of interest	WUP Optimum Discharge (m^3/s)	Change in m^3/s with Stream-Specific HIS				
		Likely Lower	Possibly Lower	No Change	Possibly Higher	Likely higher
Spawning						
Chinook Salmon	18.3			Insufficient Data		
Steelhead Trout	11.7	✓				
Coho Salmon	11.7			✓		
Chum Salmon	10.9			✓		
Rearing						
Steelhead Fry	1.6				✓	
Steelhead Parr	4.4			✓		
Coho Fry	1.6				✓	

Table B. Summary of impact hypothesis results

Impact Hypothesis	Description	Outcome
$H_0 1$	*Habitat requirements observed post-WUP implementation (Test Flow Regime 2) do not differ significantly from those used in WUP habitat modeling.*	Rejected
$H_0 2$	*Habitat targets are not achieved by flows different than those defined in the Coquitlam-Buntzen Water Use Plan.*	Accepted
$H_0 3$	*Expression of habitat preferences in indicator juvenile salmonid species are not affected by differences in stream flows.*	Unresolved
$H_0 4$	*Expression of habitat preferences in indicator salmonid species and life stages are not significantly different between study years.*	Rejected
$H_0 5$	*Expression of habitat preferences in indicator juvenile salmonid species are not significantly different between day and night.*	Rejected
$H_0 6$	*Expression of habitat preferences in Chum spawners are not confounded by the upwelling of "deep" ground water.*	Rejected

These analytical results allowed for the test of impact hypotheses, the outcomes of which are summarised in Table B.

Although significant differences were found between generic and stream-specific HIS functions, which in some cases lead to changes in predicted optimum flows, these did not necessarily result in a change in minimum flow targets. In fact, no change is recommended at all (Table C). The only exception would be for Steelhead spawners, which had a high degree of uncertainty associated with it due to low sample sizes and inability to correct habitat use data for habitat availability constraints. In this latter case, the possibly exists that lower optimal discharges may be required to maximize spawning habitat.

Table C. Summary of likely consequence of substituting stream-specific HSI functions into the PUW calculations that lead to the flow targets set by the CC using generic HSI functions.

Month	WUP (m^3/s)		Species Driver[1]	WUP Optimum (m^3/s)	Species Specific Optimum
	Target	Minimum			
January 1 - 14	5.9	3.6	CM/CO Spawning	11.7/10.9	little to no change
January 15- 31	2.9	2.9	Incubation	N/A	-
February	2.9	1.8	Incubation	N/A	-
March	4.3	1.1	SH Spawning	11.7	likely lower optimum
April	3.5	1.1	SH Spawning	11.7	likely lower optimum
May	2.9	1.1	SH Spawning	11.7	likely lower optimum
June	1.1	1.1	SH Parr Rearing	4.4	little to no change
July	1.2	1.1	SH Parr Rearing	4.4	little to no change
August	2.7	1.1	SH Parr Rearing	4.4	little to no change
September	2.2	1.1	SH Parr Rearing	4.4	little to no change
October	6.1	3.6	CH/CO Spawning	11.7/10.9	little to no change
November	4.0	1.5	CH/CO Spawning	11.7/10.9	little to no change
December	5.0	2.5	CH/CO Spawning	11.7/10.9	little to no change

[1] As per the study terms of reference, Chum (CM) and Coho (CO) serve as surrogates for Chinook spawning

Table of Contents

List of Tables

List of Figures

1 Introduction

1.1 Background

During the Coquitlam-Buntzen WUP process, an empirically-derived habitat-flow model was developed to predict the effects of different flow releases on the fisheries habitat of Coquitlam River (BC Hydro 2003b). Model development was loosely based on the Instream Flow Incremental Methodology (IFIM) developed by the US geological Survey (USGS) which uses a physical habitat simulation model (PHABSIM) to predict changes in the quality and quantity of fish habitat as a function of instream flow (Bovee 1982). This generally yields a negatively skewed, dome-like habitat-flow relationship that describes how total area (m^2) of equivalent quality habitat changes with stream discharge. The discharge that provides the highest area of equivalent quality habitat is considered the optimum discharge. Key to the model's habitat calculation is the use of a weighting system to assign a "utility" or "preference" value to each cell[1] in a stream section, which are in turn summed to obtain a Weighted-Usable-Area (WUA) metric. There are different weighting schemes for each physical characteristic of interest, which include average cell depth, velocity and some metric describing substrate composition. These weighting schemes are commonly referred to as habitat suitability index (HSI) functions or criteria and are generally multiplied to form composite HSI values.

Use of the IFIM approach to habitat-flow modelling typically involves the development of stream-specific HSI functions where the habitat preferences of resident fish are empirically characterized from instream observations. This however, was not done for the Coquitlam River. Rather, generalized HSI functions from other BC rivers were used (MWLAP 2001). Some study work was done in 1999 to develop such stream specific HSI functions, but the results were not incorporated into the habitat-flow model for the following two reasons:

a) the sample size for many of the fish species observed was not considered large enough to develop strong habitat suitability relationships; and

b) in some situations, the available habitat was believed to be too limiting for salmonid juveniles, resulting in relationships that were biased towards available, less optimal habitat types. Stream flows during these surveys may have been too low to create the diverse hydraulic conditions needed to support habitat preference research.

Nevertheless, the WUP consultative committee (CC) did consider the habitat-flow modeling results when developing their recommendations related to Coquitlam-Buntzen WUP operations, which included a flow study that compared two test-flow regimes (i.e., COQMON#7, BC Hydro 2006). The first consisted of the existing flow regime at the time of the WUP process and the other a flow regime devised by the CC based in part on the habitat-flow model results. The latter is highly prescriptive with targeted flow releases from Coquitlam Dam specified for each month. Each test flow regime was to last several years so that empirical measures of fish productivity could be compared. Confidence in the habitat flow model however, remained low and was identified as one of the key uncertainties to be resolved by additional study following WUP implementation. Specifically, the CC recommended that a monitoring study be carried out to develop a series stream-specific HSI functions based on empirically

[1] A cell is a section of river usually located on a transect line. Its width is defined by the distance between two measurement stations across a transect line, while its length is defined by the distance between an upstream and downstream transect line divided by two.

derived habitat-use/availability data for several fish species of interest. In addition, the data were to include the habitat-use/availability data collected during the WUP process (pre-WUP) as well as collect new data following implementation of WUP operations in 2007 (WUP). These empirically derived curves were then to be compared to the generalised curves used during the WUP process and the differences assessed in terms of how they may redefine the instream flow needs for Lower Coquitlam River fishes.

1.2 Objectives and Scope

The overarching goal of this study, as defined by the CC, is to develop stream-specific HSI functions for the juvenile and spawning life stages of indicator salmonid species using empirical pre-WUP and WUP implementation observations of habitat-use. These are to be compared to the province-wide generic HSI functions used during the WUP process and if significant differences are found, revise the habitat-flow models developed for the Coquitlam River watershed to incorporate the stream-specific HSI functions. Results of the revised habitat flow model will then be used to re-assess the instream low needs of each life stage of the indicator salmonid species. These outcomes will in turn be used to inform the results of the fish productivity monitoring program (COQMON#7). The flow habitat model used during the WUP however is no longer available, so the effects of empirical stream-specific HSI functions are evaluated subjectively.

1.2.1 Management Question

To help guide the implementation and subsequent interpretation of the monitoring study, the CC provided the following management question to be addressed:

Do habitat requirements (defined in terms of habitat suitability index curves) for the fish species of interest observed during the monitoring program differ from those integrated into the habitat modeling conducted during the WUP?

1.2.2 Impact Hypotheses

The CC formulated the following two null impact hypotheses to be addressed in this monitoring study:

$H_0$1: Habitat requirements observed following WUP implementation (Test Flow Regime 2) do not differ significantly from those used during the WUP process (i.e., general HSI Curves).

$H_0$2: Habitat targets are not achieved by flows different than those defined in the Coquitlam-Buntzen Water Use Plan.

This study also explores the following null hypotheses that were derived through the implementation of other monitoring studies, as well as questions that arose from carrying out the present study:

$H_0$4: Expression of habitat preferences in indicator juvenile salmonid species are not affected by differences in stream flows.

$H_0$5: Expression of habitat preferences in indicator salmonid species and life stages are not significantly different between study years.

$H_0$6: Expression of habitat preferences in indicator juvenile salmonid species are not significantly different between day and night.

$H_0$7: Expression of habitat preferences in Chum spawners are not confounded by the upwelling of "deep" ground water.

1.2.3 Study Area

All study work was limited to Reaches 2a, 3b, 3 and 4 of the lower Coquitlam River downstream of Coquitlam Dam. Where possible, sampling effort was distributed evenly across all reaches when collecting salmonid spawning habitat information. For juvenile fish, focus was more on Reaches 2a, 2b and 3 where instream flow releases from Coquitlam Dam were augmented by Orr Creek and other inflow sources. Care was taken to ensure that a broad range of habitat types were sampled, particularly for the juvenile fish. Precise sampling locations are provided in the sections that follow.

1.2.4 Species and Life Stages of Interest

The salmonid species/life stage combinations of interest were identified as follows (BC Hydro 2006):

Target Species	Life Stage
Chinook Salmon	Spawning
Chum Salmon	Spawning
Coho Salmon	Spawning and Rearing (0+ and 1+)
Steelhead Trout	Spawning and Rearing (0+ and 1+)

Although age 1+ coho salmon were identified as a separate cohort for sampling, too few (n = 13) were encountered during the survey work to warrant the development of separate HSI functions. Rather, these fish were pooled with the age 0+ Coho.

1.2.5 Flow-Habitat Models

Flow-habitat relationships developed during the Coquitlam River WUP process was loosely based on the IFIM methodology used by the USGS (Bovee 1982). Rather than calculate WUA where the weighted cells of water across multiple transects are summed in a given stream reach, a weighted useable width was calculated for each transect of interest, which was then rescaled as a percent of total wetted width to yield a percent usable width (PUW) metric. The PUW metric was calculated separately for each transect and test discharge, and were treated as 'independent' samples for modelling purposes.

When calculating PUW, only water depth and average velocity was considered as weighting factors. Substrate composition was not used. Rather, substrate composition, along with habitat type and Channel Width: Depth (W/D) ratio, was used to identify each transect as representing one of three possible mesohabitat types (Table 2). Thus, when developing a flow habitat relationship for rearing fish, only those transects identified as representing rearing mesohabitats were considered for analysis; particularly those found in Reaches 2 and 3. This was similarly done for spawners. It would appear however, that transects through rapid mesohabitats were excluded from model development. Also notable was the absence of pool habitat. A detailed description of the transect locations and classification, along with the methodology for PUW calculation is provided by BC Hydro (2003b).

Table 1. Scheme used during the WUP process to classify transect locations as representing one of three mesohabitat types.

Mesohabitat	Defining characteristics	No. Transects
Rearing	"shallow" riffles with small (<30cm) D90; W/D ratio > 75	18
Rapids	"deep" riffles with large (>50cm) D90; W/D ratio 30-75	12
Spawning	"deep" runs and glides with moderate (30-50cm) D90; W/D ratio ≈ 30	9

Habitat flow models were developed from the PUW data by first rescaling each PUW observation as a proportion of the maximum value for the species and life stage of interest. A maxima function of the form

$$y = Ax^c \cdot e^{nx^b}$$

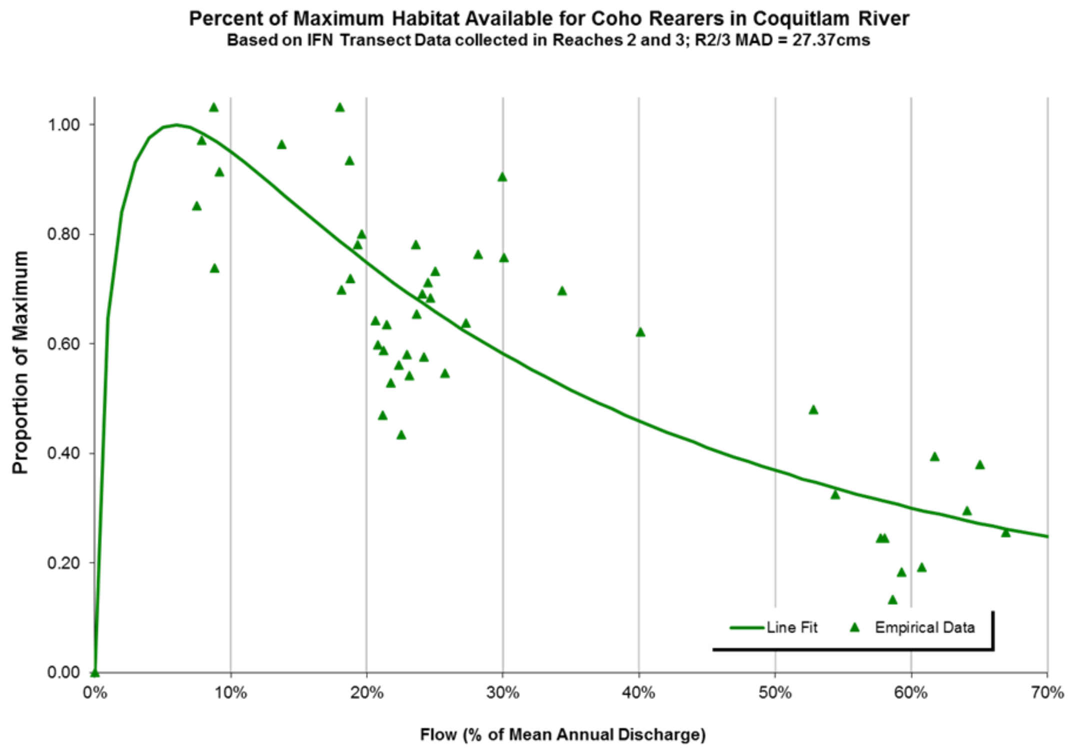
where:

- y = amount of habitat units;
- x = amount of flow units;
- A = parameter for habitat magnitude;
- n = parameter for the rate of incline/decline of the relationship;
- c = parameter for the lag response of habitat to flow; and
- b = parameter for the magnitude of the post-peak habitat response to flow

was then fit to the rescaled PUW data using least-squares non-linear regression techniques (i.e., Solver in Excel) where it was assumed that no habitat would exist in the absence of discharge (i.e., 0 habitat at 0 flow). The resulting equation was considered to be representative of the underlying flow-habitat relationship for the Coquitlam River and was used to model the consequence of varying discharges from both the dam and local tributary inflows. Optimum flow for maximum weighted habitat width was also obtained from this regression equation. A sample flow-habitat relationship is provided in Figure 1.

Critical to the development of PUW are the habitat suitability weighting functions that assign a value between 0 (Avoided/Unusable) to 1 (Preferred/Usable) to each station along a given transect line. As noted earlier, the HSI functions used during the WUP process were not site specific. Rather, they were generalized functions provided by the BC Ministry of Water, Land, Air and Parks (2001, Pers. Comm.) that were considered applicable to most coastal streams in British Columbia (BC Hydro 2003). It is important to note again that the PUW values were calculated solely using HSI functions for water column depth and average velocity. It was assumed that being selective in which transects are used for model building would take into account the preferences for particular substrate types.

Figure 1. Flow-habitat model derived from empirical PUW data illustrating the functional form of the maxima function used to represent the data (from BC Hydro 2003). Individual triangles are PUW values (scaled as a proportion of the maximum observed PUW value) for a given transect and discharge, which are treated as independent samples for model building.



The original intent of this study was to use the PUW model to compare optimal flow predictions based on the general HSI curves used during the WUP process with those using empirically derived HSI functions. This model however, was not available at the time of this report and its reconstruction (including transect selection for each species and life stage of interest) was considered outside the scope of this study. Comparisons of HSI functions therefore were largely descriptive in nature and the potential impact of empirical HSI curves on modelled optimum flow predictions was inferred from how the paired sets of depth and velocity preference curves differed from one another. Also important was the spread (standard error) of regression residuals in available PUW-based flow habitat models (as illustrated in Figure 1); the larger the spread/standard error of regression residuals, the less likely a difference in predicted optimum flow would be detected.

1.2.6 WUP Operations

Habitat suitability data were collected during two different flow treatment periods. The first was in 1999 prior to WUP implementation where the 'existing' flow regime (flow treatment 1) was maintained until December 31, 2007. For this treatment, two fish valves were kept fully open year-round, with discharge varying as a function of reservoir elevation. Typical monthly average discharges are provided in Table 1. Starting January 1 2007, the second flow treatment was started. In this case, flow releases from Coquitlam Dam followed as set prescribed flow values. These are also summarised in Table 1. The flow prescriptions are made of two parts; a target discharge that is to be met if conditions allow, and a minimum flow limit, below which releases cannot drop unless there is insufficient water in the reservoir to meet this requirement. All other occasions when habitat suitability data were collected occurred during this latter flow treatment period (i.e., the WUP implementation period). Daily average discharge at the time of data collection is provided in the sections that follow.

Table 2. Monthly discharges from Coquitlam Dam for the two flow treatments during which habitat suitability data were collected. Flow treatment 1 consists of having two fully open valves where variations in discharge reflect seasonal changes in reservoir elevation. Flow treatment 2 consists of two parts, a target flow to be released if reservoir conditions allow, and a minimum flow below which discharge cannot drop except in drought conditions.

Month	Coquitlam Dam Flow Releases (m^3/s)		
	Pre-WUP	WUP (2007 onwards)	
	2 Valves Open	Target	Minimum
January 1 - 14	1.0	5.9	3.6
January 15- 31	1.0	2.9	2.9
February	1.0	2.9	1.8
March	0.8	4.3	1.1
April	0.8	3.5	1.1
May	1.1	2.9	1.1
June	1.4	1.1	1.1
July	1.4	1.2	1.1
August	1.1	2.7	1.1
September	0.8	2.2	1.1
October	0.8	6.1	3.6
November	1.1	4.0	1.5
December	1.1	5.0	2.5

1.2.7 Key Water Use Decision Affected

The monthly, targeted flow releases specified in the WUP were set to maximize fish productivity downstream of Coquitlam Dam by providing optimal habitats (i.e., maximum WUA or equivalent high quality habitat area) based on the flow-habitat modeling results developed during the WUP process (BC Hydro 2003a). Should the stream-specific HSI functions derived from the present study deviate significantly form those used to develop the habitat-flow model for the WUP process, the habitat-flow model will have to be revised accordingly, potentially changing the flow targets initially believed to maximize fish productivity. It is important to note that the results of the habitat-flow model will also be used to inform the outcome of the fish productivity monitoring program (COQMON#7), which is designed to measure the fish productivity differences between pre-WUP and WUP flow regimes.

2 Methods

2.1 General Approach

HSI function were derived using the standardized approach developed by Bovee (1982) and later refined by Bovee (1986) and Payne and Allen (2009). It relies on the habitat use to habitat availability (U/A ratio) to develop an electivity index that reflects the apparent preference behaviours of animals under study – in this case fish in the Coquitlam River. This is similar to the approach used by BC Hydro (2003b) when attempting to develop site specific HIS function for the WUP process. A key difference in this study however is that frequency histograms were used rather than attempt to develop a continuous function using kernel density estimation techniques. This allowed for the use of Kolmogorov-Smirnov tests to compare shapes of habitat use histograms, as well as electivity histograms (also referred to as electivity distribution functions or *edfs*)

Habitat use and availability data were collected in a single year (1999) prior to WUP implementation in 2007, and in multiple years during the WUP monitoring period. The number of sites sampled varied from year to year, as did their location. Site selection in each year was based in part on prevailing sampling conditions (e.g., weather and discharge), ease of access, likelihood of finding fish to sample and degree of overlap with the sampling sites of other studies (to maximise sampling efficiency by combining field efforts of multiple studies). The distribution of sampling effort over the course of the study period is summarized in Table 3.

Table 3. Distribution of sampling effort (No. of sampling sites per year) over the course of the 2009 to 2016 sampling period. (-) indicates that no sampling was done in that year. Habitat-use. (SC) indicates the number of sites where side channels were included in the sampling effort. These were generally treated as separate sites.

Species / Life Stage	No. Habitat-Use Sampling Sites/Study Year					
	1999	**2008**	**2009**	**2010**	**2011**	**2016**
Steelhead Trout						
Spawning	-	-	8	8	5	-
Rearing	10	-	6 (+ 1 SC)	5 (+ 2 SC)	6 (+ 3 SC)	2
Coho Salmon						
Spawning	-	4	5	3	5	-
Rearing	10	-	6 (+ 1 SC)	5 (+ 2 SC)	6 (+ 3 SC)	2
Chum Salmon						
Spawning	-	5	6	-	3	10
Chinook Salmon						
Spawning	-	-	-	2	1	1

2.2 Habitat Use

2.2.1 Salmonid Spawners

Habitat-use information for salmonid spawners was only collected at newly formed redds, the assumption being that spawning fish choose redd locations in response to prevailing, suitable hydraulic and substrate conditions. These redd sites were easily identified by a change in substrate color compared to surrounding areas. The presence of a shallow pit and the build up of a tail-spill mound immediately downstream were also a telling sign. In most cases, these redds were either still under construction or actively defended. This made species identification relatively easy for the survey crew. For those redds that were not obviously still 'active', the close proximity of other spawners and survey timing were used as factors to identify species. Redds that could not be positively identified were ignored. To maximize survey success, redd surveys were timed to the following peak spawning periods:

Species	Peak Spawning Period
Chinook Salmon	October 21 – November 7
Chum Salmon	October 21 – November 7
Coho Salmon	November 7 – December 7
Steelhead Trout	April 7 - May 31

For all species, the following information was collected at each redd location:

1. Substrate depth (m) at the head of the redd and on each margin, as well as the redd pit and top of the tail-spill (measured to the nearest 0.01 m),
2. Average velocity (m/s) at the head of the redd and on each margin (taken by a Swoffer 1200 current velocity meter at a depth of 0.6 x water column depth)
3. Distance from bank (m) and closest bank (left or right)
4. Supplemental habitat information such as; water column temperature, riparian cover, channel width, mainstem or side channel spawning.

In the case of Chum spawners, redd density could at times be very high. In such instances, the sample site was divided into smaller 30 to 50 m subsections, of which only one was randomly selected for redd sampling. All redds (or clusters of redds) within a subsection were in turn sampled.

It should be noted that for the present study, only substrate depth and average water velocity was considered for analysis, values recorded at the head and margins of each redd were averaged to yield a single redd-specific value. These were the only habitat variables used to calculate PUW values and in turn used in the development of the Coquitlam River flow-habitat model. The effect of substrate composition was taken into account by limiting the modelling effort to those transects that represent spawning mesohabitats (Table 1). The number of sites that were sampled in each year of study are summarised in Table 3.

2.2.2 Juvenile salmonids

Habitat-use information for juvenile salmonids were collected by snorkel observation in 30 to 50m sections of river centered on transect locations classified as representing rearing mesohabitat conditions (Table 2). At each sample location, a two-person crew would first snorkel the site, working in tandem in an upstream direction. Both crew members were equipped with brightly colored lead weights that were place at the location of each fish observation. Orange flagging tape was attached to these weights so they could easily be found after the snorkeling session. The weights were also uniquely numbered so that a species and age class designation could be assigned to each weight on an underwater writing pad. The crew were each equipped with 25 weights with the aim of collecting a total of 50 fish observations per site. When fish were grouped into small schools, only a single colored weight would be placed at the site and the total number of fish noted along with the species and age class information.

Once the crew had finished snorkelling the site, they would return to the starting point and locate each of colored weights. At the head of each weight, water depth (m) and average column velocity (m/s) data were collected using a Swoffer 1200 current velocity meter. Information on substrate composition cover availability and the distance from the left or right bank were also collected, but these were not used in the present analysis. The substrate and cover metrics were taken into account by limiting all modelling effort to those transects that appeared to represent rearing mesohabitats (Table 2). Once the habitat data were collected, the lead weights would be retrieved and the crew would move on to the next weight until all weights had been located. The number of sites that were sampled in each year of study are summarised in Table 3.

2.3 Habitat Availability

2.3.1 Salmonid Spawners

Habitat availability information associated with spawning activity were generally collected at a spawning transect site nearest to an identified redd or group of redds. Typically, five sampling transects would be selected at the site, which did not necessarily include the establish transect line. At each of the transects, the channel width would be divided in to five parts (right bank, right of center, center, left of center and left bank) and a random location with each part would be sampled for water column depth (m) and average velocity (m/s). Information on substrate composition was also collected, though not used in this analysis. All water velocity data were collected using a Swoffer 1200 velocity meter. Thus, for each transect site a total of 25 habitat availability observations would be collected. Data collection at some sites extended into side channel habitats, which were treated as a separate site from the mainstem channel. A minimum of 100 habitat availability observations were typically sought in each sampling year.

In the case of Chum Salmon, sampled redds were generally clustered near these transect sites, so all could be considered to be within the habitat availability sampling area and thus suitable for electivity analysis. This was not the case for Steelhead trout spawners, whose redds tended to be scattered throughout the river basin. Of the 155 steelhead redd observations collected overall all three sample years (Table 3), only 64 (41%) were considered to be sufficiently close to established spawning transect sites to be considered part of the habitat availability sampling area. Because so many redd observations were outside these habitat availability sampling areas, electivity analysis was considered inappropriate as the habitat availability data were unlikely to fully represent spawning habitat availability in the river. Thus, for steelhead, habitat suitability was derived solely from the habitat-use data (i.e., uncorrected for habitat availability constraints).

The redd distribution of Coho spawners was also wide spread, but not to the same extent as steelhead. In this case, the majority redd observations (81 of a total of 116 redd observations or 70%) were in areas relatively close to established spawning transect sites. To determine if inclusion of redd data outside the availability sampling areas would have a significant effect on preference function outcomes, electivity analysis was carried out both with and without these redds observations and then compared using the Kolmogorov-Smirnov test of distribution independence. If no significant difference in preference was found, the data were pooled to develop HSI functions.

Only 41 redds were identified as belonging to Chinook Salmon. Like the Chum Salmon, all were found in close proximity to established spawning transect sites and were as a result considered suitable for electivity analysis. The sample size of habitat availability data however was relatively small; with only 75 observations across all three years of sampling (Table 3). This data was considered to be insufficient to characterize the availability of the spawning habitats available to Chinook salmon at the time of spawning. Depth and velocity characteristics associated with these redds are described, but no attempt was made to convert these 41 Chinook observations into a potential HSI function.

2.3.2 Juvenile salmonids

Habitat availability associated with juvenile rearing was characterised in the same way as the spawning habitat. Habitat availability data were collected at established rearing transect sites across five temporary transect locations roughly 10 m apart. The transects were divided into 5 segments where water column depth (m) and average velocity (m/s) was measured at a random site within each segment. This resulted in 25 paired measurements per rearing transect site.

Unlike the spawning data where a number of habitat-use observations fell outside the availability sampling areas, all juvenile salmonid observations were within these sampling areas. As a result, all were suitable for electivity analysis.

2.4 HSI Functions

Derivation of HSI functions from the habitat-use (U) and availability (A) data was a multistep process beginning with the construction of frequency histograms for each U and A data set. Key to successful HIS function development is the selection of histogram bin widths that ensure a reasonably smooth histogram shape (Bovee 1986, Payne and Allen 2009, Lele et al. 2013). There are a number of methods available to select optimal bin widths that ensure a smooth histogram function. Most are based on sample size and some also include a measure of dispersion (standard deviation or interquartile range) or assume an underlying Gaussian distribution (Wand 1997). The simplest of these was the square or cubic root of the sample size. In the present study however, the sample size of the U and A data varied considerably between each other, as well as between species, age classes, and year of sampling. To carry out electivity analysis, histogram bin widths needed to be the same for all data sets. Thus, the standard approaches for bin width selection as described by Wand (1997) could not be used. Rather, trial and error of various band widths was carried out to find a common value that would yield reasonably smooth histograms for all data sets. This resulted in a common band width of 0.15 m, which was used for all electivity analyses as well as subsequent HSI function derivations.

All U and A histograms were converted to frequency distributions by dividing bin count by the total number of samples so that the sum of bin frequencies would then equal to 1. These frequency data were then used to calculate electivity index values for each bin category by dividing the individual U and A bin frequencies (i.e., the U/A ratio). The resulting electivity indices were then rescaled so that they summed to 1. The converted the individual electivity data into an electivity distribution function (*edf*) that allowed for statistical comparisons using the Kolmogorov-Smirnov test for independent distributions (see below). The electivity indices were rescaled again to form a HSI functions that ranged from 0 to 1 by dividing the individual bin electivity values by the maximum value.

The electivity calculations were done separately for each habitat variable, species, age class and year of study. When pooling study years, unweighted average bin probability values were calculated, and then scaled as above to derive pooled HSI functions.

It should be noted that electivity indices are prone to "over-correction", where individual electivity values, particularly at the distribution tails, become highly distorted (Bovee 1986, Payne and Allen 2009). One way to avoid such distortions is to only carry out electivity calculations if the habitat-use and availability distribution functions are dissimilar from one another, which can be tested using the Kolmogorov-Smirnov test for two distributions. In instances where the test for independence was rejected, only the un-corrected habitat-use *edfs* were used to derive site-specific HSI functions; as recommended by both Bovee (1986) and Payne and Allen (2009). Over correction could also occur when there are outlier values in either of the pdf's. Unfortunately, there is no way to statistically remove the effect of these outliers except to delete the associated observations from the data set. Selection of a 0.15m bin width for all histograms however, appeared to minimise the effect of outlier values in most cases. Thus, there was no need to delete any of the observations.

2.5 Specific Hypothesis Testing

2.5.1 Between Site Differences Rearing HSI functions

Test of the hypothesis that depth and velocity *edfs* (and hence HSI-functions) did not differ between sample sites was done using the pre-WUP data set only. They generally had 100 habitat availability observations per site (rather than 25 in WUP years) and in at least four sites, had a minimum 30 fish observations per site. This ensured reasonably smooth *edfs* for each of the juvenile rearing salmonid species of interest and allowed for a robust test of between site differences.

Test of the null hypothesis involved multiple between-site comparisons using the Kolmogorov-Smirnov test for two independent distributions (See Section 2.6.1 for details). Because the multiple comparisons involved four sites (i.e., 6 comparisons in total), the α level for each test was adjusted to 0.0083 using the Bonferroni correction, which was in turn used to adjust the critical D statistic for hypothesis testing. If any one of the 6 comparisons resulted in a Kolmogorov-Smirnov D statistic that exceeded D_{Crit}, the null hypothesis of no difference between sites was rejected. This test was carried out separately for each species, as well as for each depth and velocity variable.

2.5.2 Day/Night Differences in Rearing HSI functions

Day/night differences in rearing juvenile salmonid *edfs* (and hence HSI-functions) was explored in August 2016 at two different sites in Reach 2b of the Coquitlam River. These were located 5.70 and 6.15 km downstream of the dam (Appendix A). At both sites, habitat availability data were collected by measuring water depth (m) and average velocity (m/s) at 1m intervals in a zigzag pattern (from bank to bank) along the length of the site for a total of 100 observations per site. Habitat-use at each site was collected using the same procedures outlined in Section 2.2.2. *Edfs* were calculated as described in Section 2.4.

Day/night comparisons were done using the Kolmogorov-Smirnov test for independent distributions (See Section 2.6.1 for details) on the pooled data of both study sites. An evaluation of site vs day/night interactions was not considered to be meaningful due to low sample sizes (see Section 2.6.1). Because these tests only involved a single comparison of pooled data, a Bonferonni correction was considered unnecessary and α was set at 0.05.

2.5.3 Groundwater upwelling effects on Chum Spawning HSI functions

General Study Design

To determine whether ground water upwelling influenced spawning site selection among Chum Salmon spawners, a simple two-part study was carried out. The first part was designed to determine if there were any upwelling areas at any of the known spawning locations. The second part examined if strong upwelling currents could be detected at known chum salmon redd sites and in turn quantify the extent with which such upwelling currents occur. In both cases, the potential for upwelling currents was determined by measuring the difference between surface and hyporheic water temperatures (°C). It was assumed that ground water temperature would be relatively stable compared to surface waters, and thus would be cooler in the summer and warmer during winter.

Hyporheic Water Temperature Measurements

Hyporheic water temperatures were measured using a temperature probe attached to the inside tip of a stainless-steel rod that could be hammered into the substrate to a depth of 25 to 30 cm (Figure 2). Once in the substrate, the hyporheic probe was left in place for a minimum of 10 min before taking a reading. This allowed time for the water temperature reading to stabilize to ambient conditions. Water temperature was also taken near the surface adjacent to the hyporheic probe so that the measurements could be paired. All measurements were made using a VWR Ultra Water Resistant meter (model 016-050-03).

Upwelling at Known Spawning Sites

Paired water surface/hyporheic water temperature measurements were collected across transect lines situated at seven different sites (Appendix A). Site locations were randomly selected and all are well known, highly used chum spawning habitats (J. Macnair, Living Resources, Pers. Observation). All measurements were taken September 25, 2016; prior to the in-migration of chum spawners. A

Figure 2. Hyporheic temperature probe used to measure water temperature 25 to 30 cm into substrate.

minimum of 10 paired temperature measurements were taken per transect. Temperature differences between surface and hyporheic waters at each site were compared using simple box whisker plots.

Upwelling at Chum Salmon Redd Sites

Paired water surface/hyporheic temperature measurements were collected at a total of 222 redd sites spread out across 11 sites (Appendix A). Ideally, the redd sampling sites would have overlapped transect locations, but was not possible due to access constraints, prevailing flow conditions, proximity to other study work in the area and ability to positively identify Chum Salmon redds. As with the transect data, only the difference between surface and hyporheic temperatures was examined. The were plotted in a frequency histogram to help identify these groups of redds that appeared to be in strong upwelling areas, weak upwelling areas, and areas where there were no apparent differences.

2.6 Statistical Comparisons

2.6.1 Electivity Functions

All statistical comparisons of histogram data were done using the Kolmogorov-Smirnov test of two distributions (Zar 1979). The histogram bin counts for each distribution were divided by the total count of observations to create a probability distribution function. These were then summed across bin counts to create a cumulative distribution. Differences in cumulative bin probabilities between two histograms were then calculated and the maximum difference selected. This difference was considered to be the Kolmogorov-Smirnov test 'D' statistic. Unfortunately, sample sizes were generally too low to reliably calculate probability values associated with the statistic (Gail and Green 1976). Rather, null hypothesis testing relied on critical D values calculated for a specific α level (D_{Crit}) using the following equation:

$$D_{Crit,n_1,n_2} = C(\alpha)\sqrt{\frac{n_1+n_2}{n_1 n_2}}$$

where

$$C(\alpha) = \sqrt{-\frac{1}{2}ln\left(\frac{\alpha}{2}\right)}$$

and n_1 and n_2 are the number of observations used to construct each histogram. In cases where D values were less than D_{Crit,n_1,n_2}, the null hypothesis (i.e., the hypothesis of no difference) was rejected. Otherwise, the hypothesis was accepted. When the Kolmogorov-Smirnov test was used for a single comparison, α was set at 0.05. However, when multiple comparisons were made, α was corrected using the Bonferroni correction procedure (Hochberg and Tamhane 1987). To maintain a family wide α = 0.05, the α level for individual comparisons was set as α/m where m is the number of comparisons. For this study, D_{Crit} values greater than 0.5 were considered to be too low in terms of statistical power for meaningful results interpretation. When encountered, such tests were abandoned. These are not reported or discussed in the document except to note that sample sizes were too low for meaningful analysis.

2.6.2 HSI Functions

Because many of the HSI functions obtained from the literature or used during the WUP process are open ended (i.e., could not be converted to a distribution function), statistical comparisons using the Kolmogorov Smirnov test was not possible. As a result, all HSI function comparisons were entirely descriptive in nature. Furthermore, the effects of substituting generic HSI functions for stream-specific functions were evaluated subjectively based on how differences in curve shape would increase or decrease optimum flow predictions, and how the difference in area under the curve (AUC) of the HSI function would increase or decrease PUW at the optimum flow. This analysis assumes that the depth and velocity HSI functions are independent of each other when combined. This is often the case when calculating WUA using IFIM (Bovee 1982), but in reality, this assumption may not be valid (Korman et al. 1994), introducing uncertainty in the assessment outcome. As a result, the assessment is reported in terms of the following scale of outcomes; a likely decrease, possible decrease, no change, possible increase, and a likely increase.

3 Results

3.1 Habitat Availability

3.1.1 Salmonid Spawners

Habitat availability data for salmonid spawners were only collected 2008 onwards (Table 3) and as a result, no pre- WUP/WUP comparisons could be made.

Steelhead Trout

There were a total of 550 paired water depth and average velocity observations collected from 2009 to 2011, across a total of 21 transects. Of these, three had been sampled twice, and one transect was sampled in all three years. Kolmogorov-Smirnov tests showed that there were some between-year differences in frequency histograms for both the depth or velocity variables (Table 4), possibly reflecting the considerable variability in the discharge conditions at the time of measurement (Table 5). Because different transects were sampled each year, it was not possible differentiate the effects of different discharges from between-site differences in channel geomorphology. As a result, no conclusions could be derived from the pattern Kolmogorov-Smirnov test outcomes except that when pooled, the depth and velocity data reflected a broad range river conditions. Water depths ranged from 0.03 to 1.30 m when pooled across all sites and sample years and had a median of 0.44 m. Average velocity ranged from 0.00 to 1.44 m/s and had a median of 0.58 m/s. Pooled frequency histograms of available depth and velocity conditions at the time of redd sampling are provided in Figures 3a and 3b.

Table 4. Summary of Kolmogorov-Smirnov statistics (D) used to compare yearly Steelhead Trout spawning habitat availability frequency histograms. The test's α level was set at 0.0167 to maintain a family wise error rate of 0.05 and in turn calculate D_{Crit}.

				Depth (m)		Velocity (m/s)	
Comparison		**n_1/n_2**	**D_{Crit}**	**D**	**Outcome**	**D**	**Outcome**
2009	2010	200/200	0.155	0.130	*Accept*	0.175	*Reject*
2009	2011	200/150	0.167	0.115	*Accept*	0.242	*Reject*
2010	2011	200/150	0.167	0.225	*Reject*	0.125	*Accept*

Table 5. Discharge in the Coquitlam River as measured at the WSC Station 08MN002 at the time when Steelhead spawning habitat availability data were collected. Transect locations are provided in Appendix A.

Year	Date	Discharge (m^3/s)	Transects Sites
2009	29-Apr	7.64	A3, B1, C1
	05-May	19.00	E4, E1
	21-May	8.27	D1, C3, D3
2010	16-Apr	7.75	B1, B2, C1, D6
	10-May	5.32	D4, D4, D1, D3
2011	26-Apr	9.87	C2, D3, A4
	22-May	7.74	C1, E1, D2
Average		9.37	

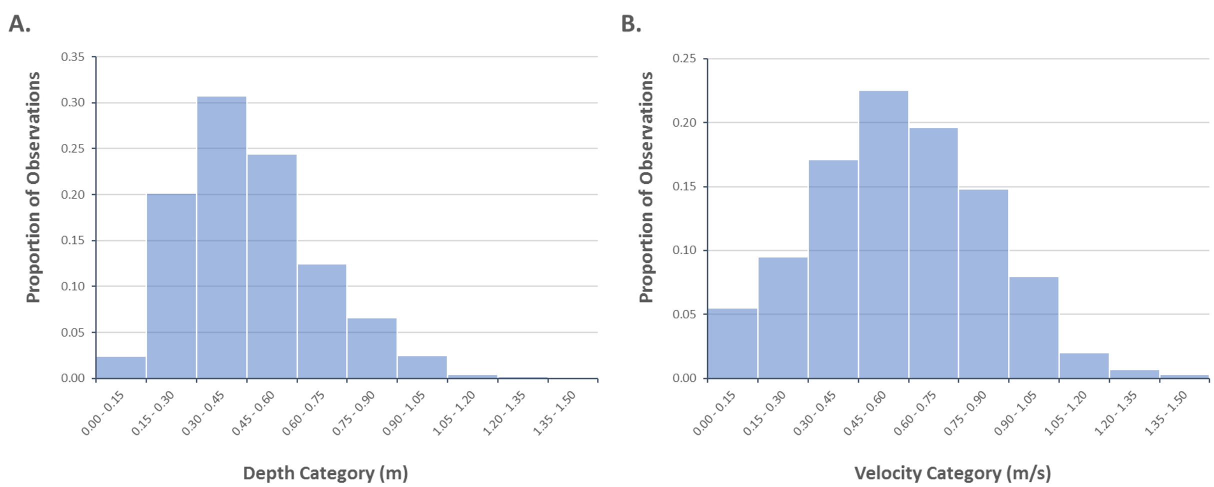


Figure 3. Pooled depth (A) and velocity (B) frequency histograms of 550 paired observations at 21 transect sites (Table 5) considered to be representative of available steelhead trout spawning habitat from 2009 to 2011. Sampling dates and discharge at the time of sampling are also provided in Table 5.

Coho Salmon

Habitat availability data for Coho Salmon at the time of spawning were collected over a 4-year period starting in November 2008. There were 425 paired observations in total that were collected across 17 transects (Table 6). Two of these transects were sampled in three of the four years, and another was sampled twice (Table 6). Paired comparison of frequency histograms using the Kolmogorov-Smirnov test found no significant differences in habitat availability between most sampling years for both the depth and velocity variables (Table 7). This is consistent with the narrow range of discharges recorded at the time of sampling (Table 6), and the clustering of transect sites, which included many repeated sets of observations. Nevertheless, because a single null hypothesis was rejected for each variable, the Kolmogorov-Smirnov analysis indicated statistically significant between-year differences overall. Pooled histograms of available water depths and velocities are provided in Figure 4a and b. Minimum observed depth was 0.12 m and the maximum 1.27 m. The median of all depth observations was 0.59 m. Average velocities ranged from 0.00 to 1.19 m/s and had a median of 0.46 m/s.

Table 6. Discharge in the Coquitlam River as measured at the WSC Station 08MN002 at the time when Coho Salmon spawning habitat availability data were collected. Transect Locations are provided in Appendix A.

Year	Date	Discharge (m^3/s)	Transects Sites
2008	24-Nov	8.70	E2, E3, E4, E5
2009	12-Dec	6.68	B2, D2, E3, E5, E6
2010	21-Dec	7.22	E1, E2, E4
2011	08-Dec	6.08	D1, D4, D5
	21-Dec	7.27	E2, E3
Average		7.19	

Table 7. Summary of Kolmogorov-Smirnov statistics (D) used to compare yearly Coho Salmon spawning habitat availability frequency histograms. The test's α level was set at 0.0083 to maintain a family wise error rate of 0.05 and in turn calculate D_{Crit}.

				Depth (m)		**Velocity (m/s)**	
Comparison		**n_1/n_2**	**D_{Crit}**	**D**	**Outcome**	**D**	**Outcome**
2008	2009	100/125	0.222	0.110	*Accept*	0.154	*Accept*
2008	2010	100/75	0.253	0.143	*Accept*	0.210	*Accept*
2008	2011	100/125	0.222	0.158	*Accept*	0.146	*Accept*
2009	2010	125/75	0.242	0.253	*Reject*	0.064	*Accept*
2009	2011	125/125	0.209	0.056	*Accept*	0.208	*Accept*
2010	2011	75/125	0.242	0.237	*Accept*	0.248	*Reject*

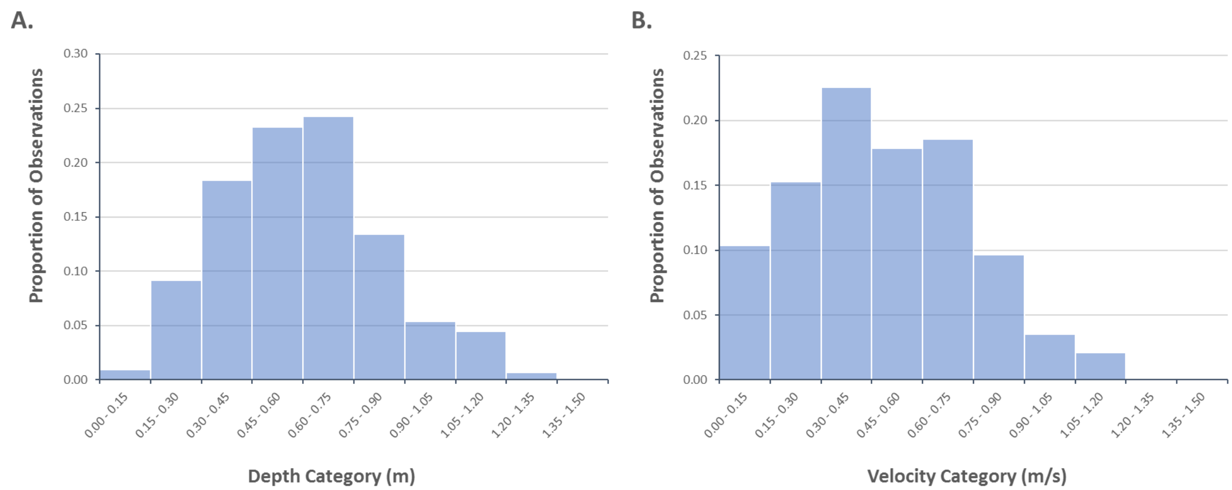


Figure 4. Pooled depth (A) and velocity (B) frequency histograms of 425 paired observations at 17 transect sites (Table 5) considered to be representative of available coho salmon spawning habitat from 2008 to 2011. Sampling dates and discharge at the time of sampling are also provided in Table 6.

Chum Salmon

Habitat availability data related to chum salmon spawning was collected in years 2008, 2009 and 2011. No spawning surveys, and hence habitat availability surveys, were carried out in 2010. Sampling dates and daily average discharge are summarized in Table 8. A total of 14 transects sites were sampled over the threes years of sampling, of which transect A1 and A2 were sampled all years. There were a total of 350 paired depth and average velocity measurements. Kolmogorov-Smirnov test showed that the yearly frequency histograms did not differ significantly between years for both the depth and velocity variables. This occurred despite the broad range of discharge values observed at the time of sampling and possibly reflects the repeated sampling of transects each year. Pooled frequency histograms of these observations are provided in Figures 5a and b. Measured depths ranged from 0.17 to 1.04 m with a median of 0.52 m. Average velocity depths ranged from 0.06 to 1.27 m/s and had a median value of 0.67 m/s.

Table 8. Discharge in the Coquitlam River as measured at the WSC Station 08MN002 at the time when Chum Salmon spawning habitat availability data were collected. Transect Locations are provided in Appendix A

Year	Date	Discharge (m^3/s)	Transects Sites
2008	31-Oct	7.28	A1, A2, D1, D2, E1
2009	25-Oct	9.37	A1, C2, D3
	15-Nov	25.0	A2, C4, E2
2011	16-Nov	6.89	A1, A2, A3
Average		12.14	

Table 9. Summary of Kolmogorov-Smirnov statistics (D) used to compare yearly Coho Salmon spawning habitat availability frequency histograms. The test's α level was set at 0.0167 to maintain a family wise error rate of 0.05 and in turn calculate D_{Crit}.

				Depth (m)		Velocity (m/s)	
Comparison		**n_1/n_2**	**D_{Crit}**	**D**	**Outcome**	**D**	**Outcome**
2009	2010	125/150	0.187	0.089	*Accept*	0.149	*Accept*
2009	2011	125/75	0.226	0.176	*Accept*	0.123	*Accept*
2010	2011	150/75	0.219	0.100	*Accept*	0.120	*Accept*

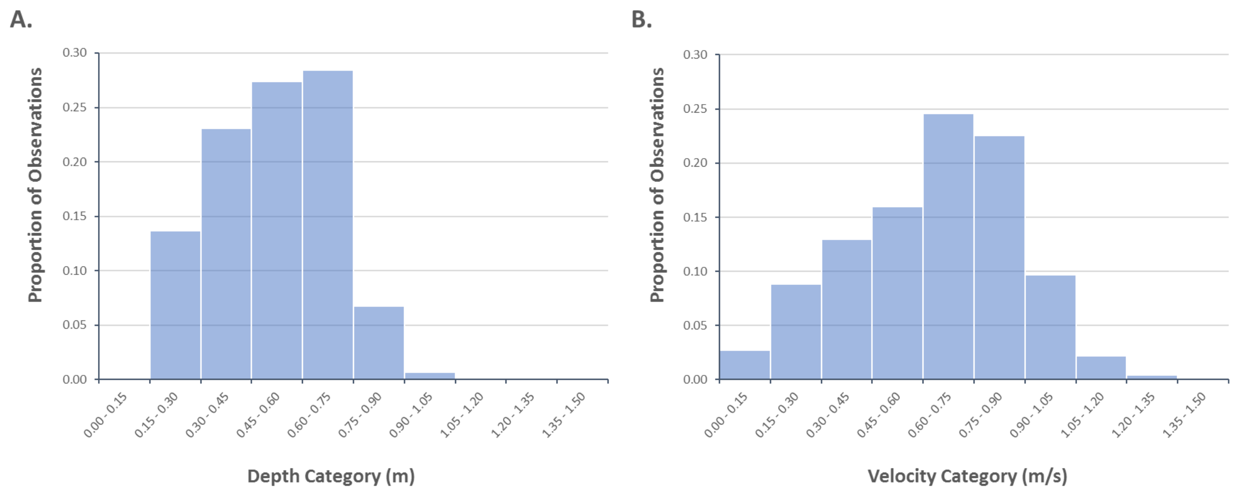


Figure 5. Pooled depth (A) and velocity (B) frequency histograms of 350 paired observations at 14 transect sites (Table 6) considered to be representative of available chum salmon spawning habitat from 2008 to 2011. Sampling dates and discharge at the time of sampling are also provided in Table 8.

Chinook Salmon

Chinook spawning habitat availability data were only collected at two transect sites in 2010 (Nov 8, Transects D2 and E3 when river discharge was 6.55 m^3/s) and a single site in 2011 (Dec 21, Transect D6 when river discharge was 7.27 m^3/s) for a total of 75 paired depth and velocity measurements. This was considered insufficient to characterize habitat availability in the river for Chinook spawners. As result, no frequency histogram analysis was carried out. Of the data that were collected, minimum and maximum depths were 0.14 and 0.77 m respectively with a median of 0.44 m. Average velocities ranged from 0.00 to 1.28 m/s and had a median of 0.58 m/s.

3.1.2 Juvenile Salmonids

Habitat availability data for juvenile salmonid rearing were first collected in 1999 at the time of WUP process (pre-WUP), and then again over a 3-year period following implementation of the WUP in 2007 (WUP). The WUP studies were carried out in 2009, 2010 and 2011. Unlike the salmonid spawners where site section was in part determined by its proximity to identified redds sites, habitat availability data were collected at pre-selected sites that were known to harbour high concentrations of juvenile salmonids from past survey work and/or carried out as part of COQMON #7 (Schick et al 2015). The distribution of this sampling effort, along with the average daily discharge at the time of data collection, is summarised in Table 10. It should be noted that these habitat availability data are not species specific like that of salmonid spawners. Rather they apply to all juvenile salmonids species. Also, each site is considered a "rearing habitat sample" with habitat conditions as described in Table 1. Thus, the habitat availability data do not collectively represent available habitat conditions for the river as a whole. Rather they only relate to what were believed to be juvenile salmonid rearing habitats.

Pre-WUP Habitat Availability

During the pre-WUP survey, up to 100 depth and average velocity measurements were made per site for a total of 981 paired observations. Water depths ranged from 0.02 m to 1.65 m and had a median of 0.33 m. A frequency histogram of the data is provided in Figure 6a. It should be noted that there was a single observation greater than 1.50 m. Rather than add another bin class to the histogram, it was added to the 1.35-1.50 m bin to maintain direct comparability with all other histograms. Average velocities ranged from 0.00 m/s to 1.87 m/s, with three observations greater than 1.50 m/s. The median velocity was 0.30 m/s. A frequency histogram of the data provided in Figure 6b. Like the depth data,

Table 10. Date of sampling and location of survey sites where habitat availability data consisting of water depth and average velocity were collected related to juvenile salmonid habitat use. Pre-WUP locations were only listed as site descriptors in the data set provided. All other sites are noted as the distance downstream from the dam. Average daily discharge (WSC Station 08MH002) for the date of sampling is also provided. Pre-WUP = 1999; WUP = all remaining years.

Year	Date	Discharge (m^3/s)	Survey Sites
1999	02-Sep	2.90	Tag_BM02, Tag_040
	03-Sep	2.83	u/s of RCMP, Cable Sign
	04-Sep	2.82	Log Jam, Road Sign
	08-Sep	2.70	Dog House, Quarry Site (Site 90)
	09-Sep	2.62	Gallette Park, Maple Creek
2009	08-Sep	6.61	0.55 km, 1.25 km, 8.25 km
	17-Sep	2.27	1.95 km , 4.05 km , 4.75 km
2010	06-Sep	2.99	3.25 km, 7.55 km
	16-Sep	2.98	2.65 km, 5.45 km, 6.15 km
2011	19-Aug	3.48	0.55 km, 1.25 km, 5.45 km
	20-Aug	3.53	3.35 km, 4.75 km, 6.85 km
Average Pre-WUP		2.77	
Average Post-WUP		3.64	

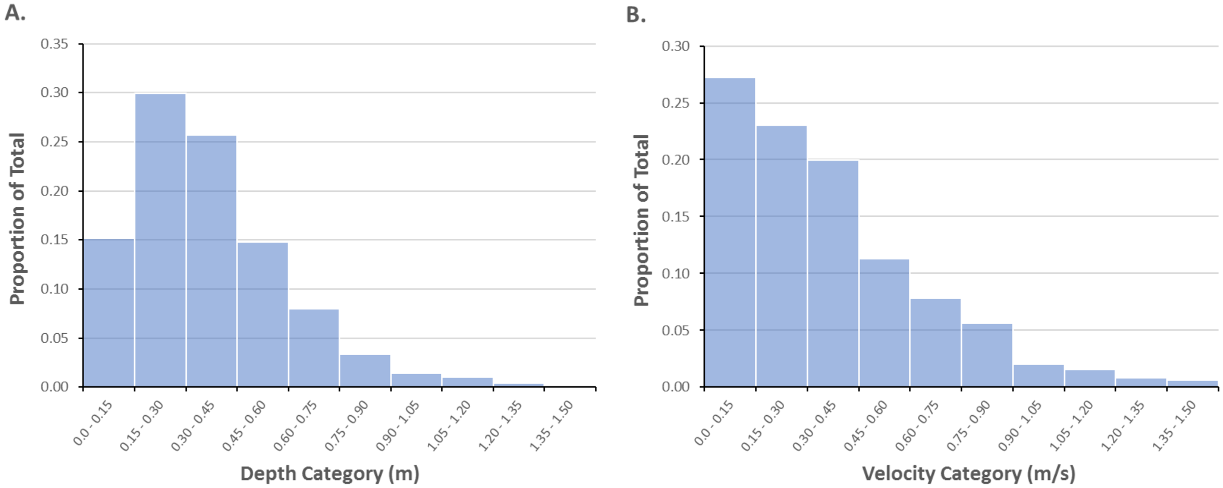


Figure 6. *Water depth (A) and average velocity (B) frequency histograms of 981 paired observations at 10 sites considered to be representative of available juvenile salmonid rearing habitat prior to WUP implementation (1999). Sampling dates and discharge at the time of sampling are also provided in Table 10.*

the outlier velocity data were added to the 1.35-1.50 m bin to maintain consistency in the number of histogram bins.

WUP Habitat Availability

WUP habitat availability data were collected at a total of 17 transect sites over a 3-year period (Table 10). Three of these sites were sampled twice, but daily average discharge at the time of sampling was different, creating a unique habitat condition. Only 25 depth and velocity measurements were made per site. To create a usable habitat availability frequency histogram, these had to be pooled across years. The pooled histograms are shown in Figure 7a and b. There was a total of 345 paired

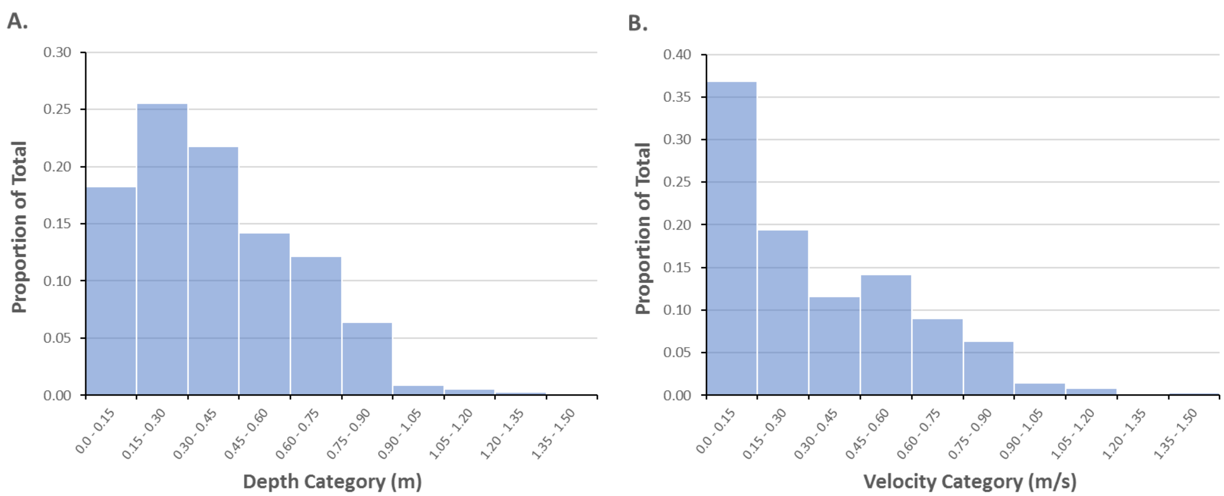


Figure 7 *Pooled water depth (A) and average velocity (B) frequency histograms of 345 paired observations at 17 sites over a 3-year period (2009 - 2011) capturing available juvenile salmonid rearing habitat following at those sites. Sampling dates and discharge at the time of sampling are also provided in Table 10.*

observations across all years and sites. Water depths ranged from 0.00 to 1.27 m and had a median of 0.35 m. Average velocities ranged from 0.00 to 1.40 m/s. The median was 0.25 m/s.

Pre-WUP/WUP comparison

A comparison of pre-WUP and WUP histograms (Figures 7 and 8) showed that available water depths were similar between treatment periods (Kolmogorov-Smirnov $D_{981,345} = 0.059$, $D_{Crit,0.05} = 0.086$, $P > 0.05$), despite the differences average discharge (Table 10). The largest bin differences appeared be related to overall smoothness of the histograms, where the pre-WUP histogram was smoother than WUP. This was likely a function of the greater sample size in the pre-WUP histogram, as well as the consistent discharge across sites. Discharge was more variable in the pooled WUP data.

Unlike the depth data, average velocity histograms were found to be significantly different between pre-WUP and WUP periods (Kolmogorov-Smirnov $D_{981,345} = 0.096$, $D_{Crit,0.05} = 0.086$, $P < 0.05$). Slow moving water (velocities < 0.15 m/s) appeared to be far more common during the WUP period, which was accompanied by a drop in the frequency of more modest velocities between 0.15 and 0.45 m/s. The reason for this change in uncertain. With the higher discharges during WUP, one would have expected a greater frequency of fast flowing habitats. This however was not the case. The difference may simply be related to the choice of habitat sites between survey periods.

3.2 Habitat-use

3.2.1 Salmonid Spawners

Steelhead Trout

Over the 3-year survey period, there was a total of 155 Steelhead Trout redd depth and velocity observations. Water depths ranged from 0.13 to 0.95 m and had a median of 0.32 m. Average velocities ranged from 0.18 to 1.22 m/s and the median was 0.55 m/s. However, only 64 of these (41%) were in close proximity to one or more of the habitat availability transect sites. Thus, for most of the redd observations, there was no reliable estimate of available habitat and as a result, could not be subject to electivity analysis. To construct an HSI function therefore, only the habitat-use data were used. The resulting habitat-use histograms are shown in Figures 8a and b.

Because the habitat use data could not be corrected for potential availability constraints, meaningful between-year comparisons in Steelhead Trout habitat preferences could not be made.

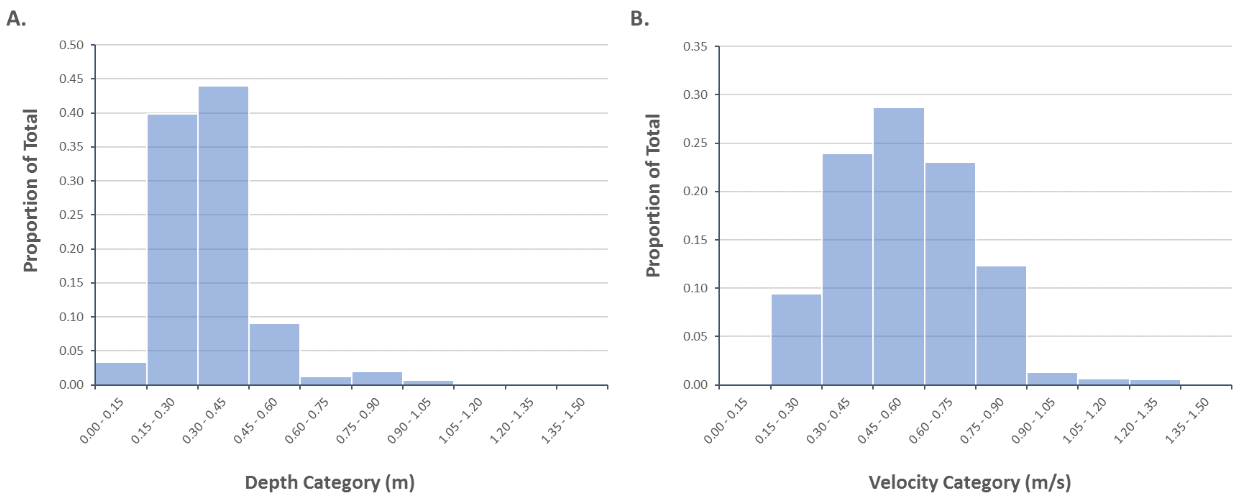


Figure 8. Water depth (A) and average velocity (B) habitat-use frequency histograms for Steelhead Trout spawners. Based on 155 paired observations at redd sites collected over a 3-year period (2009 - 2011). Sampling dates and average daily discharge at the time of sampling are provided in Table 5.

Coho Salmon

A total of 116 paired depth and velocity measurements were collected at coho redd sites over the 4-year sampling period. Frequency histograms of these data are provided in Figures 9a and b. Water depth ranged from 0.18 to 1.18 m with a median of 0.54 m. Average velocities ranged from 0.05 to 1.05 m/s and had a median of 0.44 m/s. Of these observations, 80 (69%) were in close proximity to the habitat availability sites and therefore subject to electivity analysis. Depth and velocity *edfs* for these 80 observations are provided in Figures 10a and b. To assess the possible affect of this data loss, the *edfs* were re-calculated with all 116 observations and compared to those in Figures 9a and b. For both parameters, no differences were found (Kolmogorov-Smirnov $D_{80,116}$ = 0.054, $D_{Crit,0.05}$ = 0.197, P > 0.05 and Kolmogorov-Smirnov $D_{80,116}$ = 0.049, $D_{Crit,0.05}$ = 0.197, P > 0.05 for depth and velocity respectively). Thus, exclusion of the unrelated habitat use data did not appear to have an impact on *edf* calculations.

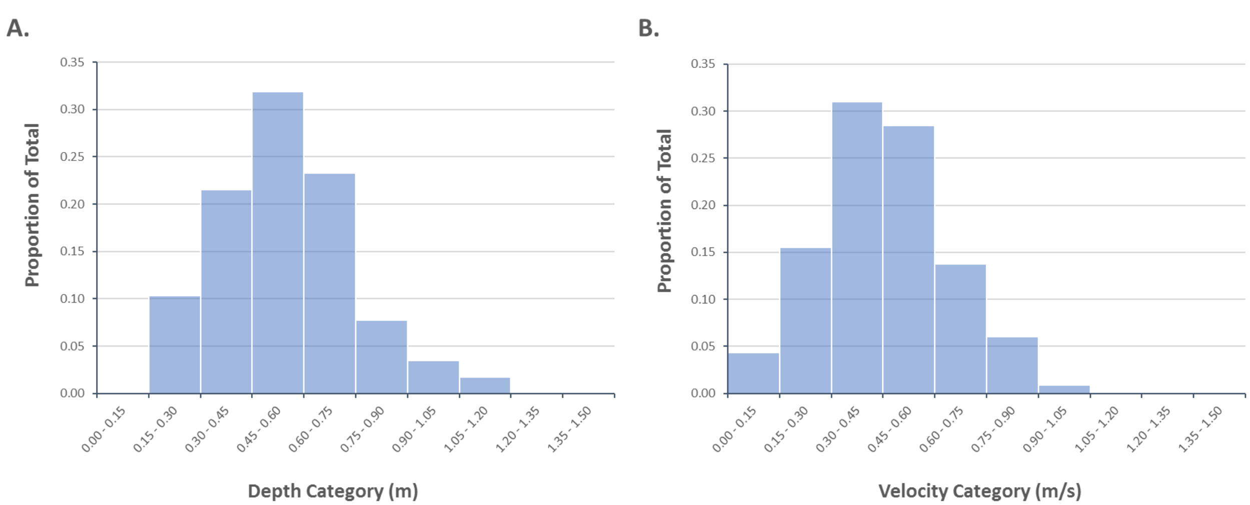


Figure 9. Water depth (A) and average velocity (B) habitat-use frequency histograms for Coho Salmon spawners. Based on 116 paired observations at redd sites collected over a 4-year period (2008 - 2011). Sampling dates and average daily discharge at the time of sampling are provided in Table 6.

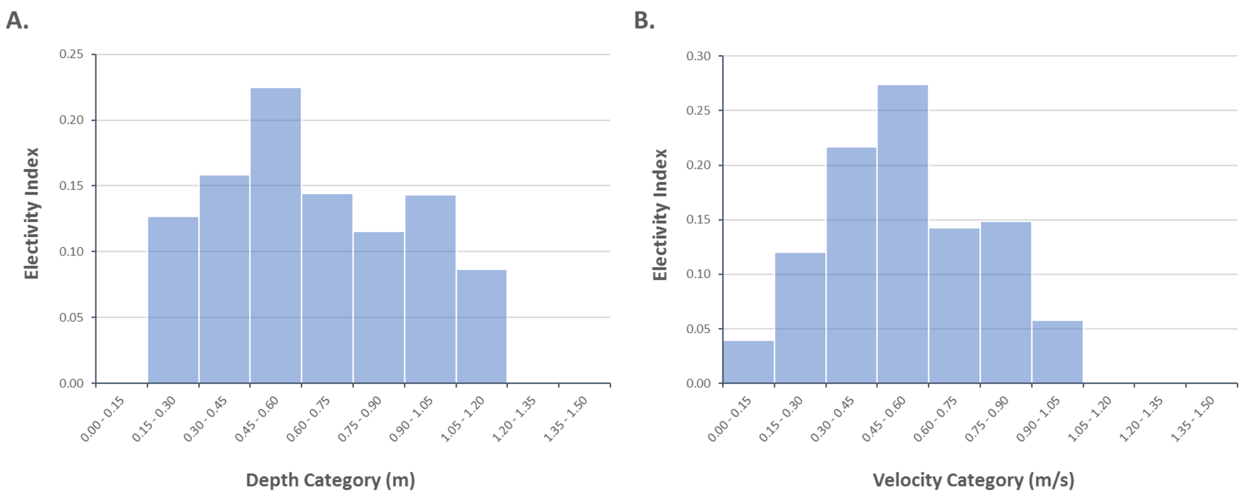


Figure 10. Electivity Index values (habitat-use corrected for habitat availability) for Coho Salmon spawners based on 80 paired depth (A) and velocity (B) measurements.

Because there were too few data meaningful between-year comparisons of Coho Salmon *edfs* could not be made, particularly with the 80-observation data set.

Chum Salmon

There were a total of 201 paired depth and velocity measurements taken at chum salmon redds over the course of the 3-year study period. Depth values ranged from 0.11 to 0.75 m with a median of 0.42 m, while velocities ranged from 0.15 to 1.04 m/s and had a median of 0.62 m/s. All were in close proximity to transect sites used to assess habitat availability and were therefore suitable for electivity analysis. Frequency histograms depicting habitat-use for these fish are found in Figures 11a and b. Habitat-use histograms corrected for habitat availability are provided in Figures 12a and b.

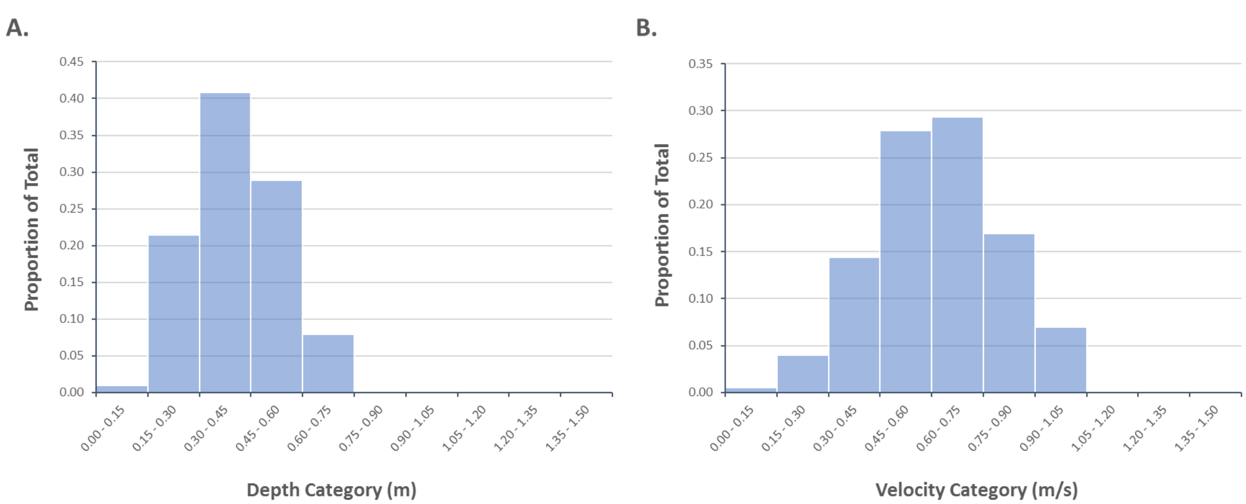


Figure 11. Water depth (A) and average velocity (B) habitat-use frequency histograms for Chum Salmon spawners. Based on 201 paired observations at redd sites collected over a 3-year period (2009 - 2011). Sampling dates and average daily discharge at the time of sampling are provided in Table 8.

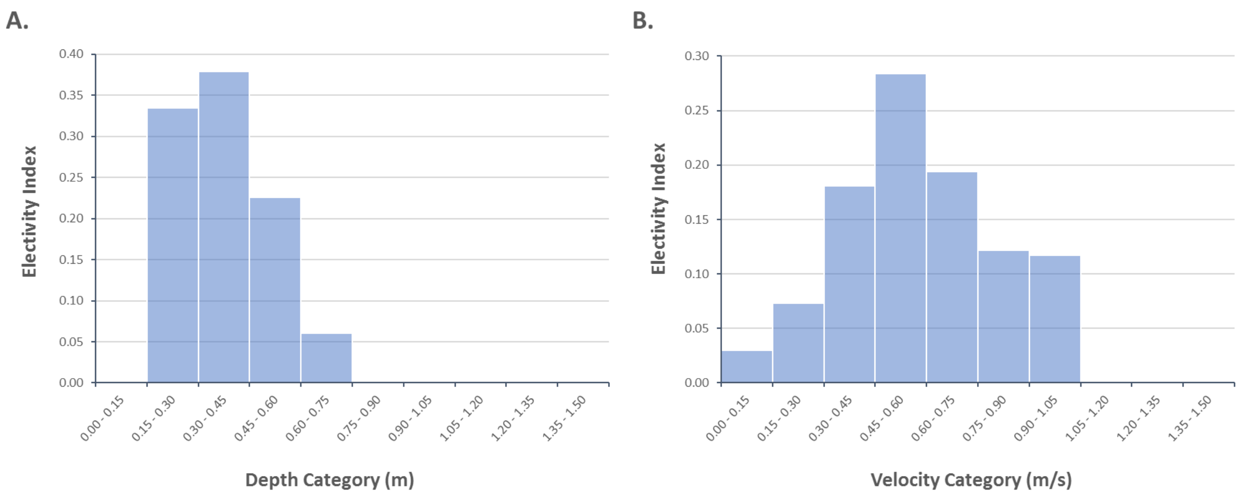


Figure 12. Electivity Index values (habitat-use corrected for habitat availability) for Chum Salmon spawners based on 201 paired depth (A) and velocity (B) measurements.

It is interesting to note that there were no significant between-year differences in Chum Salmon *edfs* during the study period (Table 11). This would suggest a strong degree of consistency in spawning habitat selection each year.

Table 11. Summary of Kolmogorov-Smirnov statistics (D) used to compare yearly Chum Salmon spawning habitat edfs. The test's α level was set at 0.0167 to maintain a family wise error rate of 0.05 and in turn calculate D_{Crit}.

				Depth (m)		Velocity (m/s)	
Comparison		**n_1/n_2**	**D_{Crit}**	**D**	**Outcome**	**D**	**Outcome**
2009	2010	60/101	0.252	0.169	*Accept*	0.190	*Accept*
2009	2011	60/40	0.316	0.118	*Accept*	0.152	*Accept*
2010	2011	101/40	0.289	0.064	*Accept*	0.248	*Accept*

Chinook Salmon

There were only 41 Chinook redd observations collected over a 2-year sampling period (2010, 2011), which was considered insufficient for HSI function development. An attempt was made in 2016 to expand this dataset, but no Chinook redds could be positively identified. Escapement was too low. However, while the survey was being carried out, 30 Chinook Salmon spawners were found holding at the Gate Pool, located at transects E1 through E3 (Appendix A), indicating that they were definitely in the river. Depth/velocity histograms were constructed nonetheless to illustrate habitat-use of these fish from the 2010/11 data (Figures 13a and b). Minimum and maximum observed depth was 0.14 m and 0.61 m respectively. Median depth was 0.40 m. Velocities ranged from 0.14 to 0.98 m/s and the median was 0.42 m/s.

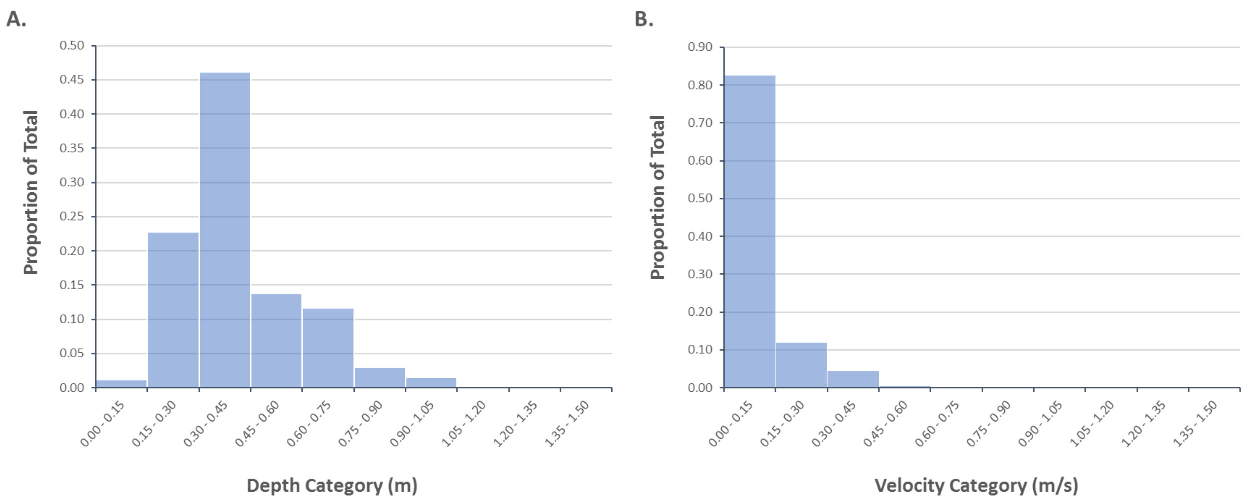


Figure 13. Water depth (A) and average velocity (B) habitat-use frequency histograms for Chinook Salmon spawners. Based on 41 paired observations at redd sites collected Nov 8, 2010 when river discharge was 6.55 m³/s and Dec 21, 2011 when river discharge was 7.27 m³/s.

3.2.2 Juvenile Salmonids

Steelhead Fry

Prior to WUP implementation, there were a total of 334 depth/velocity observations related to rearing Steelhead fry. Sampling dates and locations, as well as the average daily discharge at the time of sampling, are provided in Table 10. Pooled frequency histograms of habitat-use are provided in Figures 14a and b. The shape of the depth histogram was found to be significantly different from that derived by the 243 depth observations collected in the WUP surveys (Figure 15a; Kolmogorov-Smirnov $D_{334,243}$ = 0.147, $D_{Crit,0.05}$ = 0.115, $P < 0.05$). The difference in histograms suggests that Steelhead fry tended to

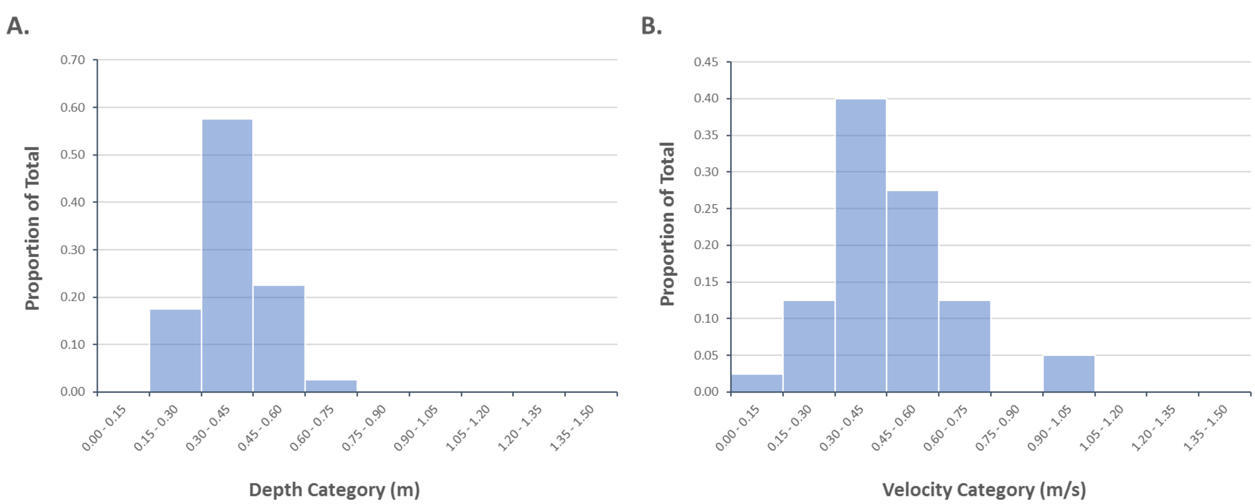


Figure 14. Water depth (A) and average velocity (B) frequency histograms illustrating habitat-use of Steelhead fry prior to WUP implementation. Based on 334 depth/velocity observations collected in 1999. Sampling dates, site locations and discharge at the time of survey is provided in Table 10.

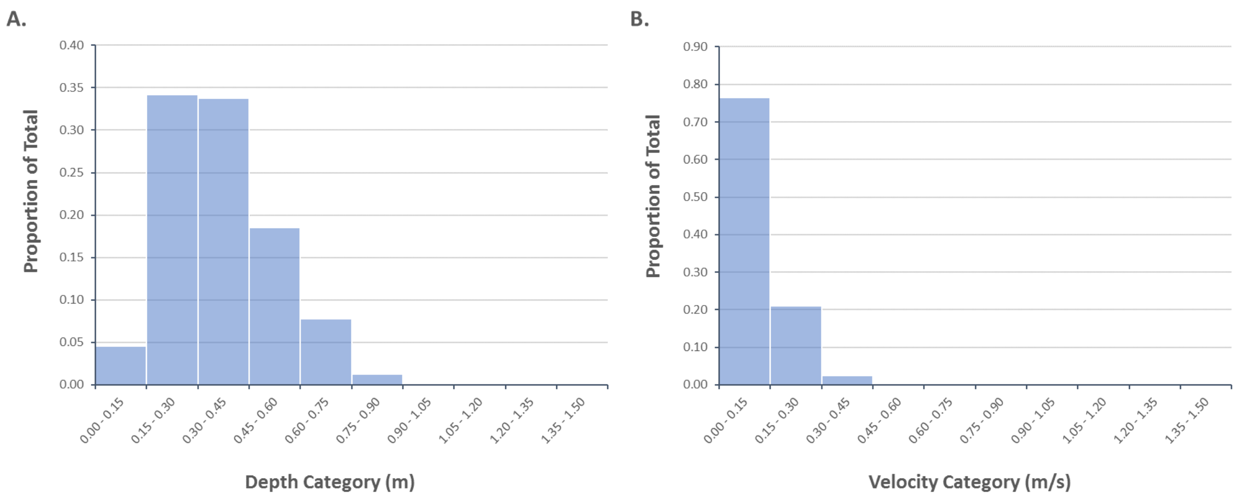


Figure 15. Water depth (A) and average velocity (B) frequency histograms illustrating habitat-use of Steelhead fry following WUP implementation. Based on 243 depth/velocity observations collected over a 3-year period (2009 – 2011). Sampling dates, site locations and discharge at the time of survey is provided in Table 7.

occupy shallow waters more frequently post WUP than prior to WUP implementation. Prior to WUP implementation, occupied depths ranged from 0.11 to 0.96 m and had a median of 0.38 m. Following WUP implementation, the range of occupied depths shifted to 0.07 to 0.79 m and the median to 0.35 m. There were no differences in velocity histograms however (Figure 15b; Kolmogorov-Smirnov $D_{334,243}$ = 0.061, $D_{Crit,0.05}$ = 0.115, P > 0.05). There was a strong preference for slow moving waters in both survey periods. Prior to WUP implementation, occupied velocities ranged from 0.00 to 0.68 m with a median of 0.05 m. Occupied velocities ranged from 0.00 to 0.35 m post WUP and had a median of 0.08.

The difference between pre-WUP and WUP implementation surveys became more apparent when the habitat-use data were corrected for availability constraints (Figures 16a and b; 17a and b respectively. Statistically significant differences in *edf* shapes were found for both depth and velocity

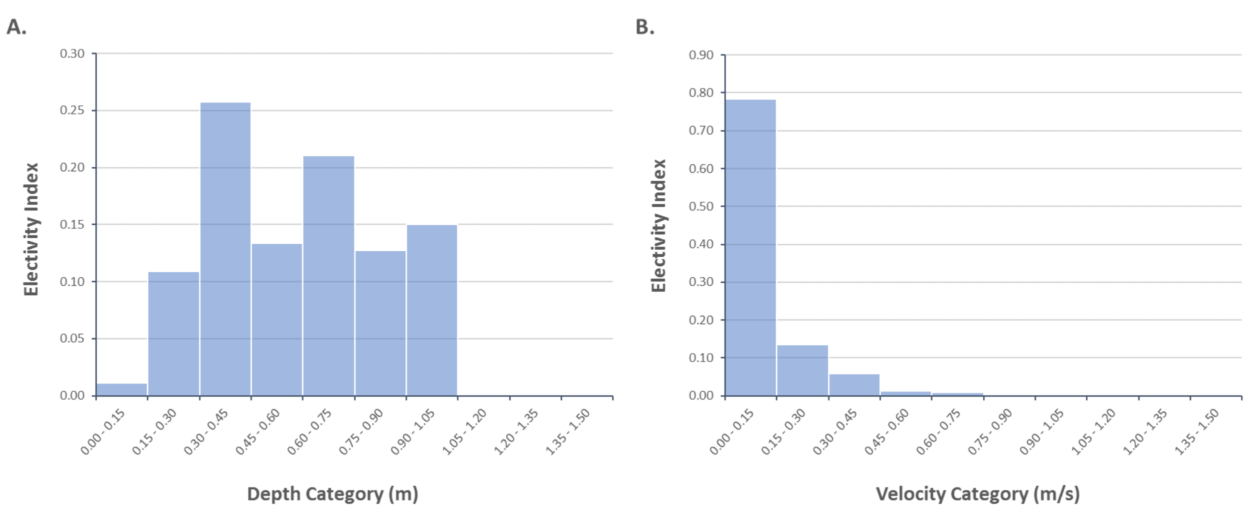


Figure 16. Electivity Index values (habitat-use corrected for habitat availability) for Steelhead fry prior to WUP implementation (1999), based on 334 paired depth (A) and velocity (B) measurements.

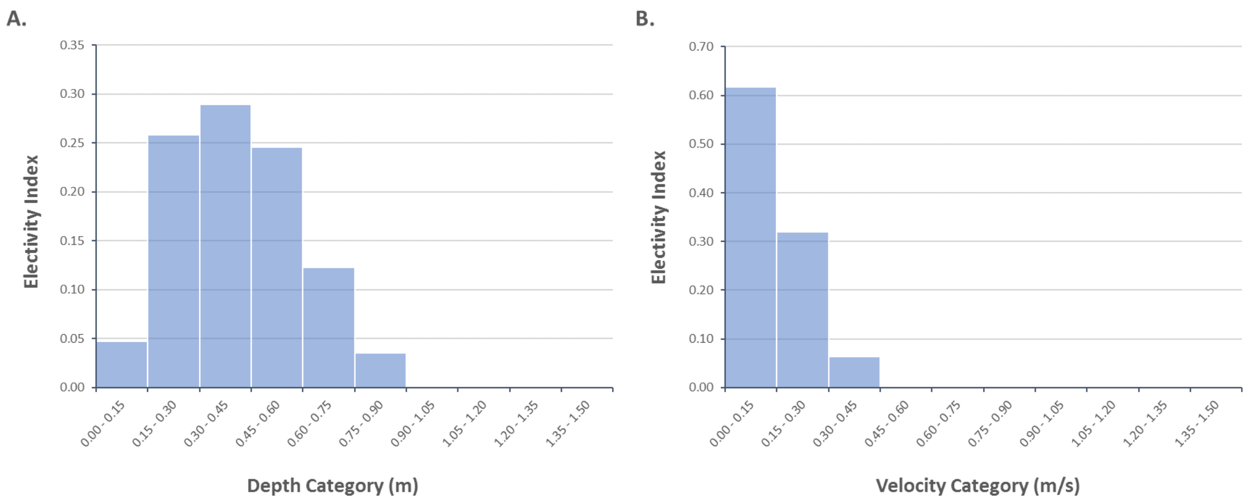


Figure 17. Electivity Index values (habitat-use corrected for habitat availability) for Steelhead fry following WUP implementation (2009 to 2011), based on 243 paired depth (A) and velocity (B) measurements.

parameters (Kolmogorov-Smirnov $D_{334,243}$ = 0.330, and $D_{334,243}$ = 0.168 respectively; $D_{Crit,0.05}$ = 0.115, $P < 0.05$ for both statistics). There appeared to be a clear preference for shallower, slightly faster waters post -WUP. Prior to WUP implementation, Steelhead fry appeared to be less selective for water depth, and more selective for very slow flowing waters. The reason for this difference is uncertain. It may be related to differences in site selection and/or average daily discharge at the time of survey between years of survey. Significant between-year differences in both depth and velocity *edfs* during the WUP study period suggests that this may indeed be a contributing factor (Table 12). More notable however, is the fact that the pre-WUP surveys were carried out during the day, while the post WUP data were collected at night. Test of this Day/Night hypothesis is carried out in Section 3.4.2. Unfortunately, there were too few site and discharge combinations to untangle the potential effects of each parameter on habitat selection.

Table 12. Summary of Kolmogorov-Smirnov statistics (D) used to compare yearly steelhead fry rearing habitat edfs. The test's α level was set at 0.0167 to maintain a family wise error rate of 0.05 and in turn calculate D_{Crit}.

				Depth (m)		Velocity (m/s)	
Comparison		n_1/n_2	D_{Crit}	D	Outcome	D	Outcome
2009	2010	54/64	0.286	0.079	*Accept*	0.254	*Accept*
2009	2011	54/125	0.252	0.159	*Accept*	0.101	*Accept*
2010	2011	125/64	0.238	0.238	*Reject*	0.254	*Reject*

Steelhead Parr

Far fewer depth/velocity data were collected for Steelhead parr than the fry life stage. Prior to WUP implementation, there were 209 paired observations, but this dropped to only 56 observations during WUP sampling. Sampling dates, locations and discharges on the date of sampling are presented in Table 10. Frequency histograms of depth and velocity habitat-use prior to WUP implementation are presented in Figures 18a and b. WUP habitat use histograms are provided in Figures 19a and b. The depth frequency histograms did not differ significantly between pre-WUP and WUP survey periods

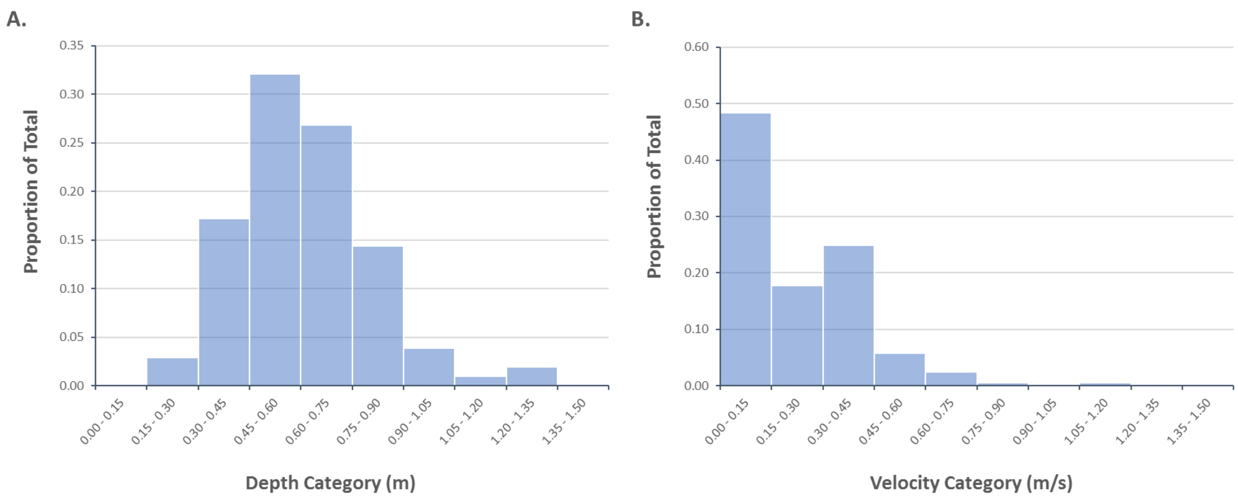


Figure 18. Water depth (A) and average velocity (B) frequency histograms illustrating habitat-use of Steelhead parr prior to WUP implementation. Based on 209 depth/velocity observations collected in 1999. Sampling dates, site locations and discharge at the time of survey is provided in Table 10.

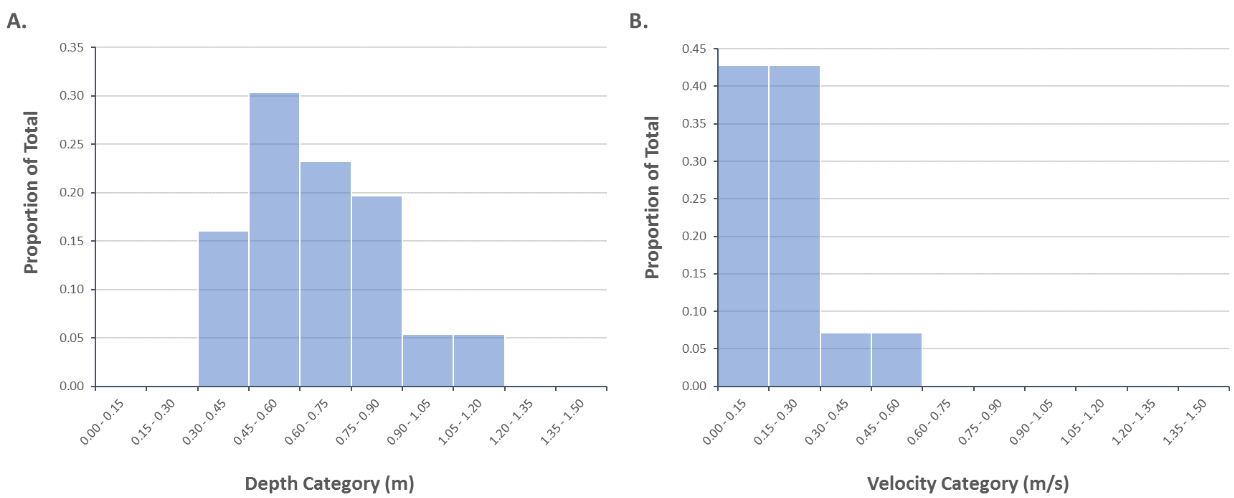


Figure 19. Water depth (A) and average velocity (B) frequency histograms illustrating habitat-use of Steelhead parr following WUP implementation. Based on 56 depth/velocity observations collected over a 3-year period (2009 – 2011). Sampling dates, site locations and discharge at the time of survey is provided in Table 10.

(Kolmogorov-Smirnov $D_{209,56}$ = 0.093, $D_{Crit,0.05}$ = 0.204, P > 0.05), nor were there significant differences in the velocity histograms (Kolmogorov-Smirnov $D_{209,56}$ = 0.197, $D_{Crit,0.05}$ = 0.204, P > 0.05). Occupied depths during the pre-WUP period ranged from 0.25 to 1.24 m and had a median of 0.60 m. During the WUP period, the range shifted to 0.17 to 1.17 m, but the median remained largely unchanged at 0.62 m. Occupied velocities ranged from 0.00 to 1.06 m/s prior to WUP implementation, but shifted to 0.00 to 0.51 m/s during the WUP surveys. Despite the large shift in range, median occupied velocities were similar (0.19 vs 0.17 m/s for the pre-WUP and WUP periods respectively).

Correcting the habitat use histograms for habitat availability resulted in significant changes when deriving *edfs*. In the case of water depth, there was a strong shift towards deeper waters, suggesting a much stronger preference for deeper waters than suggested by the habitat use curves alone (Figures 20a.and 21a). The shift was not the same between survey periods, resulting in a significant difference in *edfs* (Kolmogorov-Smirnov $D_{209,56}$ = 0.249, $D_{Crit,0.05}$ = 0.204, P < 0.05). Because the largest changes in

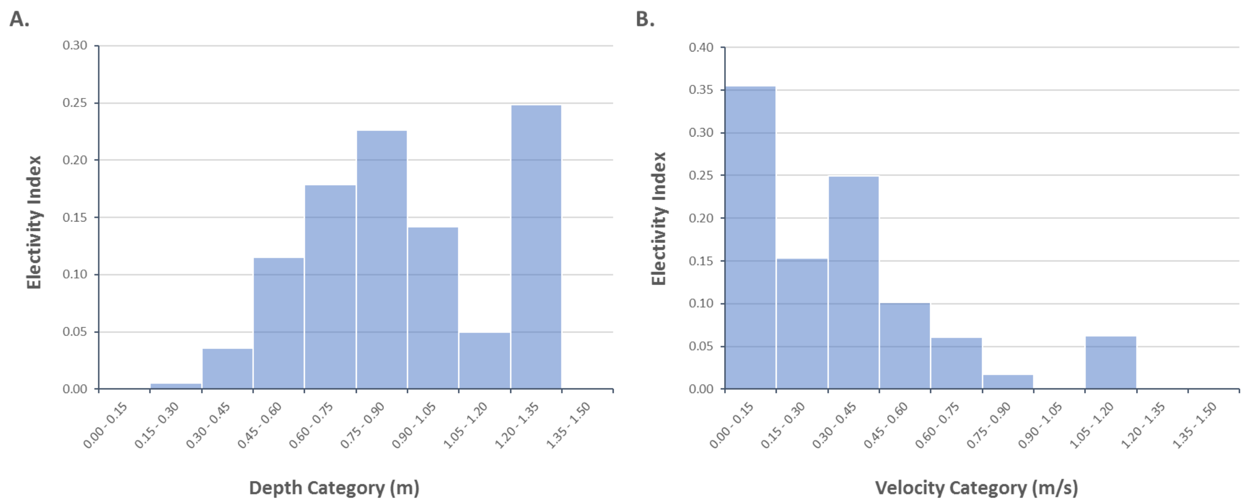


Figure 20. Electivity Index values (habitat-use corrected for habitat availability) for Steelhead parr prior to WUP implementation (1999), based on 209 paired depth (A) and velocity (B) measurements.

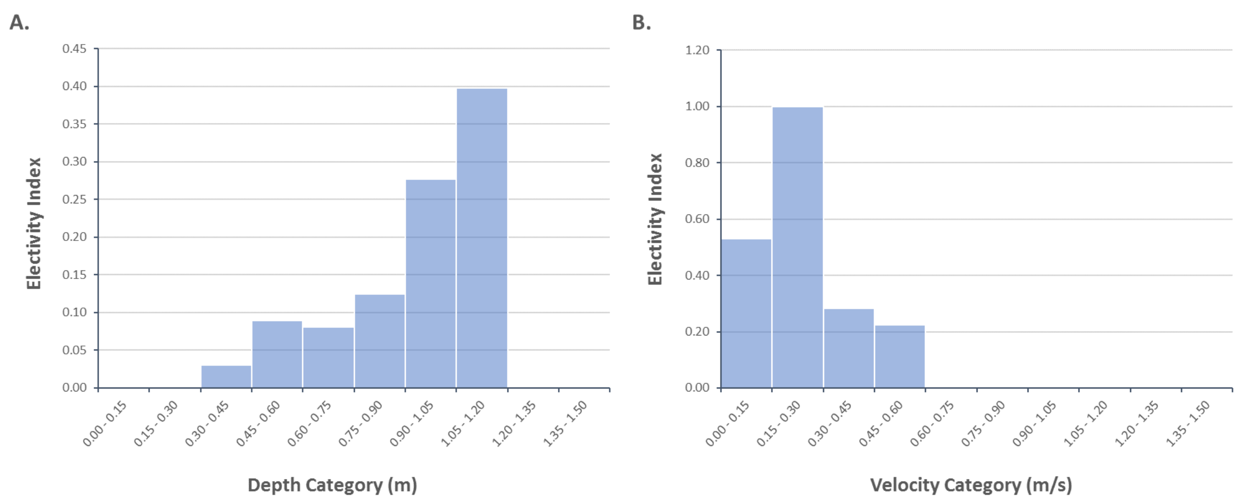


Figure 21. Electivity Index values (habitat-use corrected for habitat availability) for Steelhead parr following WUP implementation (2009 to 2011), based on 56 paired depth (A) and velocity (B) measurements.

distribution shape occurred in the right tail of the *edfs*, it suggests that the shift may be an artifact due over correction (Section 2.4). A similar right shift was also observed in the velocity data, but did not appear as dramatic (Figures 20b.and 21b). There was nevertheless a significant difference in velocity *edfs* between pre-and-post WUP study periods (Kolmogorov-Smirnov $D_{209,56} = 0.242$, $D_{Crit,0.05} = 0.204$, $P < 0.05$).

The reason for this pre/post WUP difference in both depth and velocity *edf's* is uncertain. Over correction for habitat availability appears to be a factor. There may also be differences due to site selection and/or average daily discharge at the time of survey between study years, though this could not be tested with the limited data. More notable however, is the fact that the pre-WUP surveys were carried out during the day, while the post WUP data collection occurred at night. Test of this Day/Night hypothesis is carried out in Section 3.4.2.

Coho Fry

Coho fry were the most abundant fish encountered during the 1999 habitat-use survey with a total of 1066 depth/velocity observations that were made. This pattern continued into the post WUP surveys where 353 depth/velocity observations were collected over the 3-year survey period. Sampling dates, locations and discharge at the time of sampling are provided in Table 10. The Coho fry depth/velocity histograms prior to WUP implementation are provided in Figures 22a and b, and for the WUP surveys in Figures 23a and b. Habitat use differed significantly between pre-WUP and WUP surveys, with the range of occupied depths being much broader and less selective in the pre-WUP survey (Kolmogorov-Smirnov $D_{1066,353} = 0.251$, $D_{Crit,0.05} = 0.083$, $P < 0.05$). Prior to WUP implementation, the range of occupied depths was 0.16 to 1.25 m with a median of 0.55 m. Following WUP implementation, the range narrowed to 0.15 to 0.86 m and the median decreased to 0.43 m.

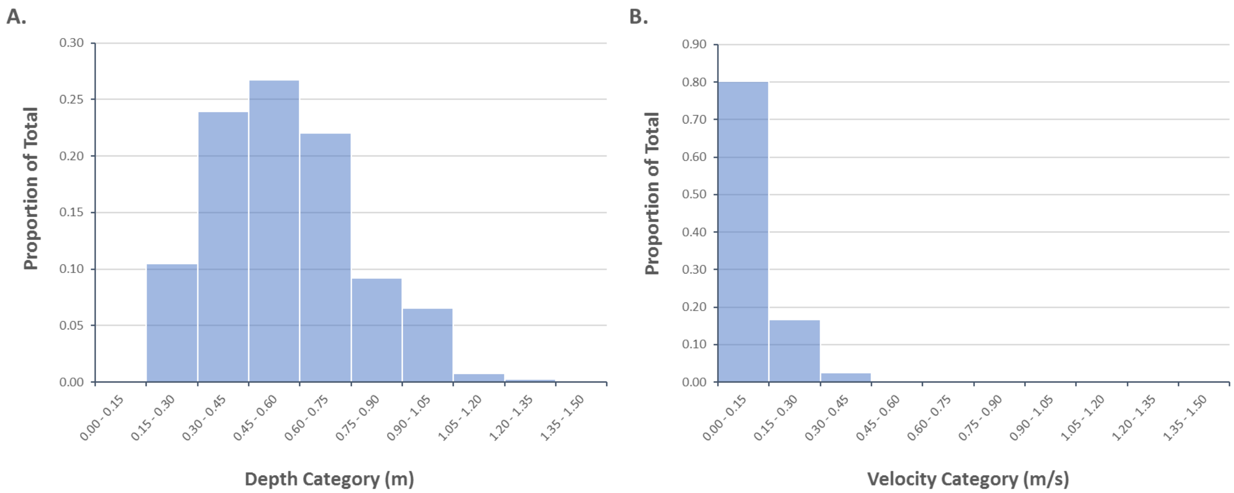


Figure 22. Water depth (A) and average velocity (B) frequency histograms illustrating habitat-use of Coho fry prior to WUP implementation. Based on 1066 depth/velocity observations collected in 1999. Sampling dates, site locations and discharge at the time of survey is provided in Table 7.

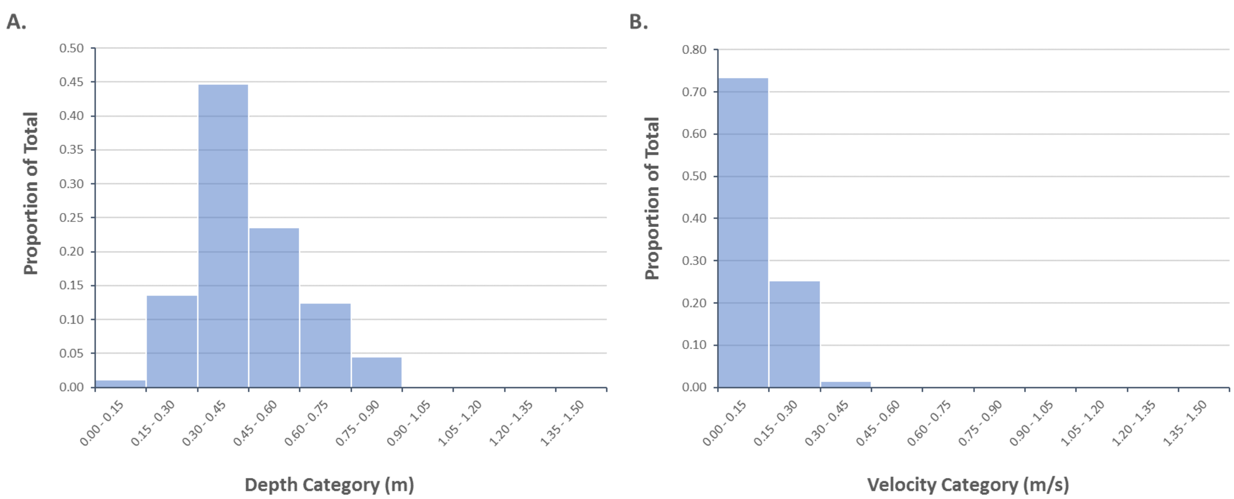


Figure 23. Water depth (A) and average velocity (B) frequency histograms illustrating habitat-use of Coho fry following WUP implementation. Based on 353 depth/velocity observations collected over a 3-year period (2009 – 2011). Sampling dates, site locations and discharge at the time of survey is provided in Table 7.

The occupied velocity histograms appeared to be very similar between study periods (Kolmogorov-Smirnov $D_{1066,353}$ = 0.068, $D_{Crit,0.05}$ = 0.083, P > 0.05). This however is not reflected in the summary statistics. The range of occupied velocities was 0.00 to 0.95 m/s pre-WUP, but narrowed to 0.00 to 0.44 m/s post WUP. This difference was largely due to 3 outlier values with velocities > 0.75 m/s in the pre-WUP data set. Median velocities remained similar (0.05 vs 0.08 m/s for the pre-WUP and WUP surveys respectively).

Correcting the habitat-use histograms for potential habitat availability constraints had the overall effect of accentuating the pre/post WUP differences. For water depth, the pre-WUP *edf* showed Coho fry had a strong preference for deep water habitats, but this shifted to much shallower waters following WUP implementation (Figures 24a and 25a, Kolmogorov-Smirnov $D_{1066,353}$ = 0.502, $D_{Crit,0.05}$ = 0.083, P < 0.05). The reason for this is uncertain. As noted already for steelhead fry, the pre-WUP surveys were carried during the day, while WUP surveys were done at night, thus potentially capturing a diel shift in behaviour. This is discussed later in Section 3.4.2. A between-year comparison of *edfs* within the post WUP study period found significant differences, suggesting that sites selection and possible differences in stream discharge at the time of survey was also be a factor (Table 13). The effects of over correction cannot be ruled out either.

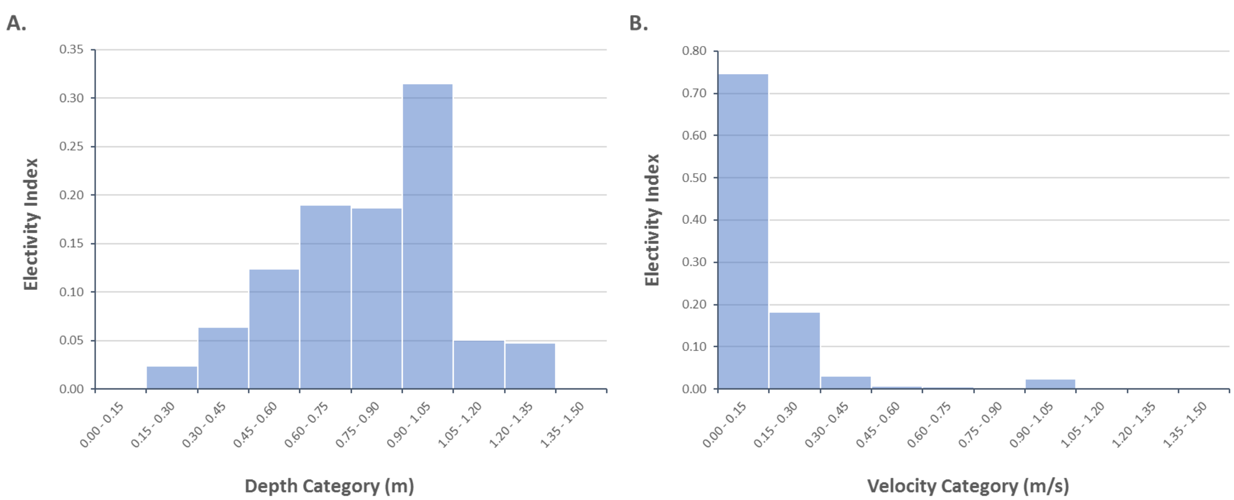


Figure 24. Electivity Index values (habitat-use corrected for habitat availability) for Coho fry prior to WUP implementation (1999), based on 1066 paired depth (A) and velocity (B) measurements.

Table 13. Summary of Kolmogorov-Smirnov statistics (D) used to compare yearly coho fry rearing habitat edfs. The test's α level was set at 0.0167 to maintain a family wise error rate of 0.05 and in turn calculate D_{Crit}.

				Depth (m)		Velocity (m/s)	
Comparison		**n_1/n_2**	**D_{Crit}**	**D**	**Outcome**	**D**	**Outcome**
2009	2010	153/85	0.209	0.321	*Reject*	0.124	*Reject*
2009	2011	153/115	0.191	0.413	*Reject*	0.265	*Reject*
2010	2011	85/115	0.221	0.066	*Accept*	0.217	*Accept*

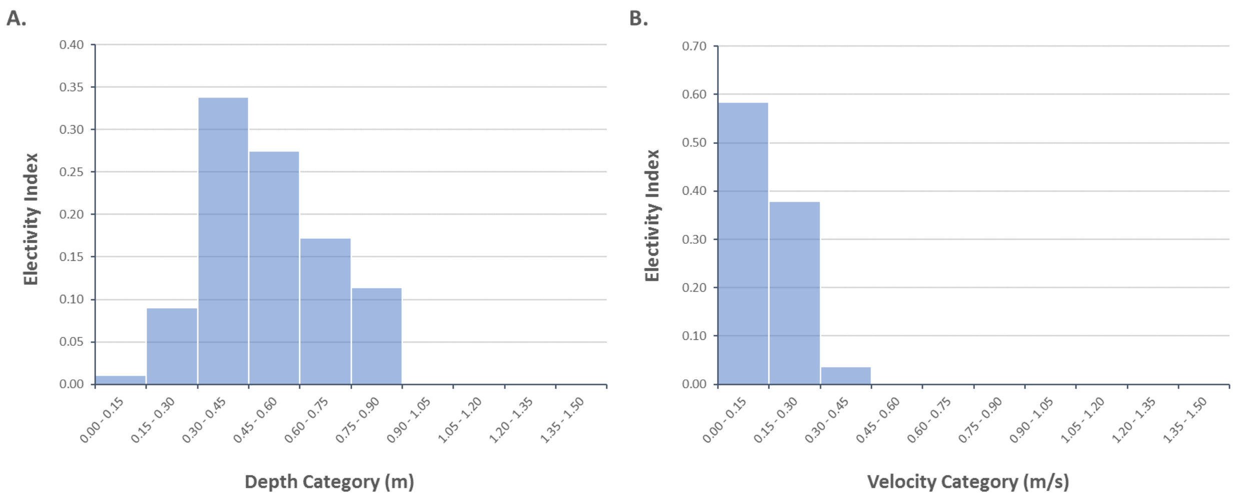


Figure 25. Electivity Index values (habitat-use corrected for habitat availability) for Coho fry following WUP implementation (2009 to 2011), based on 353 paired depth (A) and velocity (B) measurements.

Both pre-WUP and WUP velocity electivity index histograms have peaks at the lowest depth category (0.00 to 0.15 m/s), but there was a greater tendency for coho fry to favour slightly faster waters in the WUP surveys (Figures 24b and 25b, Kolmogorov-Smirnov $D_{1066,353} = 0.162$, $D_{Crit,0.05} = 0.083$, $P < 0.05$). Like the depth *edfs*, differences in site selection, discharge at the time of survey (Table 13), habitat availability over correction and the potential for day/night shifts in habitat preference could all be factors influencing this difference in velocity *edfs* between study periods.

3.3 Specific Hypothesis Testing

3.3.1 Between-Site Differences in Rearing Electivity Functions

Steelhead Fry

A comparison of steelhead fry, site-specific *edfs* between the Road Sign, Dog House, Quarry and Maple Creek sites found significant differences in both the depth and velocity variables (Table 14). In particular, the depth *edf* at the Road Sign site was significantly different from that derived at the Dog House and Maple Creek sites. The velocity *edf* at the Maple Creek Site was significantly different from

Table 14. Summary of Kolmogorov-Smirnov tests used to assess between-site differences in steelhead fry depth (a) and velocity (b) edfs derived from pre-WUP (1999) data. Values above the diagonal are Kolmogorov-Smirnov D statistics and below the diagonal, associated Critical D values. Values in red indicate P < 0.0083 (family wise P < 0.05).

A. Depth

Site	Road Sign	Dog House	Quarry	Maple Creek
Road Sign		0.307	0.307	0.307
Dog House	0.282		0.285	0.277
Quarry	0.276	0.310		0.351
Maple Creek	0.348	0.376	0.371	

B. Velocity

Site	Road Sign	Dog House	Quarry	Maple Creek
Road Sign		0.077	0.087	0.668
Dog House	0.282		0.087	0.701
Quarry	0.276	0.310		0.630
Maple Creek	0.348	0.376	0.371	

all other sites. Results of this analysis clearly show that site specific *edfs* can differ significantly between sites.

Steelhead Parr

Steelhead Parr *edfs* for depth and velocity were found to differ significantly between sites (Table 15). Between site differences were wide spread among the site-specific depth edfs, but were limited to differences between the RCMP site and the Dog House and Gallette Park sites for the velocity *edfs*. Like the steelhead fry, results of this analysis clearly show that site-specific *edfs* can differ significantly between sites.

Table 15. Summary of Kolmogorov-Smirnov tests used to assess between-site differences in steelhead parr depth (a) and velocity (b) edfs derived from pre-WUP (1999) data. Values above the diagonal are Kolmogorov-Smirnov D statistics and below the diagonal, associated Critical D values. Values in red indicate P < 0.0083 (family wise P < 0.05).

A. Depth

Site	Tag BM02	u/s RCMP	Dog House	Gallette Park
Tag BM02		0.462	0.329	0.588
u/s RCMP	0.411		0.449	0.127
Dog House	0.421	0.418		0.576
Gallette Park	0.362	0.359	0.370	

B. Velocity

Site	Tag BM02	u/s RCMP	Dog House	Gallette Park
Tag BM02		0.284	0.312	0.254
u/s RCMP	0.411		0.484	0.403
Dog House	0.421	0.418		0.162
Gallette Park	0.362	0.359	0.370	

Coho Fry

All site-specific depth *edfs* for Coho fry differed from one another (Table 16). All but two between site comparisons, that between the Tag 040 site and the Tag BM02 and Dog House sites. The depth and velocity *edf's* for coho fry were the most varied of the salmonid species tested, followed by the steelhead parr and fry *edf's*.

Table 16. Summary of Kolmogorov-Smirnov tests used to assess between-site differences in steelhead parr depth (a) and velocity (b) edfs derived from pre-WUP (1999) data. Values above the diagonal are Kolmogorov-Smirnov D statistics and below the diagonal, associated Critical D values. Values in red indicate P < 0.0083 (family wise P < 0.05).

A. Depth

Site	Tag BM02	Tag 040	Log Jam	Dog House
Tag BM02		0.325	0.547	0.574
Tag 040	0.186		0.455	0.576
Log Jam	0.198	0.232		0.898
Dog House	0.294	0.318	0.325	

B. Velocity

Site	Tag BM02	Tag 040	Log Jam	Dog House
Tag BM02		0.207	0.119	0.311
Tag 040	0.186		0.279	0.104
Log Jam	0.198	0.232		0.383
Dog House	0.294	0.318	0.325	

3.3.2 Day/Night Differences in Rearing Electivity functions

Steelhead Fry

During the day, steelhead fry (n = 50 and 43 for the 5.2 and 6.15 km sites respectively) tended to occupy a relatively narrow range of water depths spanning 0.15 to 0.60 m (Figure 26). At night however, this range broadened to include are far greater use of shallow water < 0.15 m. In addition, use of the daytime range of depths waned while occupancy of deeper habitats increased. This overall broadening or relaxation of preferred depths compared to day time conditions was statistically significant (Kolmogorov-Smirnov $D_{50,43}$ = 0.297, $D_{Crit,0.05}$ = 0.284, P < 0.05). In contrast, the selection of preferred velocities appeared to narrow at night compared to day time conditions. A Kolmogorov-Smirnov test revealed that these differences were not statistically significant (Kolmogorov-Smirnov $D_{50,43}$ = 0.221, $D_{Crit,0.05}$ = 0.284, P > 0.05). Thus, for steelhead fry, there were significant day/night differences in depth electivity, but not for velocity.

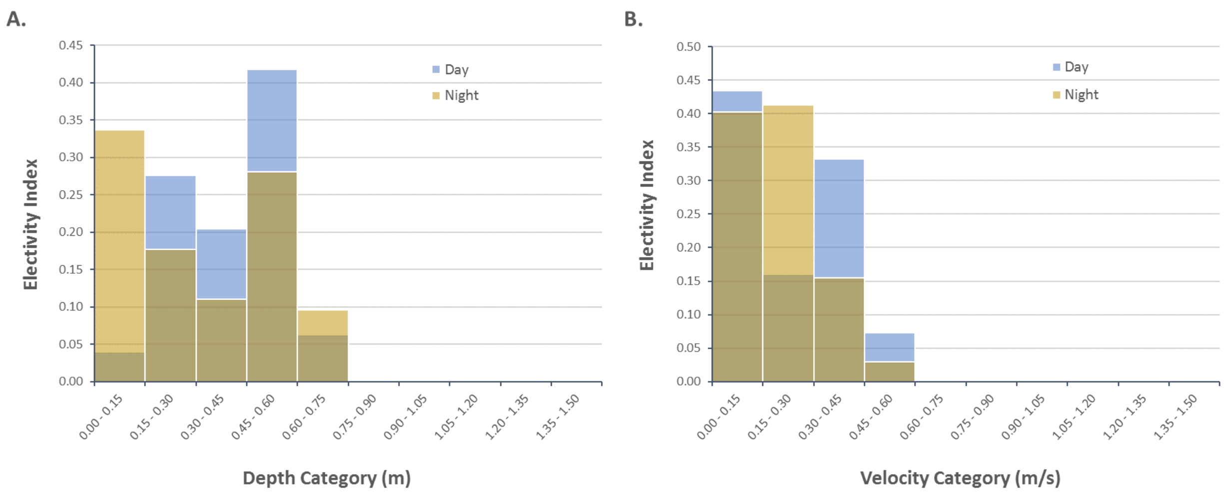


Figure 26. Day/Night comparison of depth and velocity edfs for steelhead fry based on habitat use and availability data collected in 2016.

The day/night shift in *edfs* for both depth and velocity observed in 2016 was opposite the expected response based on the pre-WUP and WUP *edfs* (Figures 16 and 17). Pre-WUP sampling occurred during the day, but the *edfs* for both depth and velocity were more closely matched with the night time response. Similarly, the WUP *edfs* were more closely matched to the day time response, despite the fact that data collection occurred at night. It would appear that the difference in pre-WUP and WUP steelhead fry *edf's* observed in Section 3.2.2 is not the result of day/night differences in habitat preference and that other factors may be involved.

Steelhead Parr

Although there are apparent day/night differences in the shapes of Steelhead parr depth and velocity *edfs* (Figure 27) , Kolmogorov-Smirnov tests revealed that these were not statistically significant (Kolmogorov-Smirnov $D_{19,35}$ = 0.282, $D_{Crit,0.05}$ = 0.387, P < 0.05 and Kolmogorov-Smirnov $D_{19,35}$ = 0.269, $D_{Crit,0.05}$ = 0.387, P < 0.05 respectively). It should be noted however, that like steelhead fry, night time

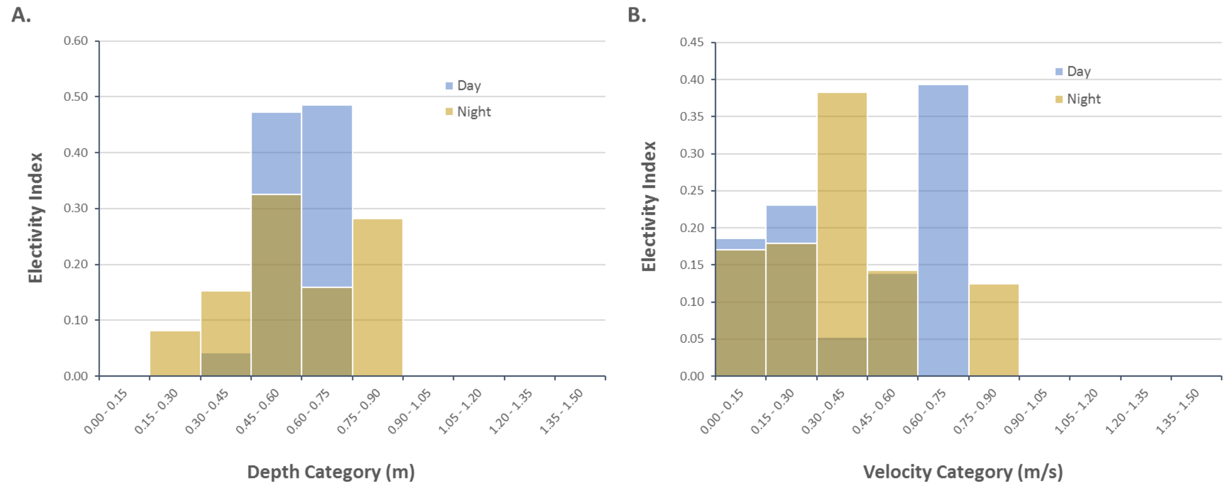


Figure 27. Day/Night comparison of depth and velocity edfs for Steelhead parr based on habitat use and availability data collected in 2016.

distribution of occupied depths appeared to broadened compared to day time. Low sample sizes however limited the power of the Kolmogorov-Smirnov test to identify the shift as being statistically significant.

The Day/Night *edf* patterns were unlike those seen during pre-WUP and WUP surveys (Figures 20 and 21), suggesting the day/night data may simply reflect another variation in *edfs* that are site, survey and/or time specific. It would appear that day/night differences in depth/velocity selection are not a factor explaining the pre-WUP and WUP differences in depth and velocity *edfs* seen in section 3.2.2.

Coho Fry

Day/night differences in both depth and velocity *edfs* of Coho fry appear to mirror that of steelhead fry (Figure 28). Day time depths ranged from 0.15m to 0.60 m and then broadened to include waters < 0.15 m as well as waters up 0.75 m deep. The shift was statistically significant (Kolmogorov-

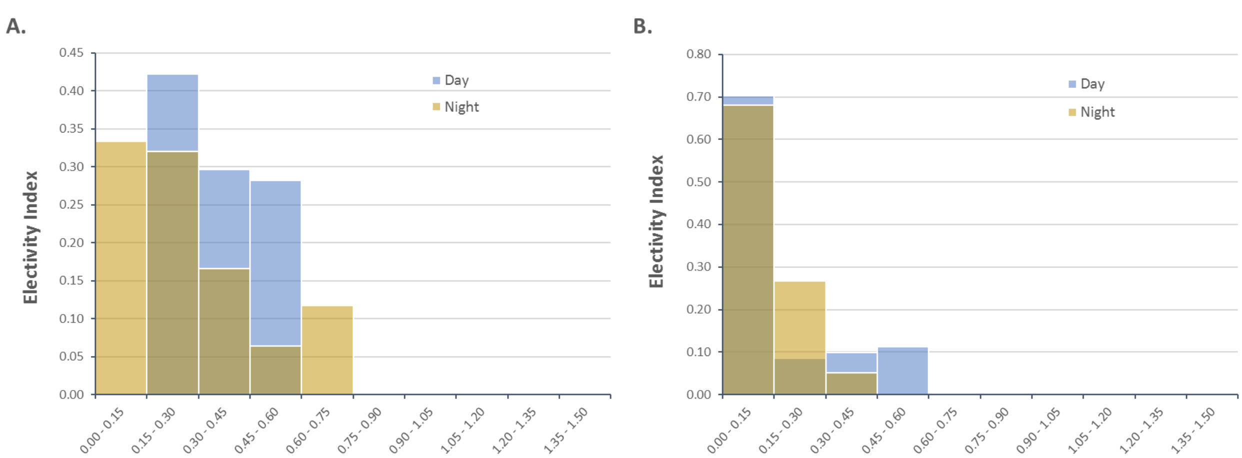


Figure 28. Day/Night comparison of depth and velocity edfs for Coho fry based on habitat use and availability data collected in 2016.

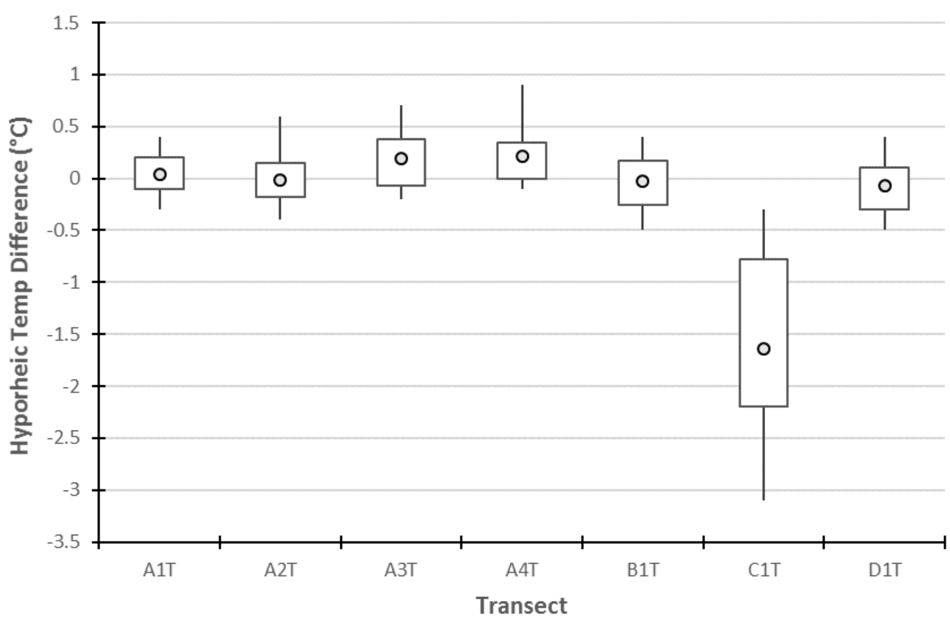
Smirnov $D_{51,58} = 0.333$, $D_{Crit,0.05} = 0.261$, $P < 0.05$). There was no significant day/night shift in velocity *edfs* (Kolmogorov-Smirnov $D_{51,58} = 0.161$, $D_{Crit,0.05} = 0.261$, $P < 0.05$).

The day/night response observed in the 2016 study did not appear to match the modal change in depth preferences seen when comparing pre-WUP and WUP *edfs* (Figures 24 and 25). In the former, there was a definite night time broadening or relaxation of depth preferences compared to daytime. In the pre/post WUP comparison, there appeared to be a shift in modal preferences where deep waters (mode = 0.90 to 1.05 m deep) were more commonly preferred pre-WUP (survey done during the day) and shallow waters (mode = 0.30 to 0.45 m) WUP (surveys done at night). In the case of velocity edfs, that was a stronger preference of slow velocities (< 0.15 m/s) pre-WUP that appeared to broaden or relax WUP to include velocities up 0.30 m/s. This was not the case for the day/night comparison. Although there are clear day/night shifts in habitat preference of Coho fry, this could not account for the differences in *edfs* seen between pre- and post WUP survey periods.

3.3.3 Upwelling effects on Chum Spawning Electivity Functions

Upwelling at known spawning areas.

Seven sites known for repeated and extensive spawning use among Chum Salmon were examined for differences between surface and hyporheic water temperatures (25-30 cm into the substrate) across transect lines. At most sites, this temperature difference fell within a ± 0.5 °C range centered about a 0°C average (Figure 29). At only one site did the temperature difference break this pattern, indicating a potential groundwater upwelling site. At this site, where surface temperatures averaged 15.8 °C, Hyporheic temperatures were between 0.3 and 3.1 °C cooler (average 1.6 °C cooler). It would appear that such deep upwelling areas do exist in the river, but seem to be relatively rare; at least in areas with suitable chum spawning habitat.



Upwelling at Chum Salmon redd sites.

Difference between surface and hyporheic water temperatures were examined in 222 Chum Salmon redd sites spread out across 11 sites (Appendix X). Data were collected on November 15, December 1 and December 8. When examining the temperature difference data, there appeared to be three distinct groups (Figure 30). The first were the early spawning on November 15 which appeared to have little temperature difference between the surface and hyporheic zones (range = -0.8 to 0.2 °C, mean = -0.3°C). Surface waters were generally still warm (mean = 9.2 °C) compared to the other sampling dates (mean = 5.2 °C) and on average hyporheic temperatures were 0.3 °C cooler.

The other distinct group were those redds with a high degree of warming relative to surface waters. These occurred at two sites, one identified in the earlier transect survey work (Site C1) and another at a newly sampled site (Site A3). At these redds, temperature differences ranged from 2.5 to 4.4 °C warmer than surface waters, and averaged 3.4 °C.

In both cases, only a portion of the redds had such large differences in temperature, some of the redds at these sites had temperature differences that were much cooler (Figure 30). These latter redds formed part of the largest group, where there was only a slight warming in the hyporheic zone temperatures compared to surface waters. In this latter group, hyporheic water temperatures ranged from 0.0 to 1.7 °C warmer than surface waters and were on average 0.8 °C warmer. This group comprised of the largest number of redds (175 or 79% of all redds) and was clearly the dominant redd condition. Only 11% of the redds sampled were warmed to a greater degree, while the remainder were

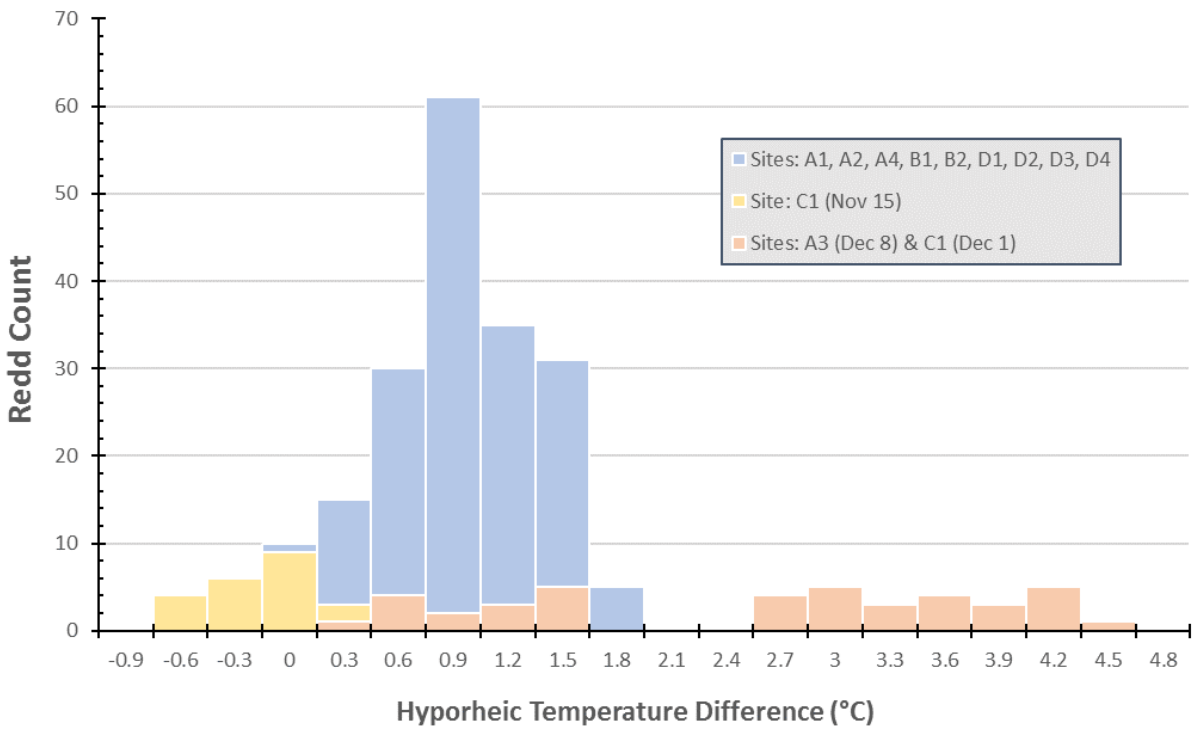


Figure 30. Distribution of hyporheic water temperature differences relative to surface waters recorded at 222 Chum Salmon redds. The data are grouped by survey locations that have to three distinct hyporheic temperature responses: modest warming (blue), slight cooling (yellow), and significant warming (red) conditions.

cooler due to the still relatively warm surface waters at the time of sampling. It is interesting to note that the warmest hyporheic zones did not occur on a single sampling date. Rather they were evenly split between the December 1 and December 8 sampling dates (13 and 12 redds respectively).

3.4 Comparison of HSI functions

3.4.1 Salmonid Spawners

Steelhead Trout

The stream-specific HSI function for depth did not match the generic function used for PUW modelling during the WUP process (Figure 31a). In shallow waters to a depth of 0.45 m, the HSI values matched well with one another, but for deeper waters, a significant divergence in preference occurred. Where the HSI function used during the WUP assigned a high preference (HSI = 1) for waters up to 1.05 m deep, the site-specific curves indicated an avoidance for such waters. In waters deeper than 1.05 m, the generic HSI function indicated an ambivalence to water depth (HSI = 0.5). The overall effect is that the area-under-the-curve (AUC) for stream-specific HSI functions was much smaller than in the generic functions. When the generic HSI function is substituted for the stream-specific cure, a downward shift in optimum discharge would be expected because of the high value placed on shallow water spawning habitats. The smaller AUC would cause the PUW to decrease at the optimum discharge. It should be stressed however, that the site-specific HSI function was developed using habitat use data only, and was uncorrected for habitat availability.

There was, however, a high degree of overlap between the stream-specific velocity HSI function and the generic function used for PUW modelling (Figure 31b). Curve shape appeared to be very similar, with the difference being largely a shift in preference for slightly lower velocities. This shift appears to be in the neighborhood of 0.15 m/s; one bin width. This would have a net effect of also shifting optimum discharge to a lower value, thought the extent of this shift would likely be small. Also of note is that the AUC for the stream-specific function was nearly identical to that of the generic function. As a result, no change in PUW would be expected at the optimum discharge. As with the depth HSI function, it should be stressed that the stream-specific function for velocity is uncorrected for habitat availability.

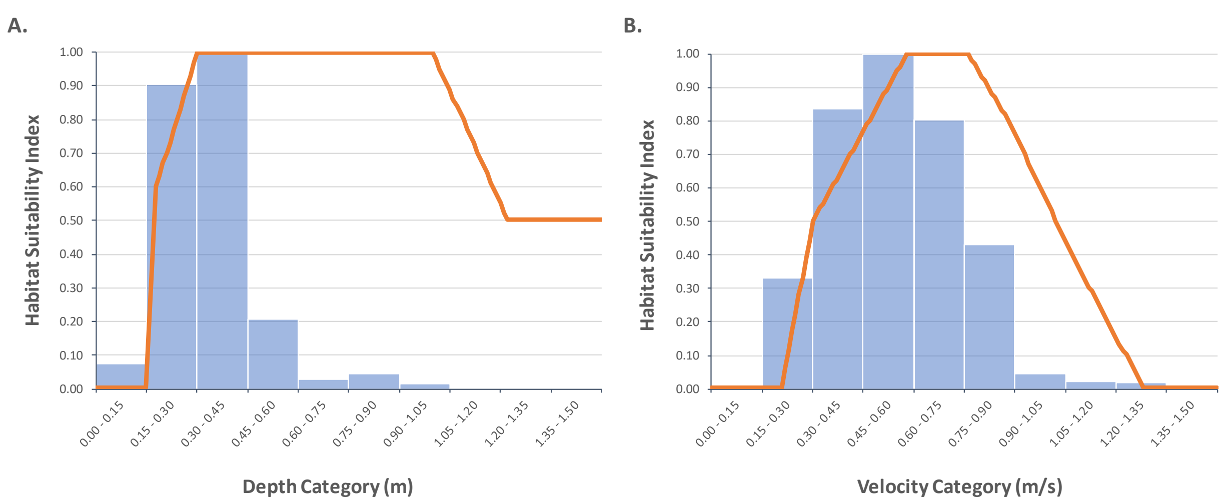


Figure 31. Comparison of generic (red line) and stream-specific (histogram) HSI functions describing depth and velocity preferences for Steelhead spawners.

Overall, the difference between generic and stream-specific HSI functions seem to indicate a preference among Coquitlam Steelhead spawners for shallower waters, but with similar, if not slightly slower, water velocities. Substituting the generic HSI functions for the stream-specific functions would likely lead to a downward shift in the optimum discharge yielding maximum spawning habitat. The extent of change is not clear, as the large difference in depth HSI functions would suggest a large downward shift, but the velocity HSI functions suggest a small change. Regardless, a lower optimum flow for maximum steelhead spawning habitat would be expected. The lower AUC for the stream-specific depth HSI function would likely result in a lower PUW value at the optimum discharge

Coho Salmon

There was very good agreement between generic HSI functions for Coho spawning depth and velocity preferences and the stream-specific functions derived here (Figure 32). The biggest disparity among depth HSI functions is the peak preference at the 0.45 to 0.60 m depth in the stream-specific function. This could simply be an artifact of limited sampling frequency and/or overcorrection. Otherwise the broad, relatively uniform preference for depths between 0.30 and 1.05 m match fairly well. Curve shape is also similar between the velocity HSI functions, though the preference for faster waters appears to be slightly stronger in the generic HSI function. This could also be a sampling artifact due to inadequate compensation for habitat availability constraints. Given the strong similarity, little difference in PUW modelling outcomes would be expected if the stream-specific HSI functions were used in place of the generic functions. This includes the PUW value at the optimum discharge as AUCs were similar as well, though slightly smaller for the velocity HSI function.

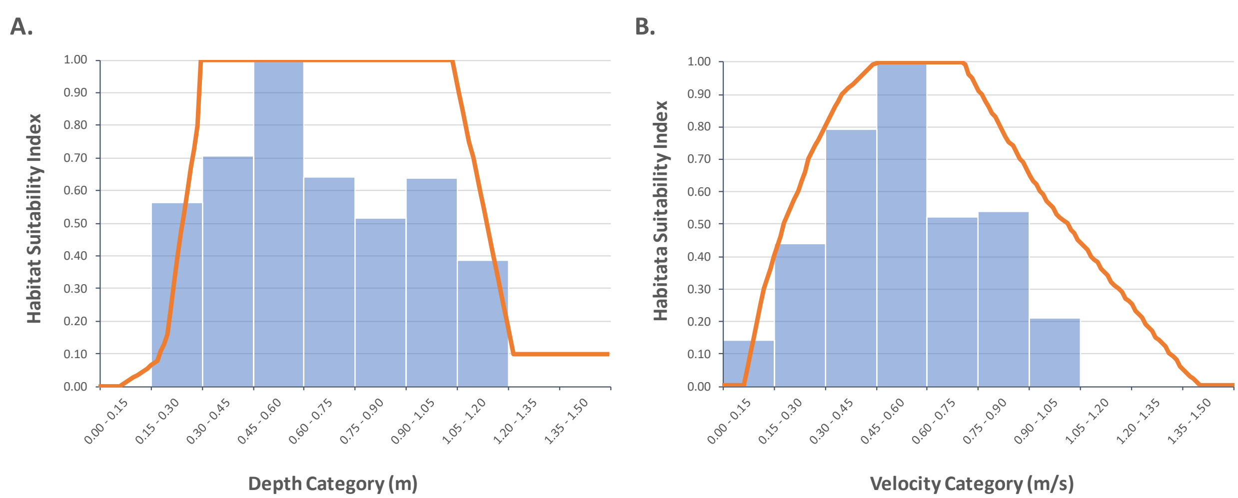


Figure 32. Comparison of generic (red line) and stream-specific (histogram) HSI functions describing depth and velocity preferences for Coho spawners.

Chum Salmon

The stream-specific HIS function for Chum spawner depth preference was a near prefect match for the generic curve, where the generic preference line intersected the middle of each bin of the stream-specific histogram (Figure 33a). Curve shape was also very similar between velocity HSI functions, but there appeared to be a shift in preference for slightly slower waters in the stream-specific function (Figure 33b). This downward shift corresponded to a single bin width, or about 0.15 m/s. This disparity could be the result of limited habitat availability that the electivity calculation was unable to fully account for.

Given the similarity in both depth and velocity HSI functions, little difference in PUW modelling outcomes would be expected if the functions were swapped. The overall preference for slightly slower velocity waters however, could potentially result in a slight downward shift in optimal discharge for chum spawning habitat. Whether this would be detectable in a PUW modelling exercise is uncertain, particularly in light of the potential for broad variance in PUW model residuals (see Figure 1 as example).

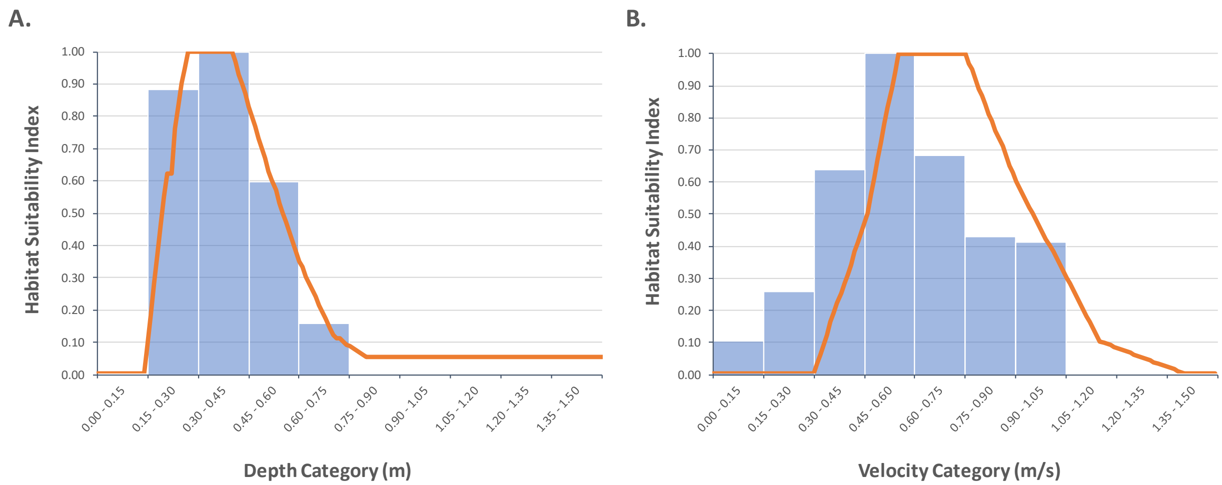


Figure 33. Comparison of generic (red line) and stream-specific (histogram) HSI functions describing depth and velocity preferences for Chum spawners.

3.4.2 Juvenile Salmonids

Steelhead Fry

The generic HSI function for preferred steelhead fry depth out placed far greater value on shallow waters (< 0.30 m) than is expressed in the stream-specific function (Figure 34a). Though pre-and post WUP stream-specific functions differed from one another, both shared a preferred range of depths that spanned 0.15 to 0.90 m with pre-WUP preferences extending out to 1.05 m. The generic curves undervalue these deeper waters, particularly in the depth range of 0.60 m to 1.05. Given that higher flows are required to generate deeper waters, use of the stream-specific curves, whether pre-WUP, WUP or combined, in PUW modelling would have the net effect of increasing optimum discharge needed to maximise steelhead fry rearing habitat. Given the disparity between generic and stream-specific curves, the shift had the potential to be large. Also, the area under the curve (AUC) of both stream specific functions, particularly when combined, are larger, which increases the breadth of preferable depths. This would have the effect of increasing modelled PUW at the optimum discharge.

Generic and stream-specific HSI functions for velocity are more closely matched, though the stream-specific function tends to put less value on velocities that are > 0.15 m/s, regardless if it was pre- or post WUP (Figure 34b). This would have the net effect of decreasing optimum discharge if swapped into the PUW model, as lower discharges would be required to create more slow water habitat. The effect however would be small given how closely matched the HSI functions are. More notable is the

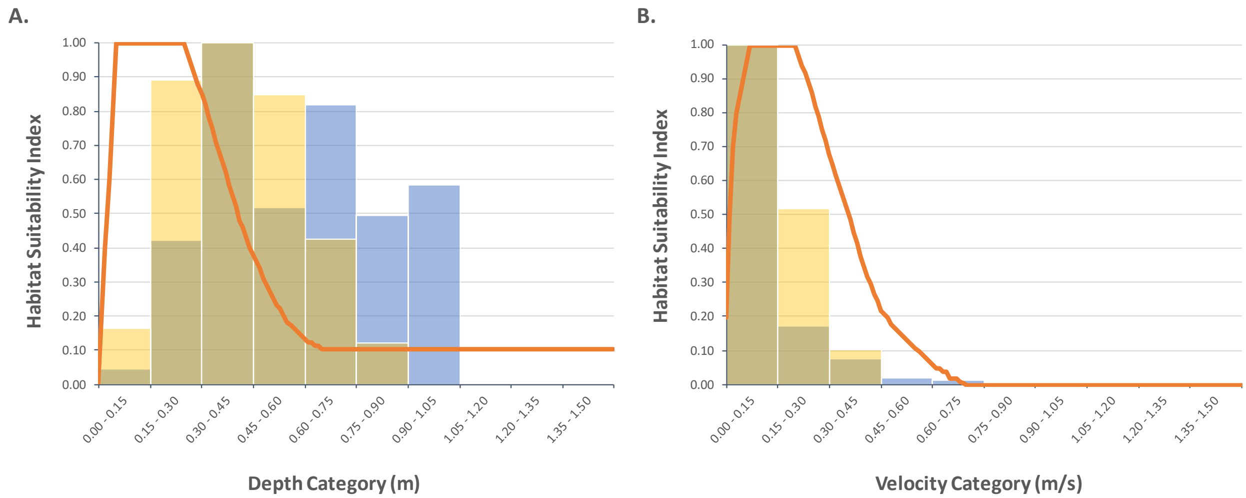


Figure 34. Comparison of generic (red line) and stream-specific (histogram) HSI functions describing depth and velocity preferences for Steelhead fry. The Pre-WUP HSI functions are in blue, WUP in gold.

fact that the change is opposite that expected from the depth HSI functions, thus tempering the upward shift in optimum flow. An upward shift in optimum discharge would nonetheless be expected given the disparity in depth HSI function. A smaller area under the curve would also result in a smaller PUW outcome at the optimum discharge.

Steelhead Parr

Although the generic depth HSI function for Steelhead parr overlapped the pre-WUP and WUP stream-specific functions, their shapes were so different that significant differences in PUW modelling comes are expected (Figure 35a). The generic curve tended to place high value (HSI > 0.80) on stream depths > 0.30 m which the stream-specific curves did not. Such high value did not occur until 0.75 m in the pre-WUP function, and 1.05 m in the WUP function. Substituting the generic HSI function for either of the stream-specific functions (or a combination of the two) would have the effect shifting the

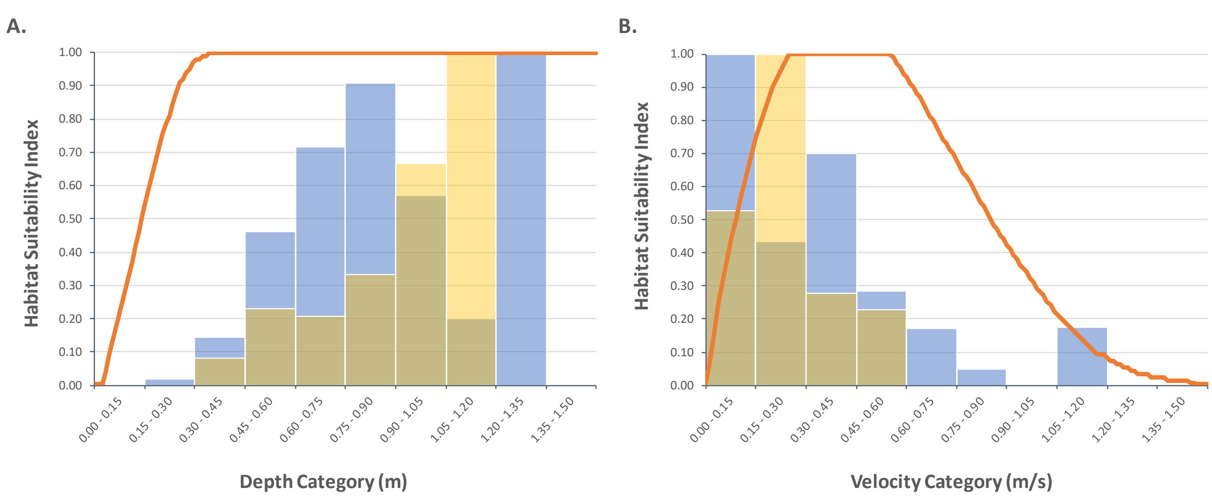


Figure 35. Comparison of generic (red line) and stream-specific (histogram) HSI functions describing depth and velocity preferences for Steelhead parr. The Pre-WUP HSI functions are in blue, WUP in gold.

optimum discharge toward higher flows. The smaller AUC of the stream-specific HSI functions would result in a lower PUW at the optimum discharge.

HSI function substitution would result in the opposite effect with the velocity variable. In this latter case, stream-specific preferred velocities occurred at much lower velocity categories than assigned in the generic function. In the pre-WUP function, peak preference (HSI = 1.0) occurs for velocities < 0.15 m/s, while post WUP, it occurred at velocities between 0.15 and 0.30 m/s. In the generic function, peak preference occurred at velocities between 0.25 and 0.60 m/s. This downward shift in peak preference compared to the generic function would have the net effect of lowering optimum discharge should the stream-specific HIS functions be used in PUW modelling. The shift would be greater if using the pre-WUP function than the WUP function. In both cases, the AUC for the stream-specific HIS functions are smaller than the generic function, resulting in a smaller PUW at the optimum discharge.

Together, it is unclear to what extent the stream-specific HSI curves would change optimum flow predictions, as the depth and velocity variables appear to have opposing effects. It is interesting to note that the AUC of the difference between the generic and combined stream-specific HSI functions are similar. If one were to assume that the rate of depth and velocity change as a function of discharge were similar, this would suggest that the effects would cancel each other out and result in no net change in optimum discharge. Whether this is the case or not can only be verified by PUW modelling. For assessment purposes however, a condition of no change in optimum discharge is be assumed. It should be noted however, that the smaller AUC of the stream-specific HSI functions would result in a smaller PUW at the optimum discharge

Coho fry

The three depth HSI functions for coho fry were very different from each other, each likely to yield a different PUW modelling result (Figure 36a). In the case of the generic function, peak HSI occurs at depths between 0.15 and 0.30 m and remains high for all depths to 1.5 m. For the WUP function, peak HSI occurs between 0.30 and 0.45 m, while for the pre-WUP function, the peak occurs between 0.90 and 1.05 m. As peak HSI shift towards deeper waters, potentially so does the PUW prediction of optimum discharge for maximum coho fry rearing habitat. The large AUC of the generic curves indicates a potential for high PUW values at the optimum discharge. The AUC for both stream-specific HSI functions are much smaller, so the shift in optimum discharge would also involve a drop in PUW at those discharges. Combining the pre- and WUP HIS functions would yield a flat topped HSI function that would have a peak preference (HSI → 1) that is relatively uniform from 0.30 to 1.05 m. This box-like HSI function would still result in an upward shift in optimum discharge, but at a value in between the pre-WUP and WUP functions. The AUC would also be larger, leading to an increase in PUW at the optimum discharge relative to the individual pre-WUP and WUP functions. Regardless of whether the pre-WUP and WUP functions are used individually or are combined, the resulting stream-specific HSI function would result in a higher optimum discharge when substituted in for the generic HSI function when modelling PUW. The shift in PUW would also be accompanied with a drop in PUW at the optimum discharge.

In contrast to the depth HSI functions, there was reasonably good agreement among all three velocity HSI functions, even though the pre-WUP and WUP HSI functions were statistically different. Because of the high degree of similarity, no difference in PUW modelling outcome would be expected

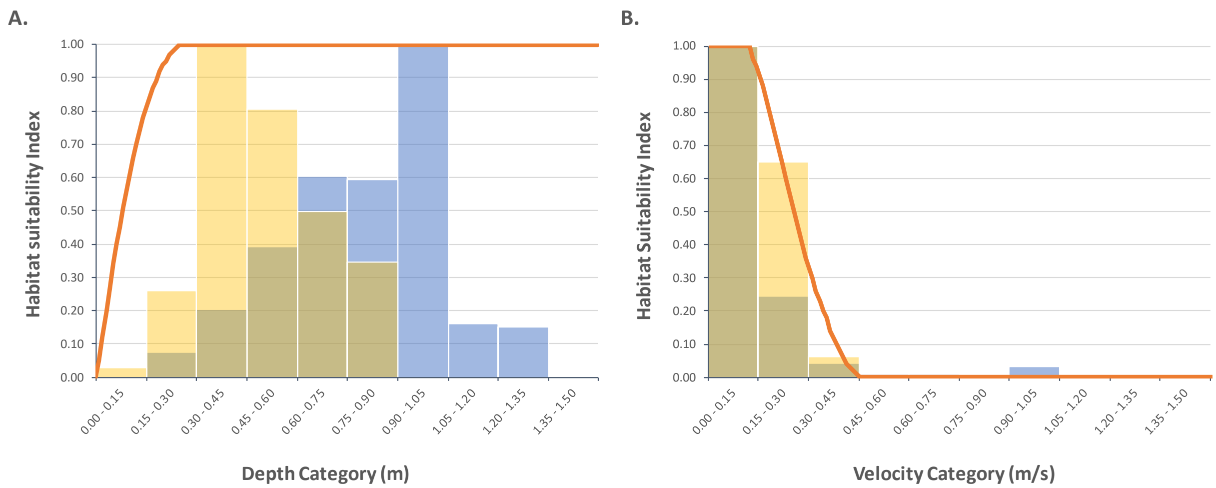


Figure 36. Comparison of generic (red line) and stream-specific (histogram) HSI functions describing depth and velocity preferences for Coho fry. The Pre-WUP HSI functions are in blue, WUP in gold.

when substituting the generic HSI function for either stream-specific function. The WUP HSI function was the most similar to the generic function. This similarity in HSI function, irrespective of which stream-specific curve is used, would have the effect of tempering any change in modelled PUW outcomes when combined with the depth HSI function. The extent of this tempering effect however can only be determined by PUW modelling. For the purposes of this study, an increase in optimum discharge for maximum coho fry rearing habitat is considered likely, albeit a small increase.

4 Discussion

4.1 General Discussion

Although the procedure to develop *edfs*, and hence HSI functions, from habitat use and availability data is a rather simple one, in practice there were many complicating factors. With respect to the procedure itself, the risk of over correction at the tails of habitat-use and/or habitat availability distribution functions is the most commonly cited one (Bovee 1982, 1986, Payne and Allen 2009). In the present study, over correction appeared to be well controlled in most cases. This was accomplished by the use of histograms rather than continuous density functions (BC Hydro 2003b) and appropriate selection of bin width (Wand 1997). The exception to this appears to be that of Steelhead parr, where habitat use sample sizes tended to be low and the potential range of occupied depth and velocity conditions were relatively broad. In fact, low sample sizes for both habitat use and availability data were problematic for all species and age classes with the possible exception of Coho fry and Chum Salmon spawners. This often lead to low power Kolmogorov-Smirnov comparisons as indicated by high D_{Crit} values for hypothesis testing. In the present study, Kolmogorov-Smirnov tests with D_{Crit} values > 0.5 were excluded from the analyses to limit the inclusion of such low power comparisons. In some instances, the pooling of data helped bolster sample sizes, allowing some of these low power tests to proceed. Nevertheless, with these control measures in place, we were able to address the impact hypotheses and management questions with reasonable confidence.

The inability to model the PUW outcomes when comparing the consequence of using the stream-specific HSI functions developed here instead of the generic HSI functions used during the WUP process limited the assessment to a qualitative analysis. Though useful information was obtained, such as the direction of optimum flow change and subjective assessment of habitat loss or gain, the magnitude of change, slope of the rising and falling limbs on either side of the optimum flow, and range of PUW model residuals (an indicator of model precision and accuracy) could not be quantitatively assessed. Should greater quantitative detail be required from this assessment of stream-specific HSI functions, it is recommended that the PUW model developed during the WUP (or a model similar to it) be reconstructed so that such quantitative assessment can be carried out.

There were very clear between-site differences in the HSI functions of all rearing juvenile salmonids, suggesting that factors other than depth and velocity may be influencing habitat selection. These may include proximity of cover, availability of food items, presence of predators, presence of other competitive species (for space and or food), and intra-species interactions such as territoriality and schooling behaviors (Bovee 1986, Bjornn and Reisser 1991, Korman et al. 1994, and Young 2004). Localised differences in all of these factors likely made some contribution to the between-site differences in occupied depth and velocities.

In this study, day/night differences in habitat selection were specifically tested. Earlier monitoring work noted strong diel patterns in habitat selection that made the capture of juvenile salmonids easier and more effective at night compared to the daytime (Schick et. al 2015). The habitat selection data showed that for all species, there was a tendency for the range of preferred depths to broaden at night compared to daytime surveys, in particular for Steelhead and Coho fry. There were no changes in velocity preferences. This 'relaxation' of preferred depths can explain the diel difference in juvenile capture efficiency observed by Schick et. al (2015). However, it cannot explain the differences in stream-specific HSI functions between pre-WUP and WUP implementation surveys. The pre-WUP surveys were conducted during the day, while the WUP surveys were done at night. It was thought that the difference could be attributed to day/night difference in behaviour, but the data showed that this was not the case. The *edf* patterns of pre-WUP and WUP surveys were unlike that seen between the day/night surveys.

Given that that flow releases from Coquitlam dam are greater during the WUP implementation period (See Table 2), it was hypothesised that that the change could alter habitat preference behaviours. Stream-specific HSI functions did indeed differ between pre-WUP and WUP survey time periods. However, whether this can be attributed to a change in discharge could not be directly tested. This was not a factor that was controlled in the study design. Habitat selection data were collected in multiple years during the WUP, each with different stream discharges at the time of survey. In all cases, depth and/or velocity HSI functions differed significantly between study years, indicating that, by association, there could have been a discharge related effect. However, different sites were sampled each year, and given how HSI functions vary between sites, it is not possible to be conclusive about the role of discharge in shaping habitat preferences. By extension, it is not possible to attribute differences in pre-WUP and WUP stream-specific HSI function to a WUP treatment effect.

With exception of Chum Salmon spawners and possibly rearing Coho fry, the stream-specific HSI functions were very different from the generic functions used during the development of the WUP. By convention, empirically derived, stream-specific HSI functions are considered to be more accurate in describing flow habitat relationships than generic curves (Bovee 1982, 1986). This was indeed the case in one of the few published studies that compared the predictive capabilities of generic vs empirically derived HSI functions (McHugh and Budy, 2004). They found that the stream-specific functions describing the habitat needs of Chinook salmon spawners tended to outperform generic relationships in predicting the locations of Chinook redds. In this study however, there was little control of confounding factors when collecting habitat selection data. Furthermore, sample sizes were small in many cases. It is uncertain to what extent the stream-specific HSI functions are more accurate reflections of Coquitlam River, fish habitat preferences. More study is required with much greater control of confounding factors.

The stream-specific HSI functions for coho and chum salmon spawners tended to be in good agreement with generic curves. This however, was not the case for Steelhead spawners. There reason for this is unclear. It may indeed reflect the habitat preferences of Coquitlam River Steelhead, but low sample sizes and inability to correct for habitat availability adds considerable uncertainty to this conclusion. Further complicating matters, the differences in depth and velocity HSI functions appear to cancel each other out, potentially resulting in no net change in PUW when the stream-specific HSI functions are used in the calculation. Clear more study is required.

It has been hypothesised that that Chum Salmon, and possibly other salmonid species (McHugh and Budy, 2004), may be attracted to groundwater upwelling sites when selecting areas to spawn (Mouw et al. 2014). Tonina and Buffington (2009) identify two forms upwelling that appear to affect egg pocket hydrology. The first of these is bedrock driven where the upwelling occurs by variation in the bedrock configuration deep within a stream bed (deep upwelling). The other is induced by redd formation, which encourages both downwelling and upwelling flows. In the present study, we were able to identify that there are some areas of deep upwelling identified by large water temperature differences between surface and hyporheic zones. These however were not common place as only one of the 7 well established chum spawning sites demonstrated this kind of upwelling. This was confirmed when water temperatures were measured at specific redd sites. Only 11% of the redds appeared to involve deep groundwater upwelling where there was a large difference between egg pocket and surface water temperatures. The vast majority of these redds (79%) had much more modest temperatures that were indicative of more localized, redd inducted, hyporheic flows. In the latter case, upstream areas of downwelling, forces water into the egg pocket where it potentially mixes with deeper, warmer ground water flows, resulting in modest temperature rises. Given that temperature differences were mostly redd induced rather than in place at the time of redd site construction, it would seem that groundwater upwelling is not a major factor in redd site selection among Coquitlam R. Chum spawners. This may simply be due to the paucity of deep upwelling sites. Given the consistency in Chum salmon redd depth and velocity preferences between study years, as well as with the generic HSI functions, it would appear that ground water upwelling is not a strong confounding factor in redd site selection.

These outcomes are used to address the following impact hypotheses and the study's overarching management question.

4.2 Impact Hypotheses

This study was designed to address two null impact hypotheses proposed by the CC, as well as three null impact hypotheses that were derived through the implementation of other monitoring studies, including the present one. These are addressed individually below.

H_01: *Habitat requirements observed during WUP implementation (Test Flow Regime 2) do not differ significantly from those used in pre-WUP habitat modeling.*

There are two aspects to this null hypothesis. The first is with respect to habitat selection preferences between pre-WUP and WUP surveys, which can only be addressed with the rearing salmonid data. Analysis of these data found there were significant differences in pre-WUP and WUP *edfs* in all cases for both the depth and velocity variables. The reason for these differences was unclear, though significant between-site, sample year (potentially including discharge) and day/night differences were observed. Though from this perspective H_01 can be rejected, it is uncertain whether this can be directly attributed to a WUP implementation, treatment effect.

The other aspect to this hypothesis is whether there were differences between the empirically-derived, stream specific HSI and the generic HSI functions that were used for PUW modeling during the WUP process. Results from this perspective are mixed. Differences were found for both the depth and velocity HSI functions of Steelhead spawners, but not for Coho or Chum spawners. There was in fact a high degree of correspondence between the two sets of HSI functions in the latter two species. Thus, for the salmonid spawners, H_01 can be rejected for steelhead trout, but not for Coho or Chum spawners. There was insufficient data to evaluate differences for Chinook salmon.

Among the rearing juvenile salmonids, there were significant pre-WUP and WUP implementation differences in depth and velocity HSI functions for all species, though the differences were not as apparent for the velocity HIS functions. Regardless, H_01 can be rejected for Steelhead fry, Steelhead par and Coho fry. Among the steelhead and coho fry, there was a general preference for deeper and slower waters than is portrayed in the generic HSI functions. Steelhead parr tended to avoid the shallow waters that were considered preferable according to the generic HIS functions, and also appeared to prefer slower water velocities.

H_02: *Habitat targets are not achieved by flows different than those defined in the Coquitlam-Buntzen Water Use Plan.*

The potential consequence of using stream-specific HSI functions in place of the generic curves used in the WUP when calculating PUW, are summarized in Table 17. It is important to note that there were insufficient Chinook spawning data to evaluate the spawning habitat requirements as described in the WUP (BC Hydro 2006). Instead, as indicated in the study terms of reference (BC Hydro 2003a), Coho and Chum spawning habitat requirements were used as surrogates. Flow targets related to salmon spawning and juvenile salmonid rearing would not likely change as result of adopting the stream-specific HSI functions developed here. This is because optimum flows are likely to experience little change. This does not apply to Steelhead spawning, which our study shows would likely lead to a lower optimum flow calculation. However, because the flow target is already well below optimum, this would mean a greater amount of available spawning habitat for steelhead trout than is expected with the existing flow target. There is considerable uncertainty associated with the Steelhead stream-specific HIS function, so any changes in Steelhead spawning flow targets should be considered with caution.

Table 17. Summary of likely consequence of substituting stream-specific HSI functions into the PUW calculations that lead to the flow targets set by the CC using generic HSI functions.

Month	WUP (m^3/s)		Species Driver[1]	WUP Optimum (m^3/s)	Species Specific Optimum
	Target	Minimum			
January 1 - 14	5.9	3.6	CM/CO Spawning	11.7/10.9	little to no change
January 15- 31	2.9	2.9	Incubation	N/A	-
February	2.9	1.8	Incubation	N/A	-
March	4.3	1.1	SH Spawning	11.7	likely lower optimum
April	3.5	1.1	SH Spawning	11.7	likely lower optimum
May	2.9	1.1	SH Spawning	11.7	likely lower optimum
June	1.1	1.1	SH Parr Rearing	4.4	little to no change
July	1.2	1.1	SH Parr Rearing	4.4	little to no change
August	2.7	1.1	SH Parr Rearing	4.4	little to no change
September	2.2	1.1	SH Parr Rearing	4.4	little to no change
October	6.1	3.6	CH/CO Spawning	11.7/10.9	little to no change
November	4.0	1.5	CH/CO Spawning	11.7/10.9	little to no change
December	5.0	2.5	CH/CO Spawning	11.7/10.9	little to no change

[1] As per the study terms of reference, Chum (CM) and Coho (CO) serve as surrogates for Chinook spawning

Given that there is no change in optimum flows for salmon spawners and juvenile rearing salmon, and the potential for greater available spawning habitat for steelhead trout, $H_0$2 cannot be rejected

$H_0$3: *Expression of habitat preferences in indicator juvenile salmonid species are not affected by differences in stream flows.*

This hypothesis could not be evaluated directly. However, discharge at the time of survey did differ significantly between study years. Significant between-year differences in *edfs* were encountered in all rearing salmonid species for one or both of the depth and velocity variables. Thus, by association, it is possible that some of the *edfs* differences could be a function of discharge related effects. Because such differences could not be ruled out, $H_0$3 remains unresolved.

$H_0$4: *Expression of habitat preferences in indicator salmonid species and life stages are not significantly different between study years.*

Direct test of this hypothesis showed that $H_0$4 can be rejected for all juvenile rearing salmonids.

$H_0$5: *Expression of habitat preferences in indicator juvenile salmonid species are not significantly different between day and night.*

Direct test of this hypothesis showed that $H_0$5 can be rejected for all juvenile rearing salmonids.

$H_0$6: *Expression of habitat preferences in Chum spawners are not confounded by the upwelling of "deep" ground water.*

Direct test of this hypothesis showed that $H_0$6 can be rejected for all spawning Chum Salmon.

4.3 Management Question

The overarching gaol of this study was to address the following monitoring question:

Do habitat requirements for the fish species of interest observed during the monitoring program differ from those integrated into the habitat modeling conducted during the WUP?

Answer to this management question depends on the species and life stage being address. This is summarised in Table 18. It should be noted that the changes shown in Table 18 do not necessarily imply a change in habitat flow targets (see Table 18).

Table 18. Summary of likely optimum flow changes resulting from use of stream-specific HSI function in PUW calculations instead of the generic function used in during the WUP process.

Species of interest	WUP Optimum Discharge (m^3/s)	Change in m^3/s with Stream-Specific HIS				
		Likely Lower	Possibly Lower	No Change	Possibly Higher	Likely higher
Spawning						
Chinook Salmon	18.3			Insufficient Data		
Steelhead Trout	11.7	✓				
Coho Salmon	11.7			✓		
Chum Salmon	10.9			✓		
Rearing						
Steelhead Fry	1.6				✓	
Steelhead Parr	4.4			✓		
Coho Fry	1.6				✓	

With respect to spawning habitat requirements, no change in optimum flow predictions are expected when substituting the generic HSI curves used in the PUW modeling with stream-specific HSI. The possible exception is with Steelhead trout, which is likely lower, indicating that they may have more suitable spawning habitat than expected. This outcome is unlikely to change the trade-off of values made by the CC when deriving the WUP spawning flow targets for Lower Coquitlam River (Tables 2 and 17).

Summer rearing flow targets were derived by the CC using Steelhead parr as the key indicator species as these fish tend to occupy deeper, faster water than either Steelhead or Coho fry. No change in predicted optimum flow is expected when the generic HSI curves used in the PUW modeling are substituted for the stream-specific HSI. Thus, the substitution is unlikely to change the trade-off of values made by the CC when deriving the WUP rearing flow targets for Lower Coquitlam River (Tables 2 and 17).

5 Conclusions

This study was able to successfully address the management question despite the fact at the habitat flow model developed during the WUP process was no longer available. Answer to the management question is summarised in Table 18. The consequence of this outcome on the schedule of flow targets developed by the CC and implemented sing 2007 are summarised in Table 17. Overall, the outcome of this study did not produce results that would cause a serious consideration of changes to the schedule and magnitude of flow targets. It should be stressed that study results are subjective in nature. If more quantitative outcomes are required, a habitat model would have to be constructed to model the consequence of using each of the HSI functions in PUW calculations.

We were also able to address all impact hypotheses. These are summarised in Table 19.

Table 19. Summary of impact hypothesis results

Impact Hypothesis	Description	Outcome
$H_0 1$	*Habitat requirements observed post-WUP implementation (Test Flow Regime 2) do not differ significantly from those used in WUP habitat modeling.*	Rejected
$H_0 2$	*Habitat targets are not achieved by flows different than those defined in the Coquitlam-Buntzen Water Use Plan.*	Accepted
$H_0 3$	*Expression of habitat preferences in indicator juvenile salmonid species are not affected by differences in stream flows.*	Unresolved
$H_0 4$	*Expression of habitat preferences in indicator salmonid species and life stages are not significantly different between study years.*	Rejected
$H_0 5$	*Expression of habitat preferences in indicator juvenile salmonid species are not significantly different between day and night.*	Rejected
$H_0 6$	*Expression of habitat preferences in Chum spawners are not confounded by the upwelling of "deep" ground water.*	Rejected

6 References

BC Hydro. 2003a. Coquitlam-Buntzen Project Water Use Plan Consultative Committee Report.

BC Hydro. 2003b. Lower Coquitlam River 2003 Interim Instream Flow Needs Assessment. Prepared by A. Leake, BC Hydro Generation Environment. Fisheries Technical Report No. 03LB1-WUP-01. 32 p + App.

BC Hydro. 2005. Coquitlam-Buntzen Project Water Use Plan: Monitoring Program Terms of Reference COQMON#3 – Lower Coquitlam River Fish Habitat Requirements Study. December 14, 2006. 20p.

BC Hydro. 2006. Coquitlam-Buntzen Project Water Use Plan. Revised for Acceptance by the Comptroller of Water Rights. April 7, 2005. 15p. + App.

Bovee, K.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper #12, FWS/OBS-82/26. Washington, DC: USDI Fish and Wildlife Service. 248 p.

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology. Instream Flow Information Paper 21. United States Fish and Wildlife Service, Biological Report 86(7). 235pp

Bjornn, T.C., and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication 19: 83-138.

Gail, M.H. and S.B. Green. 1976. Critical Values for the One-Sided Two-Sample Kolmogorov-Smirnov Statistic. J. of the Amer. Stat. Ass. 71: 757 -760

Hochberg, Y and A.C. Tamhane. 1987. Multiple Comparison Procedures. Wiley: New York, NY. 450 p.

Korman. J., C.J. Perrin and T. Lekstrom. 1994. A Guide for the Selection of Standard Methods for Quantifying Sportfish Habitat Capability and Suitability in Streams and Lakes of British Columbia. Report prepared by Limnotek Research and Development Inc. Vancouver, B.C. for B.C. Environment, Fisheries Branch, Research and Development Section, Vancouver, B.C. 87 pages and appendices.

Krausman, P.R. 1999. Some basic Principles of Habitat Use. In “Grazing Behavior of Livestock and Wildlife.” 1999. Idaho Forest, Wildlife & Range Exp. Sta. Bull. #70, Univ. of Idaho, Moscow, ID. Editors: K.L. Launchbaugh, K.D. Sanders, J.C. Mosley. p 85-90.

Lele, S.R., E.H. Merrill, J. Keim and M.S. Boyce. 2013. Selection, use, choice and occupancy: clarifying concepts in resource selection studies. Journal of Animal Ecology 82: 1183–1191

McHugh, P and P. Budy. 2004. Patterns of Spawning Habitat Selection and Suitability for Two Populations of Spring Chinook Salmon, with an Evaluation of Generic versus Site-Specific Suitability Criteria. Trans. Am Fish. Soc. 133: 89-97.

Meow, J.E.B, T.H. Tappenbeck and J.A. Stanford. 2014. Spawning tactics of summer chum salmon Oncorhynchus keta in relation to channel complexity and hyporheic exchange. Environmental Biology of Fishes. 97: 1095-1107.

Payne, T.R. and M.A. Allen. 2009. Application of the Use-To-Availability Electivity Ratio for Developing Habitat Suitability Criteria in PHABSIM Instream Flow Studies. Proceedings of the 7th International Symposium on Ecohydraulics, Concepción (Chile). 2009.

Ptolemy, R. and S. McAdam (MWLAP), 2001. Personal communication. Generic Habitat Suitability Index (HIS) curves provided for percent usable width (PUW) modelling on the Coquitlam River

Schick, J., J. Macnair and G. Lewis. 2015. Coquitlam River Fish Monitoring Program: 2000-2014 Results (COQMON #7). Report prepared for BC Hydro Water Use Planning. July 2015. 74 p + App.

Young, K.A. 2004. Asymmetric Competition, Habitat Selection, and Niche Overlap in Juvenile Salmonids. Ecology. 85: 134-149.

Wand, M.P. 1997. Data-based choice of histogram bin width. American Statistician 51: 59-64

7 Appendices

Appendix A

Map of study sites for Post WUP Implementation studies. Site locations for pre-WUP study work related to HSI function development are unavailable.