Columbia River Project Water Use Plan

Middle Columbia River Juvenile Habitat Use Assessment

Reference: CLBMON-17

Development of Habitat Suitability Indices

Study Period: 2017-2019

Ecofish Research Ltd. and Poisson Consulting Ltd.

September 16, 2019

CLBMON-17 Middle Columbia River Juvenile Fish Habitat Use Assessment

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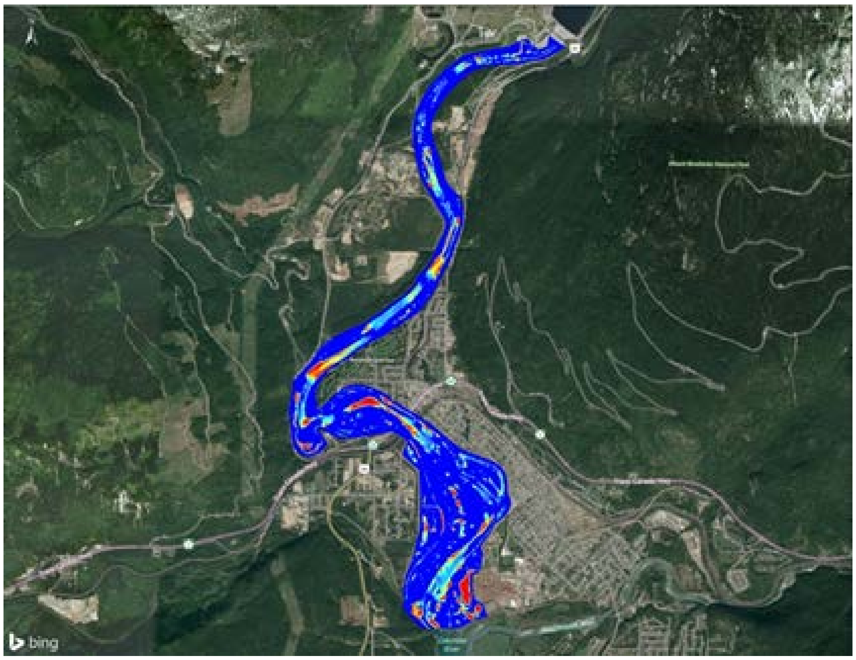

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September 16, 2019

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Published by Ecofish Research Ltd., Suite 202, 13 – 14th Avenue S, Cranbrook, BC, V1C 2W9

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Citation:

Healey, K., K. Akaoka, A. Harwood, and J. Thorley. 2019. CLBMON-17 Middle Columbia River Juvenile Fish Habitat Use Assessment. Development of Habitat Suitability Indices. Consultant's report prepared for BC Hydro by Ecofish Research Ltd and Poisson Consulting Ltd, September 16, 2019.

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EXECUTIVE SUMMARY

Fish and fish habitat data collected in Middle Columbia River (MCR) between 2008-2013 (Slivinski and Sykes 2014) were examined to develop habitat suitability indices (HSI) for key species and life stages. Data pre-processing included the separation of fish into different life stages and removal of erroneous data. There were sufficient data to develop HSI for Bull Trout juveniles, Mountain Whitefish fry, Mountain Whitefish juveniles, Rainbow Trout juveniles, Prickly Sculpin juveniles, and Redside Shiner juveniles. Depth, velocity, and substrate frequency distributions were estimated for each survey and weighted by the number of fish (within each species and age class) observed within the survey to develop habitat availability and use curves. This information was overlain with provincially recommended HSI to derive HSI for application in MCR.

The HSI were used to quantify flow-related changes in habitat associated with the addition of Revelstoke Dam's 5th generation unit (the post-Rev5 flow regime or new flow regime). Hydrometric data for the MCR were examined to characterize flow and water level conditions pre- and post-Rev5 during key periods for the study fish species (overwintering, fry emergence, summer and fall rearing). Five representative flow conditions, corresponding to typical seasonal base and peak flow conditions, were submitted to BC Hydro for 2-dimensional hydraulic modelling at high and low water levels in Arrow Lakes Reservoir (ALR). HSI for MCR were validated by applying the depth and velocity HSI to the hydraulic model output, calculating habitat suitability, and comparing predicted habitat suitability with fish observations under comparable environmental conditions (Rev discharge 296 m^3/s, ALR level 437.1 m). Weighted usable area (WUA) was calculated using the HSI for each hydraulic simulation. Changes in habitat quantity caused by the change in flow regime (Rev5) were calculated by characterizing typical base and peak flows for each season pre- and post-Rev5, and retrieving the corresponding WUA for each species and life stage. This analysis was completed for high and low water levels in ALR.

In general, the HSI modelling predicts that habitat suitability for juvenile fish is reduced post-Rev5 at both base flow and peak flow conditions, except during spring and fall, when peak flow conditions remain relatively unchanged from pre-Rev5 values (Table 1). Differences between base and peak flow conditions (i.e., daily habitat changes due to hydropeaking) are less under the post-Rev5 flow regime due to the increased base flow post-Rev5. The reduced availability of preferred habitats under the new flow regime reflects the preference for shallow, low velocity habitat by juvenile fish in the MCR. Such preferences for shallow, low velocity habitat have also been demonstrated for juvenile fish in other large river systems in the Pacific Northwest, both regulated and unregulated.

During analysis, a number of biases toward low water velocity and water depths were identified, reflective of the along-shore sampling design. These biases have been addressed to the extent possible but may still be present and reflected in the WUA results. In general, juvenile habitat quantities are predicted to be greatest at the lowest flow condition, 8.5 m^3/s, and reduced under the post-Rev5 flow regime.

These reductions in habitat quantity may be expected to result in a reduction in recruitment of juveniles to mainstem rearing habitats. However, previous studies have found weak or non-existent correlations between WUA and fish density or biomass (e.g., Conder and Annear 1987, Bradford *et al.* 2011) indicating that a reduction in WUA may not necessarily result in reduced productivity.

To assess effects of the new flow regime on juvenile recruitment, other factors in addition to habitat quantity should be considered, including: changes in wetted area, changes in productivity, changes in adult abundance, spawning and incubation success, and changes in growth, condition and survival of juveniles under the new flow regime (Table 1). To this end, we recommend that the results presented here be integrated with those from two other monitoring programs, Ecological Productivity Monitoring CLBMON-15B and Fish Population Indexing Surveys CLBMON-16, to evaluate the effects of the new flow regime, and to recommend long-term operational requirements for Revelstoke Dam. In this manner, changes to juvenile habitat suitability can be considered in the context of long-term trends in ecological productivity and abundance and condition of juvenile fish.

We consider the HSI developed in this report to be the most reasonable representation of juvenile habitat preferences in the study reach. We therefore recommend that future assessments of potential alternative flow regimes in the MCR adopt the juvenile HSI derived herein, and evaluate the expected changes to juvenile habitat in conjunction with projected changes to adult fish habitat and ecological productivity under alternative flow regimes.

To test the sensitivity of predicted habitat change results to the use of different HSI when assessing alternative flow regimes, habitat modelling could be completed using other HSI. This is particularly important when considering species and life stages where the MCR juvenile HSI developed herein resulted in significant changes from existing HSI. In such cases, a comparison of the results using the MCR juvenile HSI compared to other relevant HSI may be insightful when making management decisions. However, any such evaluation would need to consider the limitations and biases in developing the MCR HSI as well as those associated with development of the other HSI modelled.

Table 1. CLBMON-17 status of relevant Management Questions following the conclusion of this study.

Objectives	Management Questions	Conclusions
To assess the effects of the implementation of the 142 m^3/s minimum flow and Rev5 on the recruitment of juvenile life stages of fishes of the Middle Columbia River	Do operational strategies for Revelstoke Dam and Arrow Lake Reservoir impact the availability of preferred habitats?	The comparison of juvenile fish habitat quantity under different operational flow scenarios suggests that the implementation of the new flow regime has affected the quantity of preferred habitats for juvenile fish. Under base flows there were reductions in habitat quantity with the introduction of the post-Rev5 flow regime for all species and life stages, except for juvenile Prickly Sculpin during fry emergence under low ALR conditions. Under peak flow conditions, habitat quantity for juvenile fish is generally unchanged in the fall and spring, but has decreased during summer and winter under the post-Rev5 flow regime. The reduced availability of preferred habitats under the new flow regime reflects the preference for shallow, low velocity habitat by juvenile fish in the Middle Columbia River. The reduction in habitat quantity for juvenile fish following implementation of the post-Rev5 flow regime must be considered in the context of how the post-Rev5 flow regime has affected other components of the ecosystem.
	What changes in recruitment of juveniles to mainstem rearing habitat result from implementation of the 142 m^3/s minimum flow release?	The reductions in habitat quantity may be expected to result in a reduction in recruitment of juveniles to mainstem rearing habitats. However, previous studies have found weak or non-existent correlations between weighted usable area and fish density or biomass indicating that a reduction in weighted usable area may not necessarily results in reduced productivity. To assess effects of the post-Rev5 flow regime on juvenile recruitment, other factors in addition to habitat quantity should be considered including: changes in primary and secondary productivity; changes in growth, condition and survival of juvenile fish; the ability for juveniles to locate and move between areas of suitable habitat; changes in adult abundance, spawning and incubation success; changes in the hydrograph associated with the use of Rev5; changes in the hydrograph associated with climate change; and changes in water quality and temperature. To assess the biological significance of changes in habitat suitability, the results from this study should therefore be considered alongside the other CLBMON studies (e.g., CLBMON-15B and CLBMON-16). In this manner, changes to habitat suitability can be considered in the context of long-term trends in ecological productivity and abundance and condition of juvenile fish.

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1. INTRODUCTION

The Columbia River Water Use Plan (WUP) specifies conditions for management of BC Hydro's hydroelectric operations on the Columbia River (Mica, Revelstoke, and Hugh Keenleyside dams). The WUP includes a flow management plan for the Revelstoke Dam, which specifies a year-round minimum flow release of 142 m^3/s. Prior to development of the WUP, there was no requirement for a minimum flow release at Revelstoke Dam. The purpose of the minimum flow release was to increase ecological productivity and juvenile fish habitat use, increase adult fish abundance, condition and growth, and trigger Rainbow Trout spawning in the Middle Columbia River (MCR).

As part of WUP implementation, monitoring programs were designed and implemented to study the effectiveness of the 142 m^3/s minimum flow at achieving improvements to ecological and fisheries productivity. The *Middle Columbia River Juvenile Fish Habitat Use* (CLBMON-17) study was designed to assess the effects of hydroelectric operations on juvenile fish habitat use downstream of Revelstoke Dam, and is part of a wider monitoring program under the Columbia River WUP. As one component of CLBMON-17, this project developed habitat suitability indices for juvenile fish in the MCR to assess the effects of implementation of the minimum flow release on juvenile habitat.

1.1. BC Hydro Infrastructure, Operations and the Monitoring Context

The MCR is the section of the Columbia River downstream of Revelstoke Dam (REV) and upstream of Arrow Lakes Reservoir (ALR, the reservoir created by impoundment at Hugh Keenleyside Dam) (Map 1). The length of the MCR is dependent on the water level at ALR. The present study focuses on Reaches 3 and 4 of the MCR, representing the 11.2 km section of the MCR between REV and the confluence with the Illecillewaet River (near Revelstoke, BC). The hydraulics of this section of river are influenced by operations of REV and the water level in ALR.

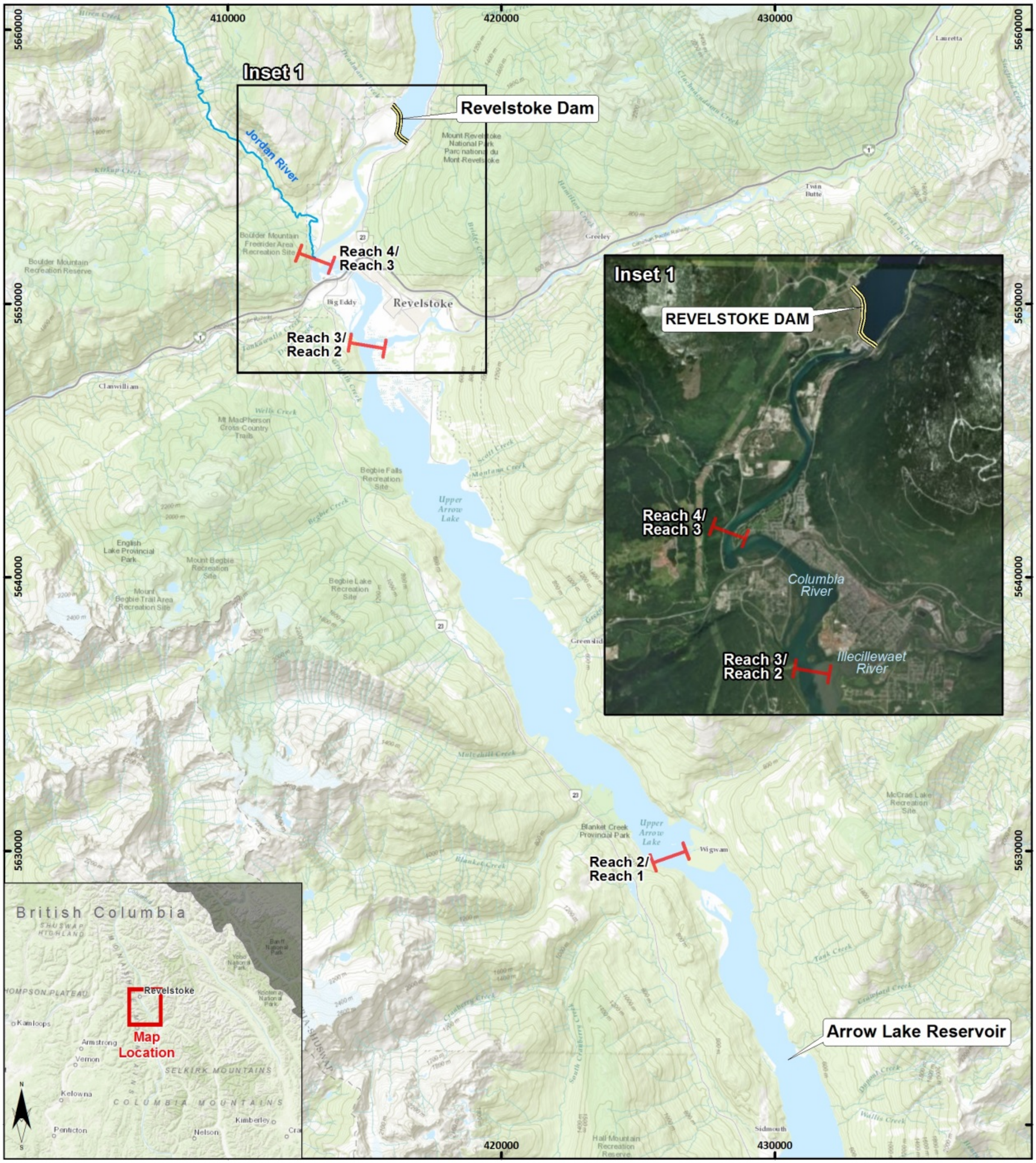
1.1.1. Revelstoke Dam

Revelstoke Dam is operated as a hydropeaking facility. Prior to the addition of a fifth generating unit (Rev5) in December 2010, the maximum operational capacity was 1,750 m^3/s and no minimum flow release was required, although ~8.5 m^3/s was released via seepage. Since Rev5, a minimum flow release of 142 m^3/s has been provided, and the maximum operational flow is ~2,124 m^3/s (Golder 2013). In practice, daily base and peak flows downstream of REV vary depending on the operational regime determined by BC Hydro.

1.1.2. Arrow Lakes Reservoir

Water levels in the ALR are not subject to any operational constraints, and the operational range is ~420.0 m to 440.1 m (Golder 2013). At low pool, MCR Reach 3 and Reach 4 are free flowing. Backwatering of Reach 3 is anticipated for ALR levels in excess of 433.1 m, and Reach 4 for ALR levels in excess of 434.2 m (Table 2, Stations 4 and 3, respectively, in Golder 2013). At very high ALR levels, backwatering extends to the base of REV.

Project Overview



Legend

- Revelstoke Dam
- Reach Break

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

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Scale: 1:200,000

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Map 1

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1.2. Management Questions and Hypotheses

There are four key management questions (or sets of questions) to be addressed by CLBMON-17. Two of these questions were addressed in prior studies, and a third question was partially addressed. The purpose of this report is to develop habitat suitability indices (HSI) and quantify juvenile fish habitat as one component of the larger CLBMON-17 study. This study will directly address management question #3(i) and the results of this study will be used to address question #4:

3(i). Do operational strategies for Revelstoke Dam and Arrow Lakes Reservoir impact the availability of preferred habitats?

4. What changes in recruitment of juveniles to mainstem rearing habitats result from implementation of the 142 m^3/s minimum flow release (aka the new flow regime)?

Question #3 is addressed by:

- Developing habitat suitability criteria that are applicable to the Middle Columbia River;
- Quantifying juvenile fish habitat under specific flow scenarios; and
- Comparing juvenile fish habitat quantity under various operational scenarios prior to and after implementation of the 142 m^3/s minimum flow release.

The results from this study will be considered alongside the other CLBMON-17 studies to address Question #4. This information will be integrated with three other monitoring programs (Physical Habitat Monitoring CLBMON-15A, Ecological Productivity Monitoring CLBMON-15B, Fish Population Indexing Surveys CLBMON-16) to evaluate the benefits of the minimum flow release, and to recommend long-term operational requirements for Revelstoke Dam.

1.3. Scope and Objectives

There were three main objectives of this project:

1. **Refinement of habitat suitability indices for juvenile fish in the MCR.** This was achieved by using fish and fish habitat data collected in the MCR between 2008-2013 (Slivinski and Sykes 2014) to develop habitat suitability criteria for key species and life stages.
2. **Integration with 2-D hydraulic model.** Hydrometric data for the MCR were examined to characterize flow and water level conditions during key periods for study fish species. These representative conditions were submitted to BC Hydro for 2-dimensional hydraulic modelling. HSI for the MCR were validated by applying the HSI to the hydraulic model output, calculating habitat suitability, and comparing predicted habitat suitability with fish observations under comparable environmental conditions. Weighted usable area (WUA) was calculated using the final HSI for each hydraulic simulation.

3. **Evaluation of flow scenarios.** Changes in habitat quantity caused by the change in flow regime (Rev5) were calculated by characterizing typical base and peak flows for each season pre and post Rev5, and retrieving the corresponding WUA for each species and life stage. This analysis was completed for high and low water levels in ALR.

2. METHODS

2.1. Refinement of Habitat Suitability Indices (HSI)

There are many different methods that can be used to derive HSI for fish. HSI may be developed via review of literature and expert judgment (Category I), frequency analysis of field data where fish have been observed (Category II, habitat utilization curves), and by adjusting Category II curves to correct for habitat availability (Category III, habitat preference curves) (Bovee *et al.* 1998). Each of these methods has its own strengths and limitations.

Frequency based approaches (Category II and III curves) require observation of fish habitat use and measurement of habitat conditions (depth, velocity, and substrate). The data set for the MCR contains this information for each survey area (generally 100 m length) but not the specific microhabitat data where fish were located, introducing a potential limitation. To overcome this limitation, we applied a hybrid approach to derive HSI that most realistically represent habitat suitability for juvenile fish species based on the data available. Habitat use and availability information specific to the MCR were considered alongside existing HSI and in the future will consider input via a workshop.

2.1.1. Pre-Processing

A number of steps were undertaken to examine and preprocess the fish and fish habitat data prior to the HSI analysis. A description of these steps and the decisions made regarding data inclusion and analytical approach is provided below.

Data Screening

We reviewed the existing Microsoft Access databases that contain fish and fish habitat data (Slivinski and Sykes 2014) and extracted the data tables containing site information and fish catch data. Review of these data identified three potential issues:

1. Typos in the databases prevented some site records from being related to the corresponding fish records. We corrected the Site or Date field for two site records and 131 fish records;
2. Some fish records (7 Mountain Whitefish, 1 Bull Trout, and 1 Largescale Sucker) had unrealistic length entries (e.g., 0, 1 mm). We removed these records from the dataset; and
3. Some unrealistic or erroneous values of velocity and depth were present; these values were removed and the data for these surveys were retained.

It was noted that many of the depth and velocity measurements for the habitat data were zero depth and velocity (i.e., measurement for 0 m from wetted edge). Because these zero data points are present in almost all surveys, they do not provide meaningful information. After thorough consideration (see

Section 2.1.2) it was ultimately decided to exclude these data, recognizing that their exclusion may bias the habitat use and availability calculations toward deeper depths and swifter velocities (whereas including the data collected at 0 m would bias toward shallow depths and low velocities).

Spatial information for the surveys was reviewed to remove data sets that were not collected within Reaches 3 and 4 of the MCR. Some spatial data (i.e., site waypoints) that were clearly erroneous were further examined to determine if the data were collected within the study area.

Fish Age Analysis

Seasonal histograms of fish length were created to evaluate whether there were distinct modes in the fish length data. This information was considered alongside the age classifications in the *CLBMON-16 Middle Columbia River Fish Population Indexing Program* (Table 6 in Golder Associates Ltd. *et al.* 2017) to identify age classifications (fry or juvenile) for application in the habitat suitability analysis.

Selection of Species and Life Stages

The number of fish in each species/age group was calculated to determine if there were sufficient data (>100 fish) to generate HSI for that species/age. The selection of species and life stages was confirmed with BC Hydro before proceeding with the HSI analysis. For each species and life stage selected, we calculated the linear density of fish (fish per 100 m) within each survey area and sampling date.

All fish sampling was completed at night to correspond to the timing of the release of the minimum flow of 142 m^3/s and the collection of data under the adult fish indexing program (CLBMON-16). Of the 815 surveys used in the analysis, fish sampling was conducted during fry emergence (Apr-May; n = 191), summer rearing (Jul-Aug; n = 345) and fall rearing (Sep-Oct; n = 279). No fish sampling was conducted during the overwintering period (Nov-Mar). Fish survey data were aggregated across seasons to improve the sample size used to generate HSI.

The timing (night vs day) and seasons over which fish sampling occurred should be considered when interpreting the HSI (Section 3.1) and changes to habitat suitability under different flow scenarios (Section 3.3).

Hydraulic Conditions

For each survey, data were obtained from Revelstoke Dam (discharge) and ALR (water level). We reviewed discharge at the start of the survey and discharge prior to the survey (1 hour before, 4 hours before, 12 hours before, and maximum, minimum within prior 12 hours) to assess the stability of flow prior to the fish/habitat sampling and the backwatering condition of the habitats. We considered whether this information suggested exclusion of specific data sets, e.g., data collected while flow was changing rapidly at Revelstoke Dam. This information was retained throughout the analysis so that the effect of dam/reservoir operations could be examined in the HSI analysis.

2.1.2. Calculate Habitat Use and Availability for MCR

Habitat use and availability were estimated from the depth, velocity, and substrate data collected for each survey.

Sensitivity Analysis

Two nuances in the data collection and recording methods could bias water depths and/or velocities toward zero:

1. Most depth and velocity data collected at 0 m from shoreline had values of zero; and
2. Velocity data for 106 of the surveys consisted entirely of zeros; the pattern of occurrence suggests that some of these zero values may actually correspond to missing data rather than 0 m/s. Without extensive review and judgment, we are unable to determine which of these surveys were truly conducted in zero velocity habitats.

To examine the sensitivity of the HSI to the zero values, we conducted the depth and velocity HSI analysis three ways:

1. Including all data;
2. Excluding depth and velocity data collected at 0 m from shoreline (reducing the number of depth and velocity data within each survey from 9 to 6); and
3. For the data set used in Analysis 2, excluding the surveys where the velocity data consisted entirely of zeros (applies to the velocity data only.

The results of Analysis 3 were retained for integration with existing information and expert judgment.

Calculate Habitat Use

Habitat use is typically calculated according to a simple frequency-based approach (i.e., histogram of depth/velocity/substrate where fish were observed). This approach is not possible for the MCR dataset because microhabitat data were not collected at the specific locations where fish were observed; rather, nine depth and velocity measurements were made in each survey area. We followed an analogous approach by creating and testing frequency distributions of depth, velocity, and substrate for each survey.

For depth and velocity, to evaluate different forms of frequency distribution, we considered 3 alternatives.

1. **Uniform distribution.** We assumed depth and velocity within a survey area are uniformly distributed, ranging between the minimum and maximum measured values during the surveys. Application of this distribution assumes that fish are equally likely to be using any habitat condition (water depth, velocity, substrate) that is present in the survey area.
2. **Normal distribution.** We assumed that depth and velocity within a survey area are normally distributed, with mean values equivalent to the sample mean, and a standard deviation equivalent to the sample standard deviation. This is equivalent to assuming that fish may use any habitats within the survey area, but are more likely to use the habitats similar to the mean survey depth and velocity. However, since depth and velocity cannot be negative, these

distributions were truncated at 0, with the total area under the probability density function still being equal to 1.

3. **Constant distribution.** We assumed that the mean measured depth and velocity within a survey area is representative of habitat occupied by fish within the survey area.

The frequency distribution of substrate within each survey was estimated from the substrate classification data (recorded as a percentage at three sites within the survey). For each survey, the overall percentage for each substrate category was calculated and assumed as the substrate frequency distribution.

For depth and velocity, three habitat use curves were calculated for each species and life stage, one curve for each of the distributions assumed above.

For each survey, species, and life stage, the frequency distribution was weighted by the linear density of fish. These weighted distributions were summed across all surveys to derive habitat use curves for each species and life stage.

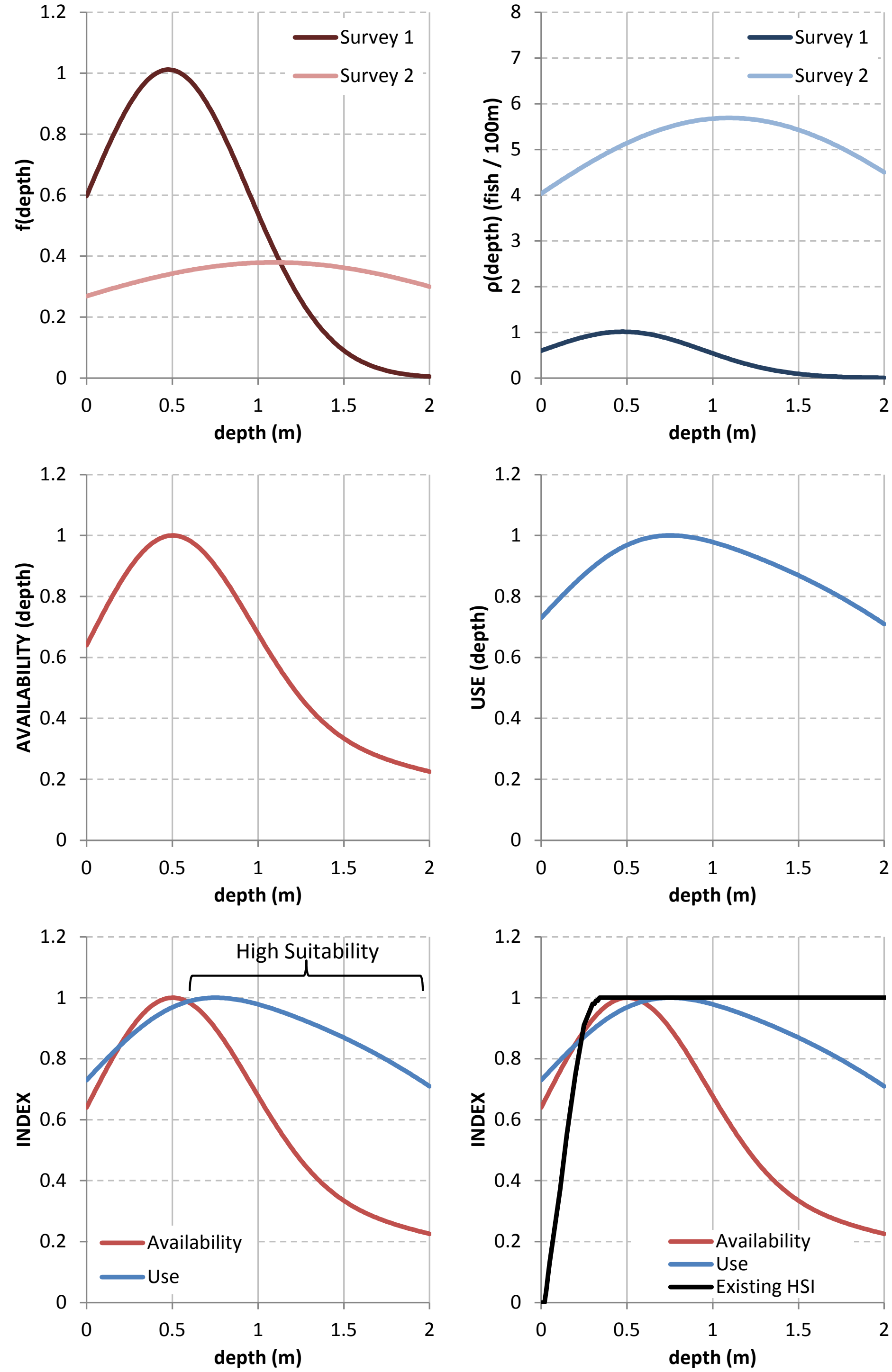
Calculate Habitat Availability

Habitat availability curves were calculated in the same way as the habitat use curves, except distributions were not weighted by fish density. Three availability curves (representing the three frequency distributions, uniform, normal, and constant) were calculated for depth and velocity, for comparison to the analogous habitat use curves.

Integrate Habitat Availability and Use

Habitat availability and use were overlain to highlight habitat conditions where use exceeds availability, i.e., habitats that may be preferred by fish. This process is demonstrated in Figure 1. For depth and velocity, overlay plots were created for each of the frequency distributions to evaluate the sensitivity of the results to the frequency distributions assumed within the survey areas.

Figure 1. **Example calculation of habitat use and availability. Habitat availability is calculated for two surveys (top left) and weighted by the linear density of Rainbow Trout juveniles within the survey (top right). These distributions are summed and normalized (middle row) and compared to one-another and existing HSI (bottom row).**



2.1.3. Integrate MCR Habitat Use and Availability with Existing HSI

The habitat use and availability curves were overlain with existing WUP HSI and other relevant HSI (Ptolemy 2001 for Rainbow Trout, Bovee 1978 for Mountain Whitefish, EMA 1991 for Bull Trout) such that any departures from existing HSI based on habitat preferences indicated by the MCR fish capture data could be identified. Middle Columbia River HSI were then developed to include depth, velocity, and substrate ranges where the data indicated relatively high habitat use in comparison to habitat availability.

2.2. Integration with 2-D Hydraulic Model

2.2.1. HSI Validation

The HSI were applied to the output of the 2-D Hydraulic model to calculate habitat suitability in each model cell. The predicted habitat suitability values at 296 m^3/s (high ALR level) were overlain with fish observations collected under similar survey conditions. Overlays were created and inspected in ArcGIS to confirm that the HSI are producing reasonable predictions of habitat quality. Quantitative comparison was not possible because the fish sampling data points represent a single point of the 100 m shoreline sampled in each survey, and our review of the survey waypoints indicated that the accuracy of these waypoints is limited. The reasonableness of the HSI was considered by identifying sites with high fish density and low predicted habitat suitability and examining the data to determine if a discrepancy may be present. Professional judgement (considering overall performance of the HSI, and confidence in the underlying information) was applied to determine if adjustments to the HSI were required.

HSI were interpolated to increments of 1 cm (depth) and 1 cm/s (velocity). These HSI were presented to BC Hydro, First Nations, and agency experts for review and discussion at a workshop.

2.2.2. Calculate Weighted Usable Area

The HSI were applied to the hydrodynamic model results and used to calculate weighted usable area (WUA) for each MCR flow and water level scenario. WUA values are based on depth and velocity criteria only, as substrate data for the complete study reach of MCR were not available.

2.3. Evaluation of Flow Scenarios

2.3.1. Selection of Flow Scenarios

Flow scenarios for simulation were selected in consideration of climate data, fish periodicity, and flow regime in the MCR.

Critical Periods for Fish

Critical periods for some fish in the MCR were provided by BC Hydro (Martel, pers. comm. 2018; Figure 2). This information was considered alongside climate data from Revelstoke to identify the following biologically relevant seasons for consideration in the flow scenario evaluation: overwintering (November to March), fry emergence (April-May), summer rearing (June-August), and fall rearing (September-October).

Flow Frequency Analysis

Flow data for Revelstoke Dam and water level data for ALR (Nakusp station) were examined to characterize operational conditions for each season, before and after Rev5 operations. Data from January 1, 2003 to December 20, 2010 were included in the pre- Rev5 regime, and data from December 21, 2010 to December 31, 2017 were included in the post- Rev5 flow regime.

For each season, representative base and peak flows were estimated from the minimum and maximum daily flow at Revelstoke Dam. The 50^{th} percentile minimum daily flow was selected to represent base flow conditions. The 90^{th} percentile maximum daily flow was selected to represent peak flows to provide a large contrast in habitat conditions relative to base flow. To limit the number of model runs required, the seasonal values of base and peak flows pre and post-Rev5 were examined to identify seasons with similar flow regimes and select representative conditions for modelling. Five flow rates were selected for modelling.

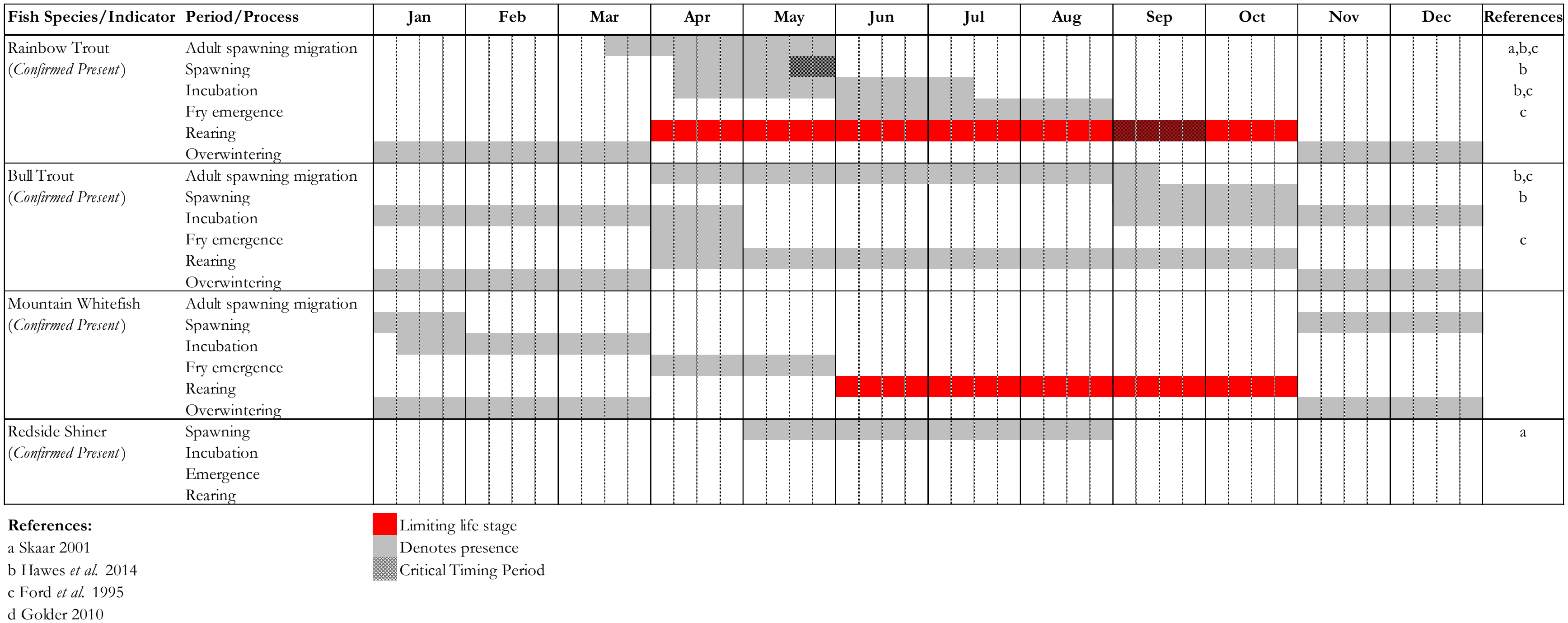
Similarly, seasonal frequency distributions of ALR water level at the Nakusp station were used to identify representative water levels for hydraulic modelling. The 10^{th} and 90^{th} percentile water levels were calculated for each season, pre and post-Rev5. To characterize low pool conditions, the 10^{th} percentile value (excluding summer, when ALR is typically at high pool) was selected as a candidate water level. This value was compared to the information provided by Golder (2013) to verify that Reach 3 and Reach 4 are expected to be free flowing under this condition. High pool condition was characterized as the 90^{th} percentile water level (excluding spring, when ALR is typically at low pool), and this value was compared to the physical monitoring data to confirm that some backwatering of the study reaches is expected to be present.

2.3.2. Evaluation of Flow Scenarios

The WUA values from the 2-D Hydraulic model were used to populate a table summarizing habitat quantity for each species and life stage under pre and post-Rev5 flow scenarios, under base and peak flow conditions, for high and low ALR levels. For each season, a representative hydraulic model simulation was selected (i.e., the simulation with the most similar flow and reservoir water level), and the WUA from this simulation were used to populate the table.

Habitat losses due to hydropeaking were calculated as the difference in WUA between base and peak flow conditions. These changes in habitat are caused by changes in wetted area, water depth, and water velocity.

Figure 2. Middle Columbia River fish periodicity (Martel, pers. comm. 2018).



3. RESULTS

3.1. Refinement of Habitat Suitability Indices (HSI)

3.1.1. Pre-Processing

Data Screening

The following adjustments were made to the fish database:

1. Corrected the Site or Date field for two site records and 131 fish records;
2. Removed 7 Mountain Whitefish and 1 Bull Trout with unrealistic lengths (e.g., 0, 1 mm) from the dataset;
3. Removed 5 unrealistic velocity values (5-100 m/s) and 13 depth values that appeared erroneous based on review of the data (7-9.9 m); and
4. Removed 425 surveys outside of MCR Reach 3 and Reach 4 (815 remaining for analysis).

Fish Age Analysis

The seasonal histograms of length for each species (Figure 3) were used to identify modes in the data that correspond to the fry life stage. For Bull Trout, Mountain Whitefish, and Rainbow Trout, there are distinct modes corresponding to fry, and the length value associated with these modes increases between May and September. Similar modes are not present for Prickly Sculpin and Redside Shiner.

The life stage classifications for Bull Trout, Mountain Whitefish, and Rainbow Trout fry were assigned based on the histogram data (Table 2). The juvenile life stage was assigned based on the histogram data (minimum length) and information in Table 6 (maximum length) in Golder *et al.* (2017). For Prickly Sculpin and Redside Shiner, fish were classified according to the histogram data.

Figure 3. Seasonal length frequency distribution of fish in the CLBMON-17 dataset for a) Bull Trout, b) Mountain Whitefish, c) Rainbow Trout, d) Prickly Sculpin, and e) Redside Shiner

a) Bull Trout

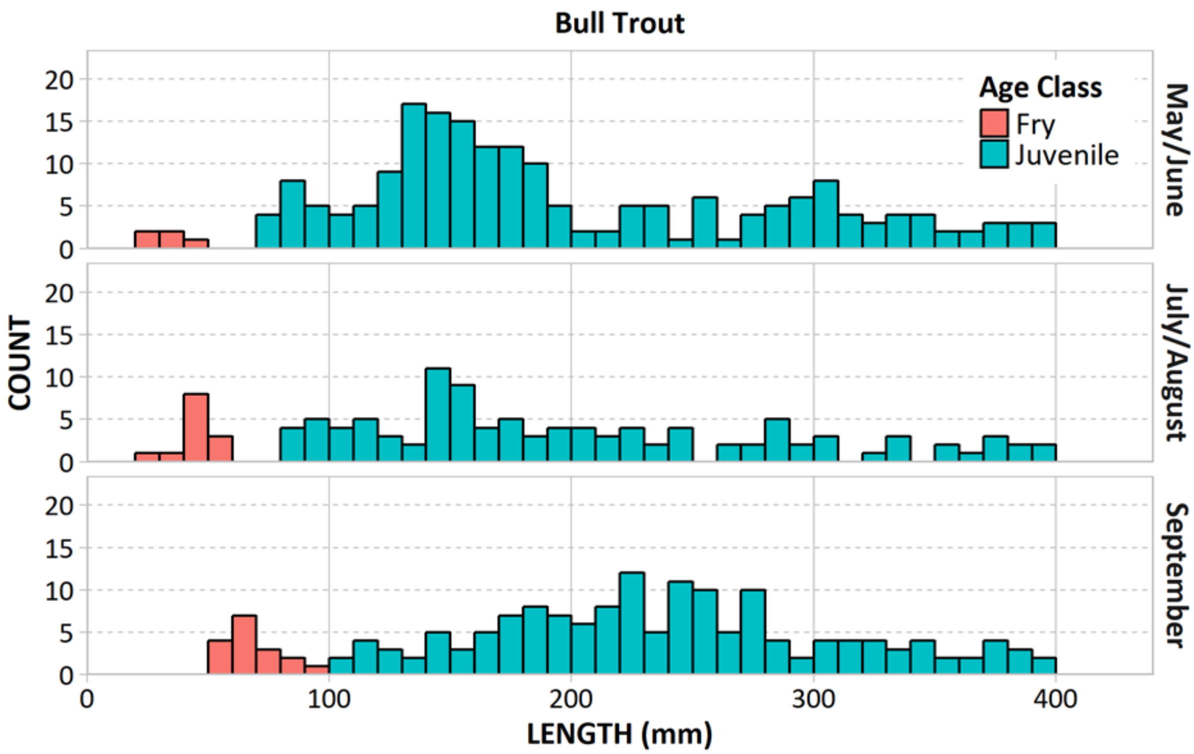
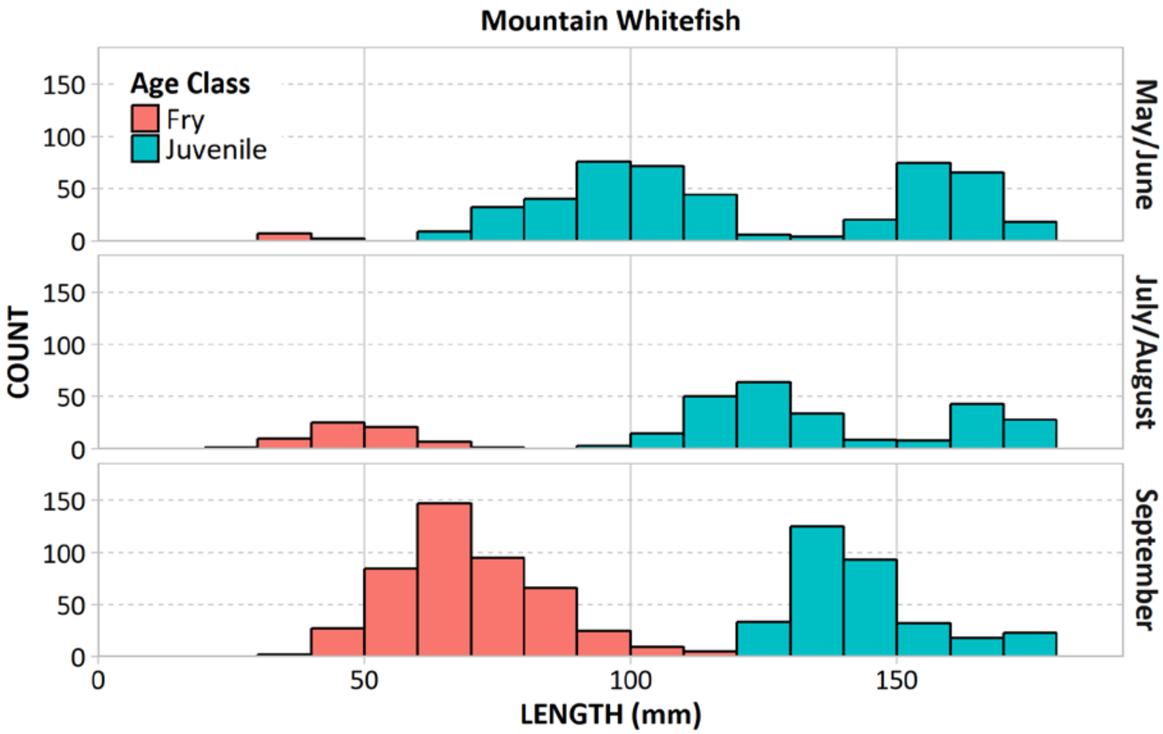


Figure 3. Continued.

b) Mountain Whitefish



c) Rainbow Trout

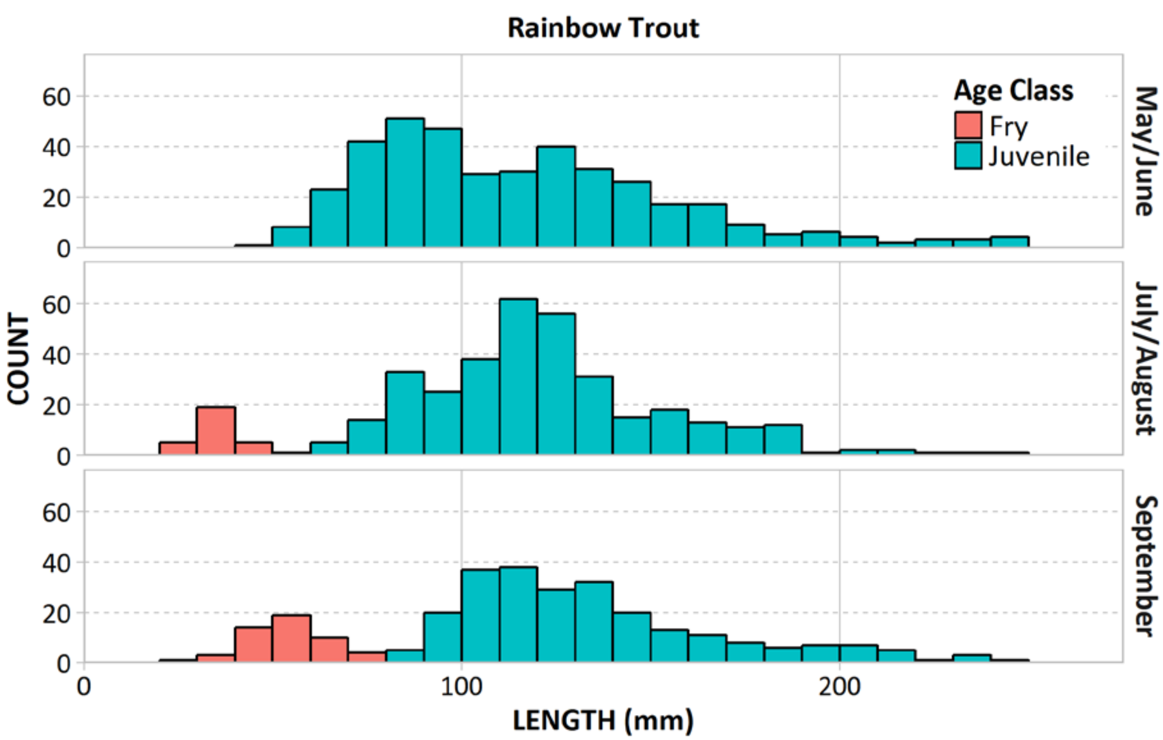
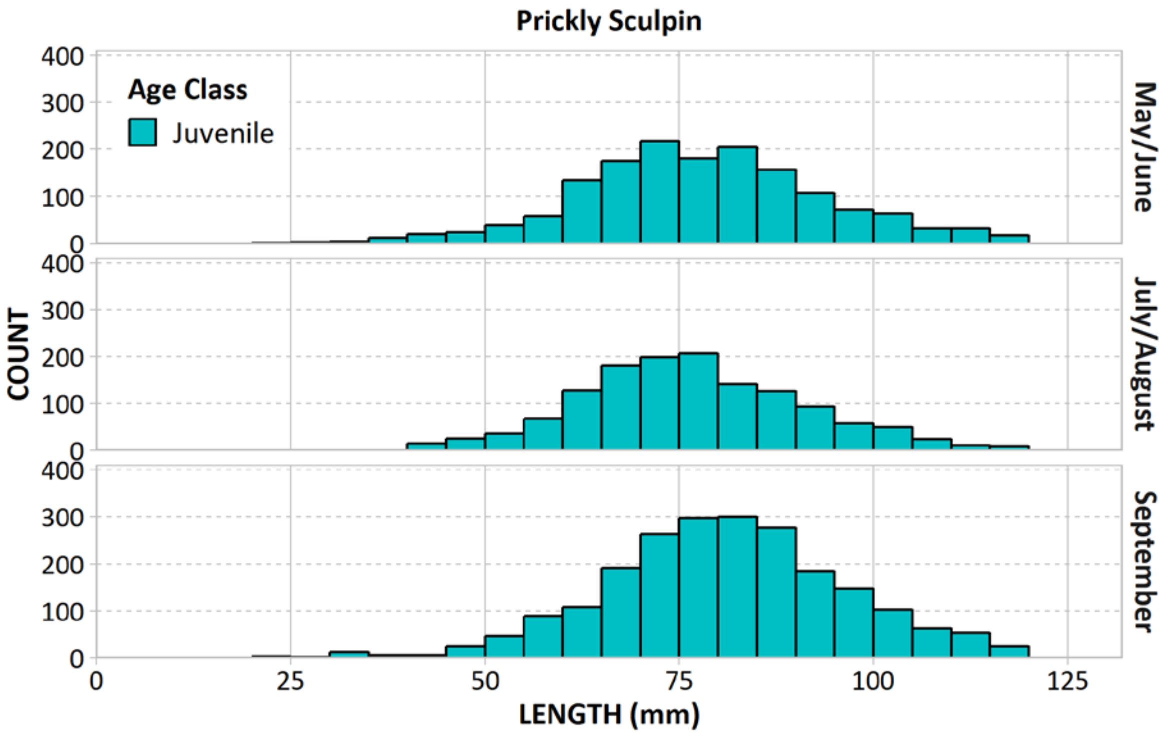


Figure 3. Continued.

d) Prickly Sculpin



e) Redside Shiner

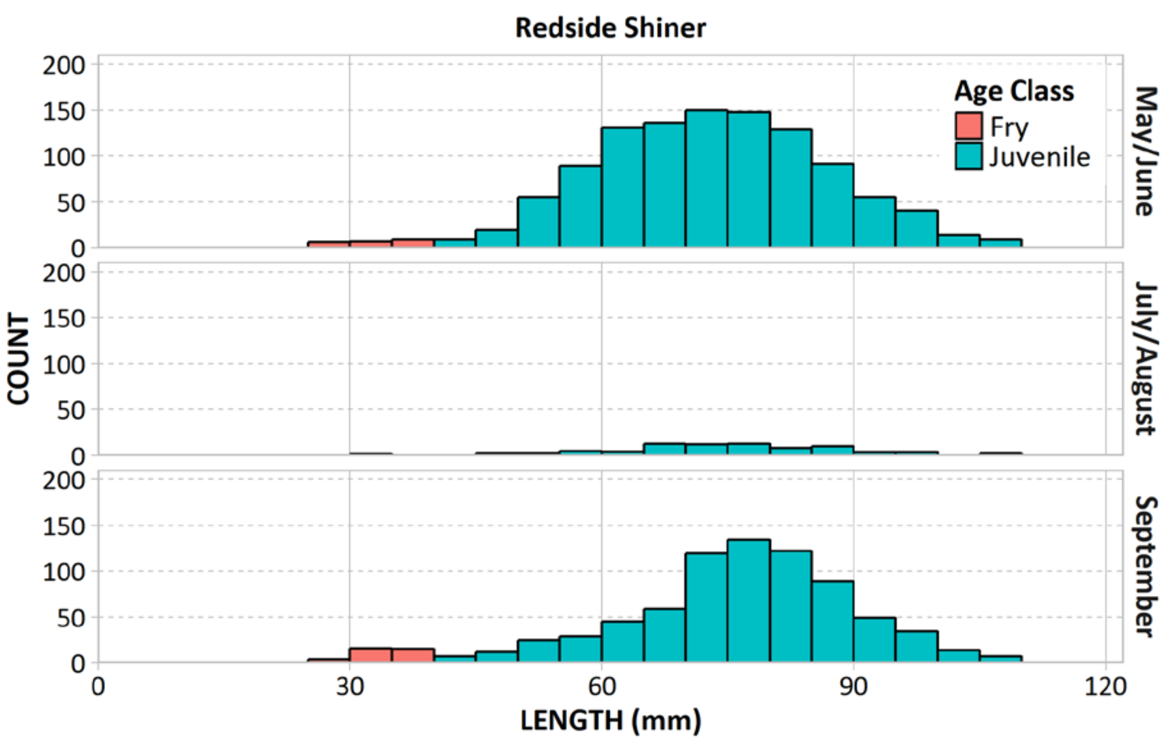


Table 2. Minimum and maximum juvenile length by season. Fry are considered to be any fish below the seasonal minimum juvenile length.

Species	Minimum Juvenile Length (mm)			Maximum Juvenile Length (mm)
	May-June	July-August	September	
Bull Trout	60	60	100	400
Mountain Whitefish	50	80	120	175
Rainbow Trout	30	60	80	250
Prickly Sculpin	20	20	20	120
Redside Shiner	40	40	40	111

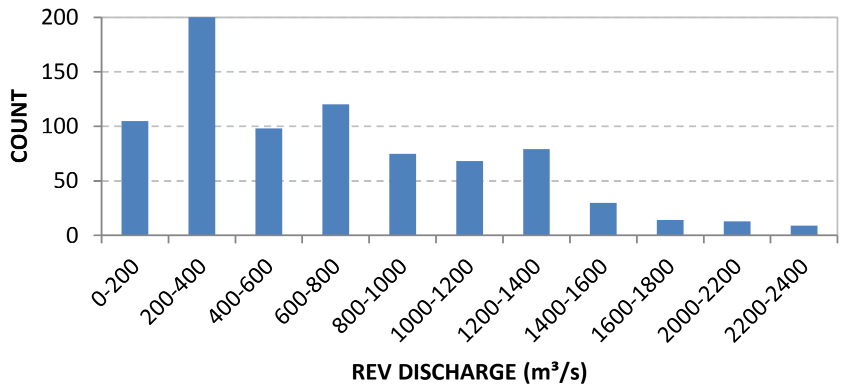
Hydraulic Conditions

The median flow rate during the fish surveys was 600 m^3/s, and flows in excess of 1,400 m^3/s were infrequent (8% of surveys) (Figure 4a). As expected, flows were not stable on the survey dates (Figure 4b); in 51% of the surveys, the flow during the survey was at least 200 m^3/s lower than the median flow over the 12 hour prior to the survey, and in 7% of the surveys, flow was 200 m^3/s greater than the 12-hour median flow. ALR levels were frequently high enough to cause backwatering in at least part of the study reach; the ALR level exceeded 433.1 m in 79% of surveys.

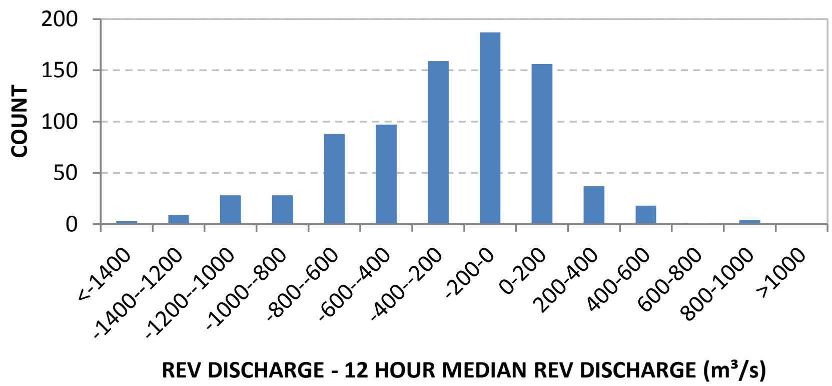
For the purpose of HSI development, we did not remove any survey data based on the hydraulic conditions on the survey dates. This approach maximizes the observations of fish habitat use, and necessarily assumes that the habitats occupied by fish during surveys reflect their habitat preference in the MCR, rather than a behavioral response to variable reservoir levels or hydropeaking.

Figure 4. Histogram of a) REV discharge during surveys, b) REV discharge relative to median discharge over prior 12 hours, and c) ALR level during surveys (2008-2013).

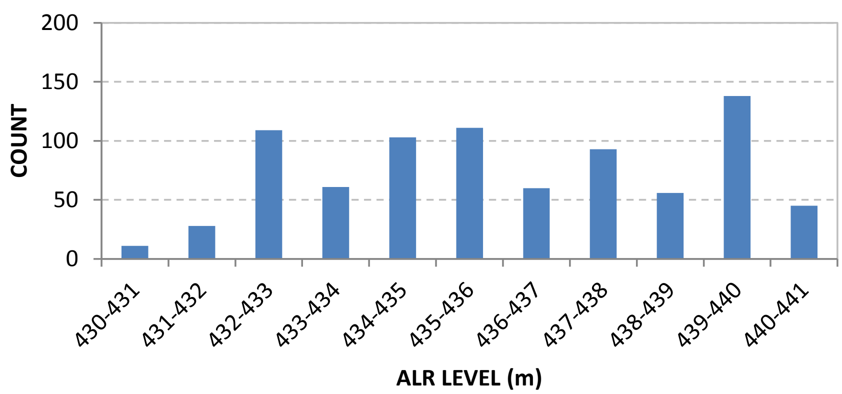
a) REV Discharge



b) REV Discharge Relative to Median Discharge Over Prior 12 Hours



c) ALR Level at Nakusp



Selection of Species and Life Stages

There were sufficient data for HSI analysis for Bull Trout juveniles, Mountain Whitefish fry and juveniles, Rainbow Trout juveniles, Prickly Sculpin juveniles, and Redside Shiner juveniles (Table 3). There were insufficient observations of Largescale Sucker (n=100, all ages).

Table 3. Number of fish used in analysis of habitat suitability data. Shaded cells indicate insufficient fish observations for HSI development.

Species	Number of Fish	
	Fry	Juvenile
Bull Trout	6	360
Mountain Whitefish	205	687
Rainbow Trout	19	517
Prickly Sculpin	0	3580
Redscale Shiner	3	712

3.1.2. Calculate Habitat Use and Availability for MCR

Sensitivity Analysis

Removing the data collected at 0 m from shoreline reduced both habitat availability and use at shallow water depths and slow velocities, however, in the case of water velocity, availability was still strongly skewed toward zero. The exclusion of these data did not meaningfully change the relationship between habitat use and availability (i.e., the range of depths/velocities where use exceeds availability).

Removing the velocity surveys with zero velocity had no effect on the habitat use and availability calculated from the normal distributions. For the uniform and constant distributions, removing these data led to a re-scaling of the habitat use/availability curves, enhancing differences between use and availability. The data still appear skewed toward zero velocity, indicating that removal of these data will not introduce a meaningful bias away from zero velocity. In Figure 8, the distributions of habitat availability for all species show a peak either at zero or near-zero velocities even with the removal of the shoreline measurements.

Ultimately, we decided to use the reduced data sets for the final HSI analysis. We determined that while the removal of unrepresentative but ubiquitous information (i.e., zero depth and velocity in most surveys) would have little effect on the biological interpretation of the HSI data, excluding these data would provide more realistic indications of water depths and velocities actually used by fish. Similarly, removal of the all-zero velocity surveys is expected to have little effect on our interpretation of the curves, while the resultant re-scaling of the uniform and constant distributions emphasizes differences between habitat use and availability.

Calculate Habitat Use

Habitat use curves are provided for each species and life stage in Figure 5. These curves are provided for the three frequency distributions (normal: green; constant: pink; uniform: blue) that were described in Section 2.1.2.

Figure 5. Habitat use curves for a) Bull Trout juveniles, b) Mountain Whitefish fry, c) Mountain Whitefish juveniles, d) Rainbow Trout juveniles, e) Prickly Sculpin juveniles, f) Redside Shiner juveniles. Normal, constant and uniform refer to distributions of depth and velocity. Refer to Section 2.1.2 for details.

a) Bull Trout juveniles

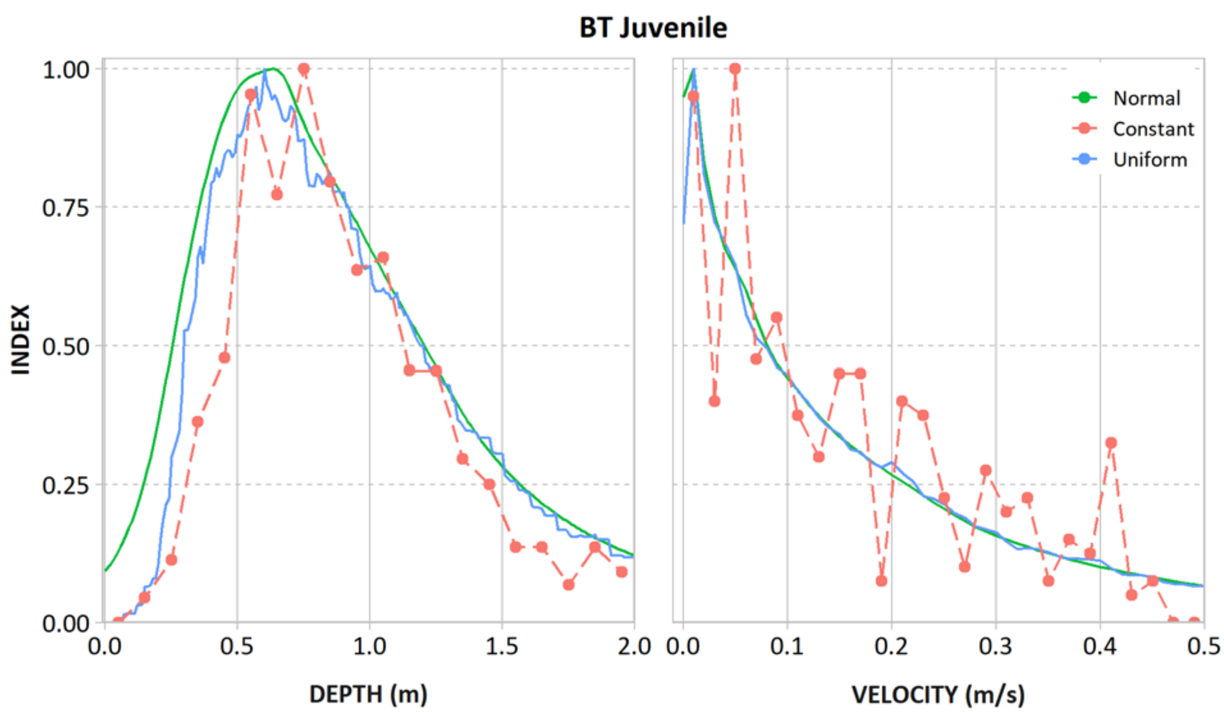
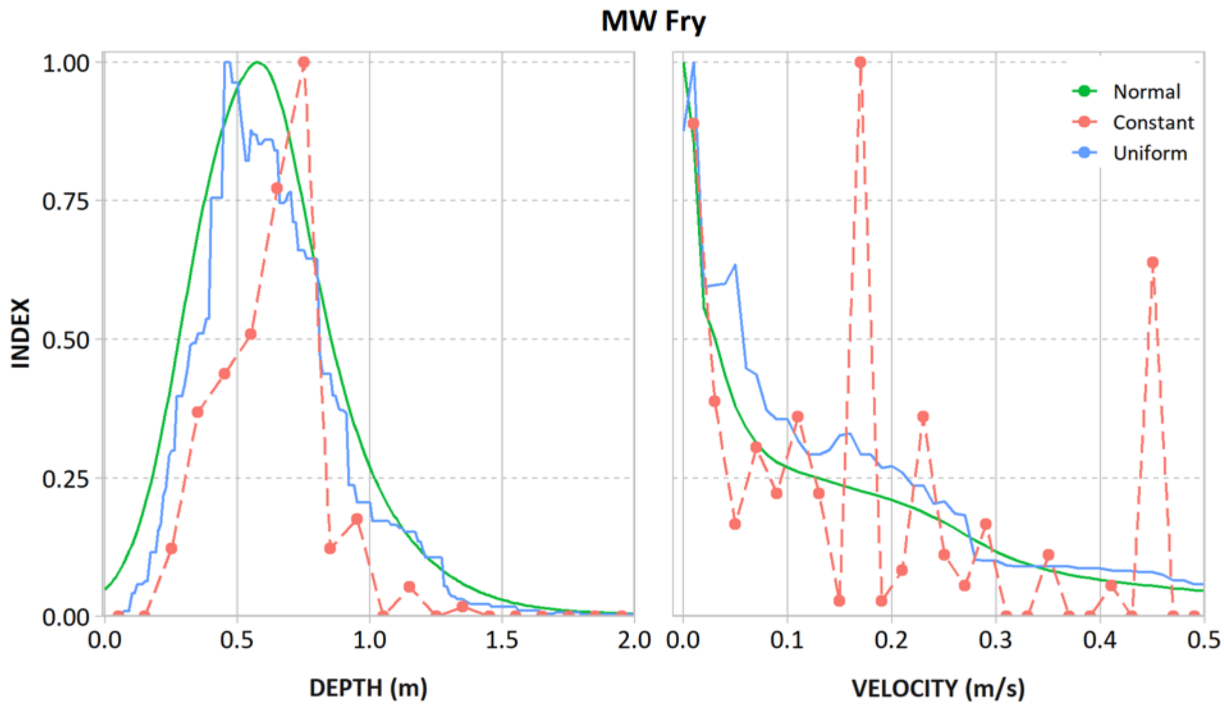


Figure 5. Continued.

b) Mountain Whitefish fry



c) Mountain Whitefish juveniles

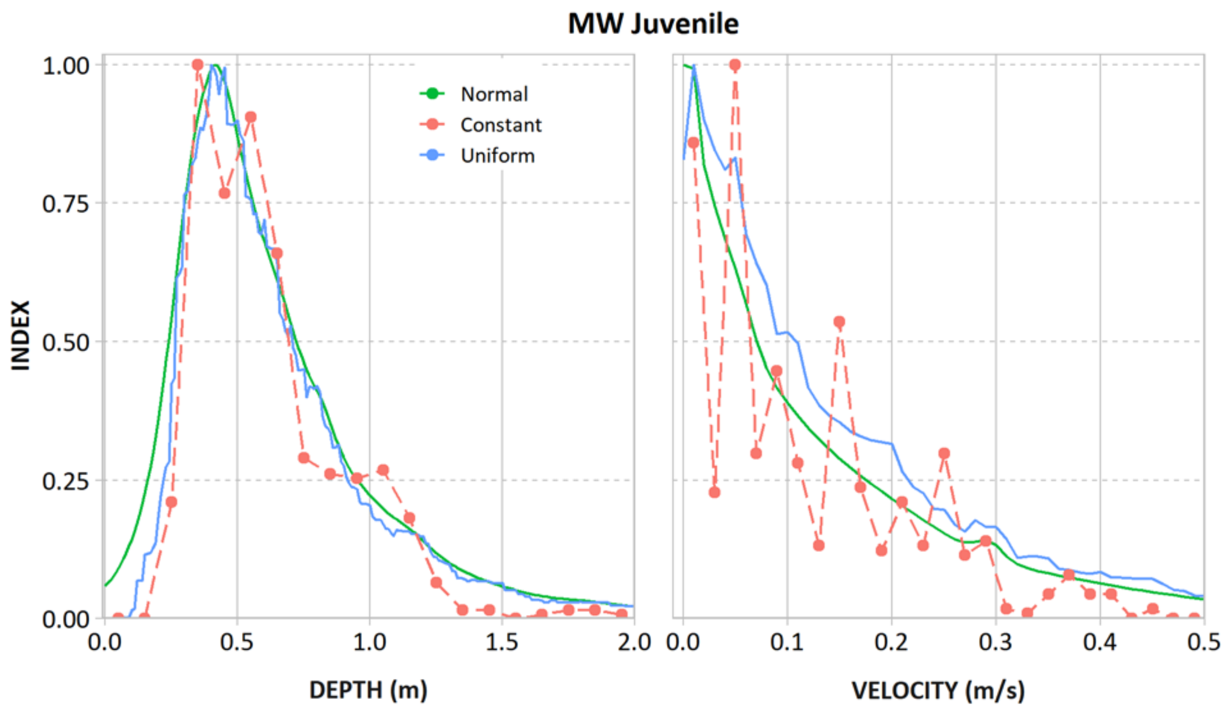
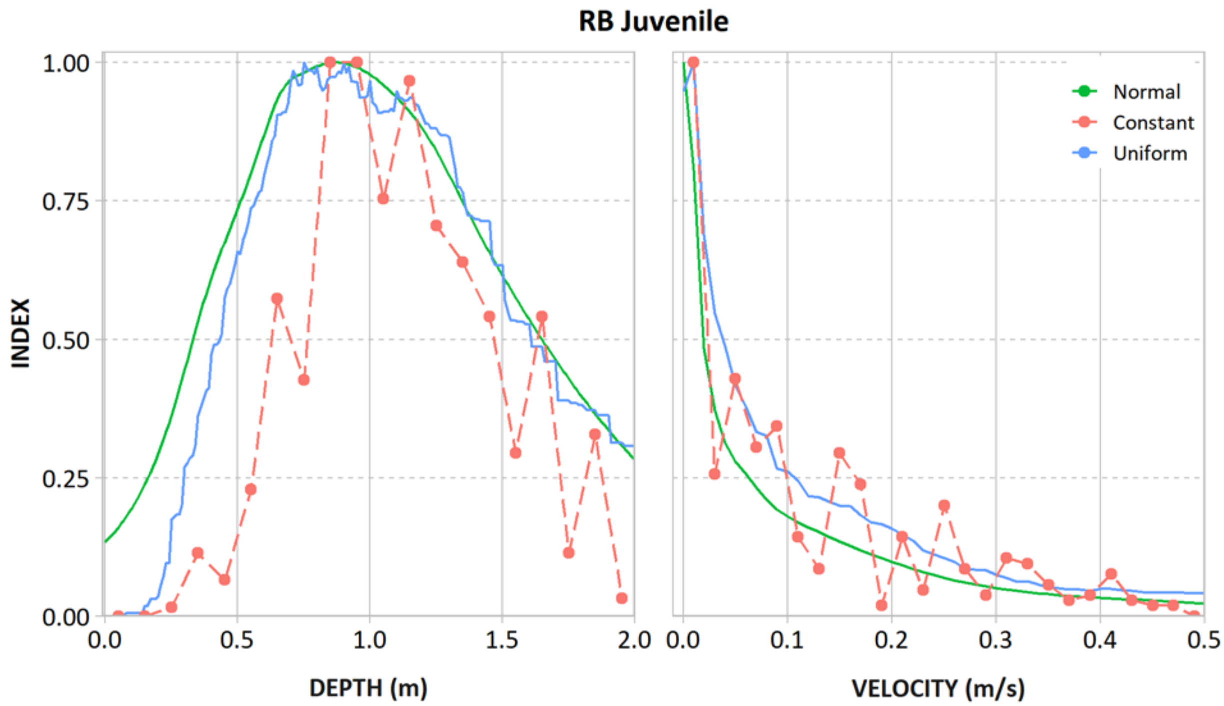


Figure 5. Continued.

d) Rainbow Trout juveniles



e) Prickly Sculpin juveniles

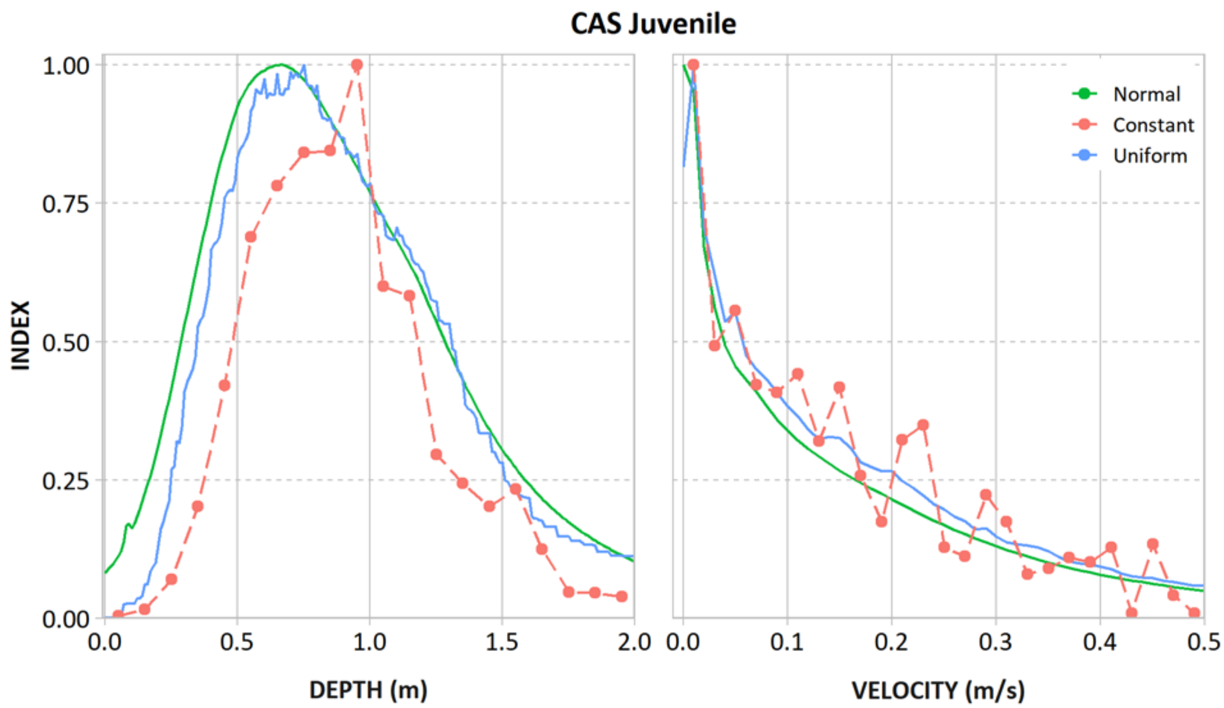
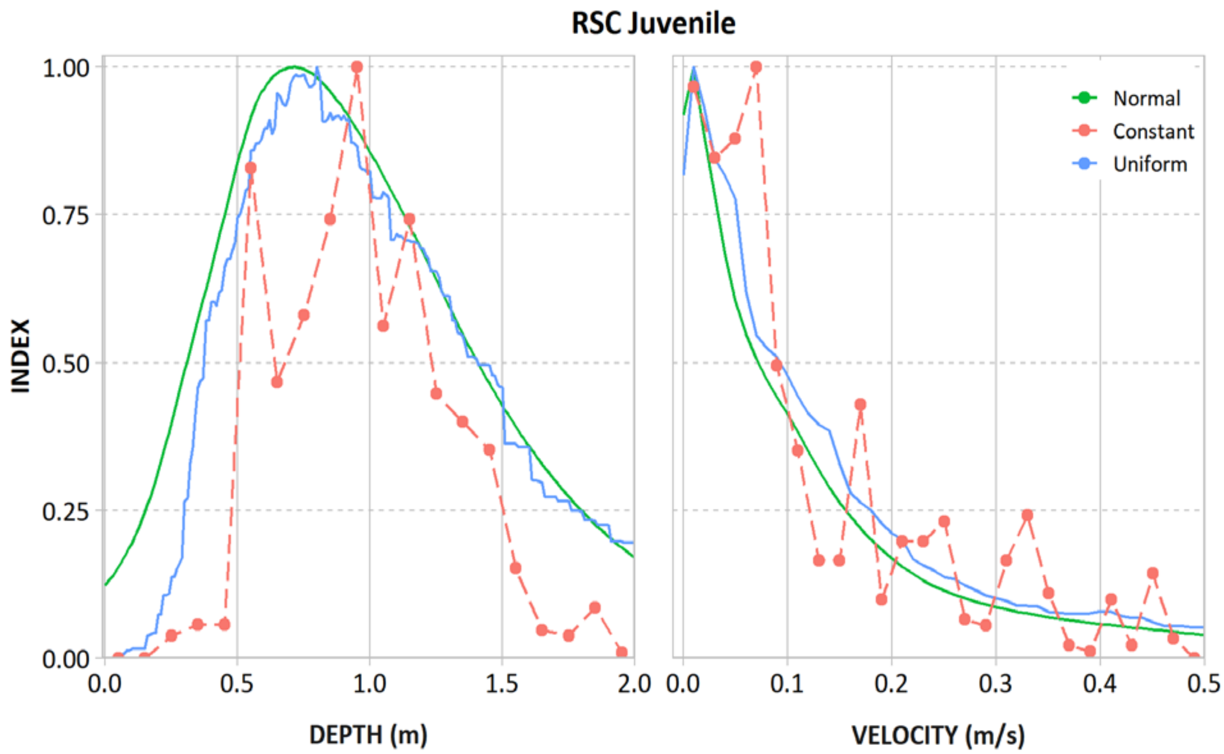


Figure 5. Continued.

f) Redside Shiner juveniles



Calculate Habitat Availability

Habitat availability curves are shown in Figure 6 for each frequency distribution.

Figure 6. Habitat availability curves for depth and velocity.

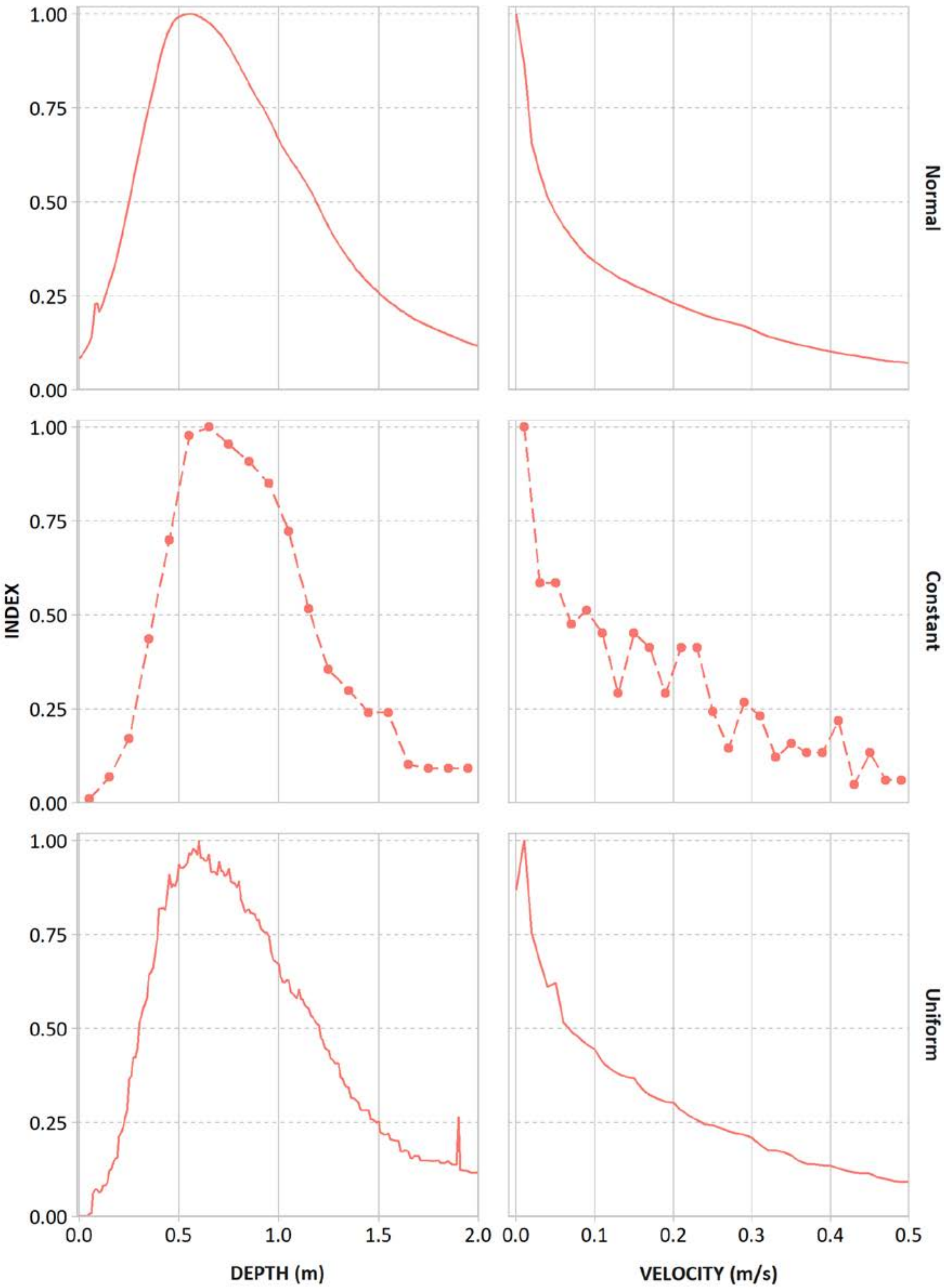
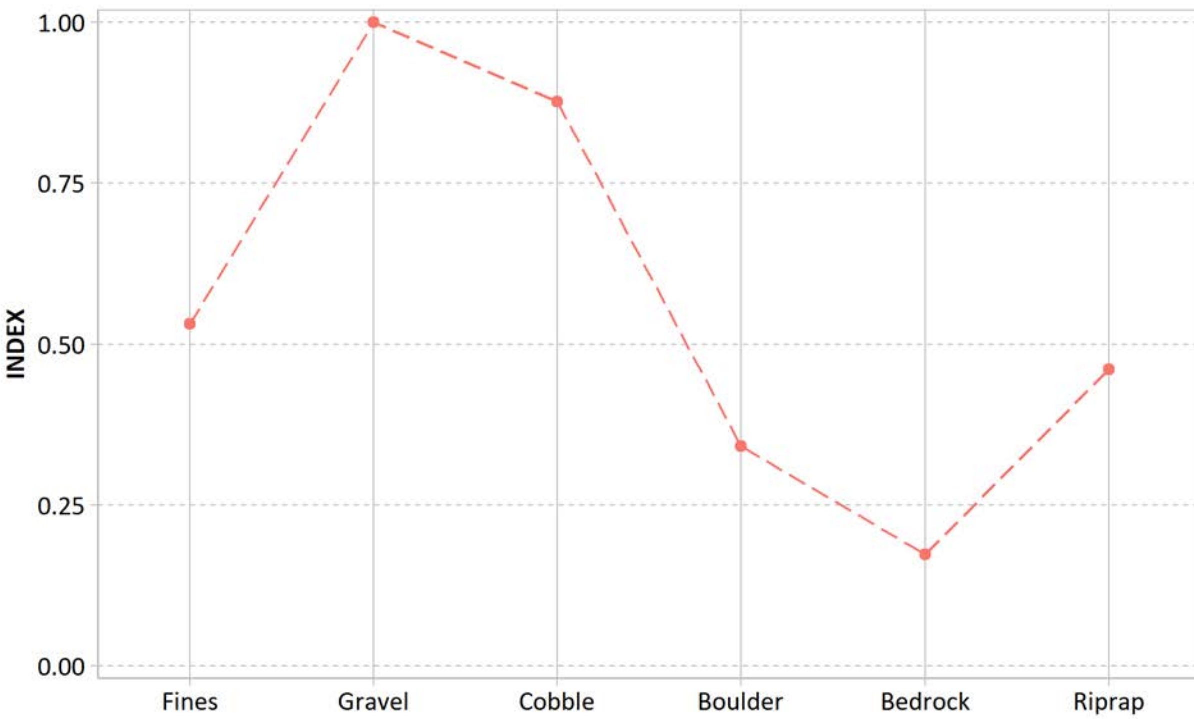


Figure 7. Habitat availability curve for substrate.



Integrate Habitat Availability and Use

For Bull Trout juveniles, the depth availability and habitat use were similar (Figure 8a), suggesting little preference for water depth. Considering the normal frequency distributions, use exceeded availability for water velocities less than ~25 cm/s, indicating a preference for slow water velocities (Table 4). Substrate availability and use were similar for size classes from fines up to boulders, but there appears to be a strong preference for bedrock and riprap based on the difference between availability and use (Figure 9a).

Habitat use for Mountain Whitefish fry exceeded availability for water depths between ~0.4 m to 0.75 m (depending on distribution, Figure 8b). Velocity use exceeded availability at ~0 cm/s in the normal distribution, ~5 cm/s in the uniform distribution and ~17 and 45 cm/s in the constant distribution. Overall, the relationships indicate a preference of depths between ~40-80 cm, and a preference for low velocities approaching 0 m/s. Substrate availability exceeded use for all substrate types except for fines, where use exceeded availability, and gravel, where use equalled availability (Figure 9b). These results suggest a preference for small substrates and were considered in conjunction with existing substrate HSI for Mountain Whitefish fry to determine a preference for gravel (Table 4).

Mountain Whitefish juvenile depth use exceeded availability at ~0.3 - 0.45 m for all three frequency distributions (Figure 8c), indicating a preference toward this depth range. Velocity use exceeded availability below ~15 cm/s, indicating preference for low water velocities. For all substrate types, habitat availability exceeded or was equal to habitat use, indicating no strong preference for substrate for this age class (Figure 9c).

Rainbow Trout juveniles exhibited preferences for water depths greater than ~0.7 m (Figure 8d). Habitat availability exceeded use for most non-zero velocities, indicating a preference toward slow water. Habitat use exceeded availability for only the riprap size range, indicating a preference for riprap (Figure 9d).

For Prickly Sculpin juveniles, habitat use exceeded availability for water depths from ~ 0.7 to 1.7 m in both the normal and uniform frequency distributions (Figure 8e). Velocity habitat use was similar to availability, indicating little velocity preference for this species. For substrate, the tendency was for use to exceed availability at larger substrate types (cobble and larger), showing a preference for these sizes (Figure 9e).

Redside Shiner juveniles demonstrated preferences for water depths greater than ~0.7 m (Figure 8f). Velocity habitat use exceeded availability below ~15 cm/s, indicating preference for slow water. Substrate use exceeded availability for the largest size classes (bedrock and riprap), suggesting a preference towards these substrate types (Figure 9f).

Table 4. Summary of HSI for the Middle Columbia River

Species and Life Stage	Water Depth (cm)		Water Velocity (cm/s)		Substrate[1]	
	Optimal[2]	Usable[3]	Optimal[2]	Usable[3]	Optimal[2]	Usable[3]
Bull Trout juveniles	20-80	10-300	0-15	0-75	GR, RR	All
Mountain Whitefish fry	35-75	2-125	0-5	0-60	GR	All
Mountain Whitefish juveniles	20-55	2-200	0-15	0-65	GR	All
Rainbow Trout juveniles	50-150	2-350	0-5	0-50	RR	All
Prickly Sculpin juveniles	52-100	15-215	n/a	n/a	GR, CO	All
Redside Shiner juveniles	50-120	2-220	0-5	0-50	RR	All

[1]FI=Fines, GR=Gravel, CO=Cobble, BO=Boulder, BR=Bedrock, RR=Riprap

[2]Suitability = 1.0

[3]Suitability > 0

3.1.3. Integrate MCR Habitat Use and Availability with Existing Knowledge

Habitat use and availability curves (for each frequency distribution) are overlain with existing HSI in Figure 8 (Ptolemy 2001, Bovee 1978, EMA 1991). This information was interpreted to obtain the HSI presented in Figure 10.

Figure 8. Habitat use, availability, existing HSI, and Middle Columbia River HSI for a) Bull Trout juveniles, b) Mountain Whitefish fry, c) Mountain Whitefish juveniles, d) Rainbow Trout juveniles, e) Prickly Sculpin juveniles, f) Redside Shiner juveniles.

a) Bull Trout juveniles

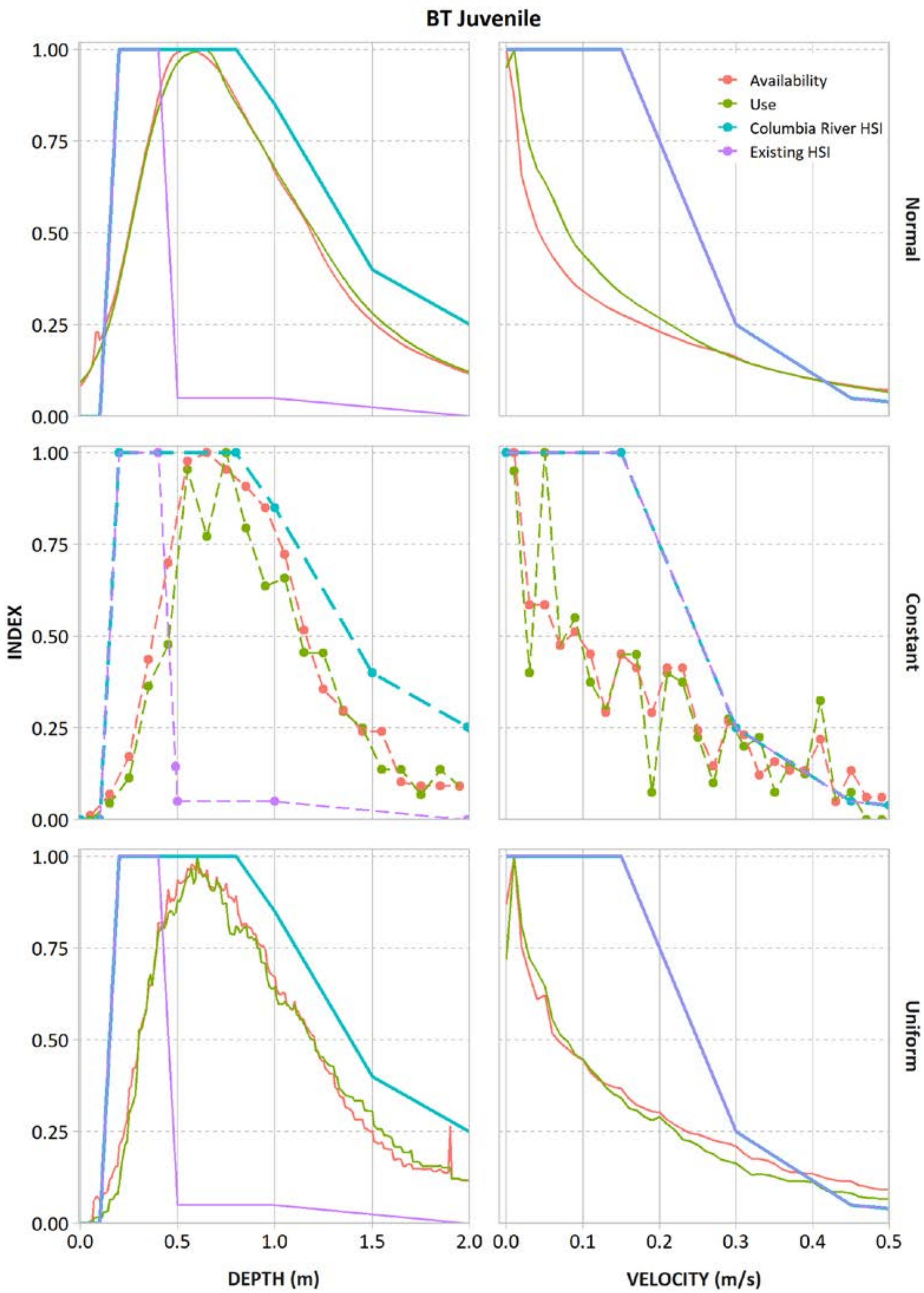


Figure 8. Continued.

b) Mountain Whitefish fry

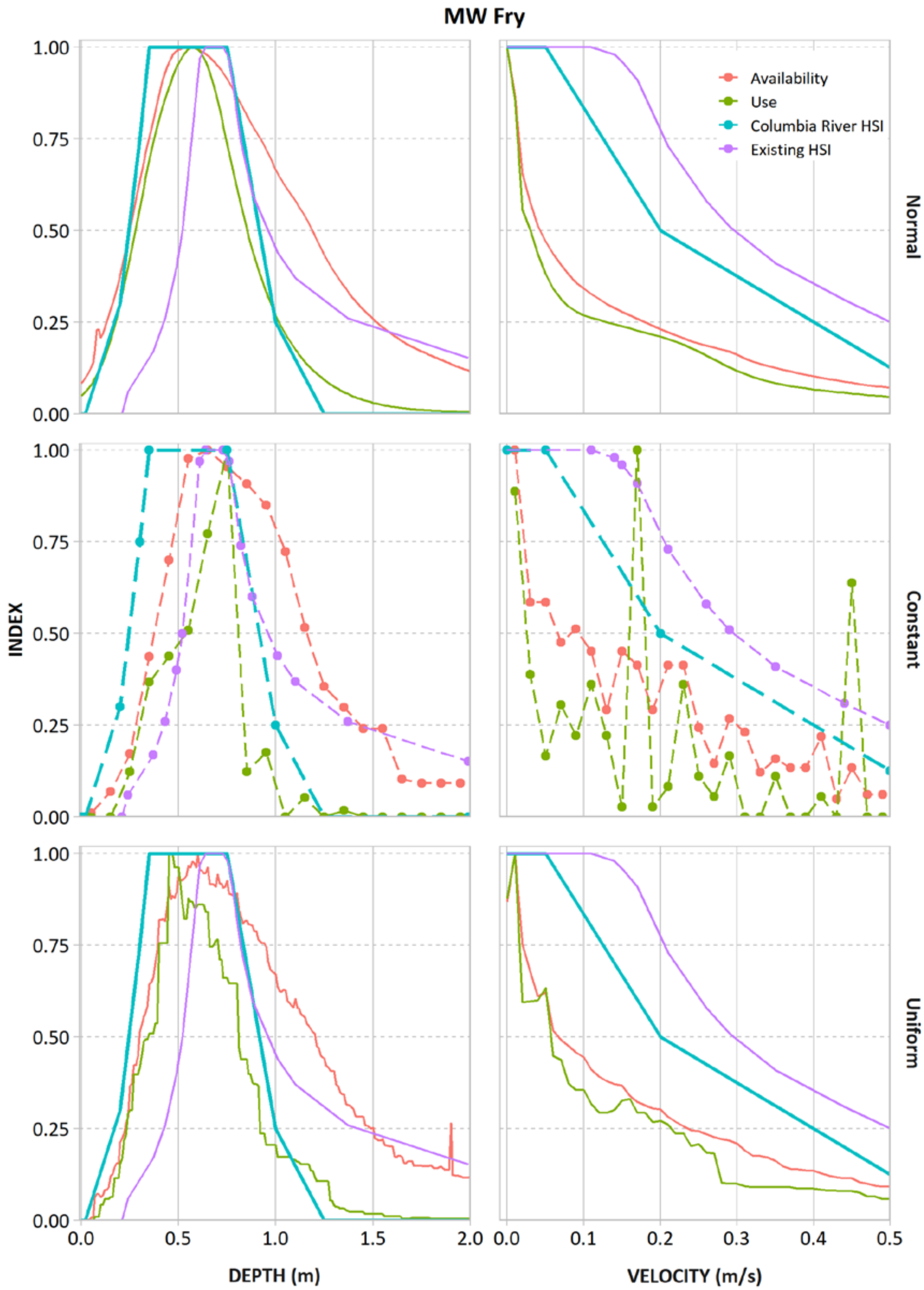


Figure 8. Continued.

c) Mountain Whitefish juveniles

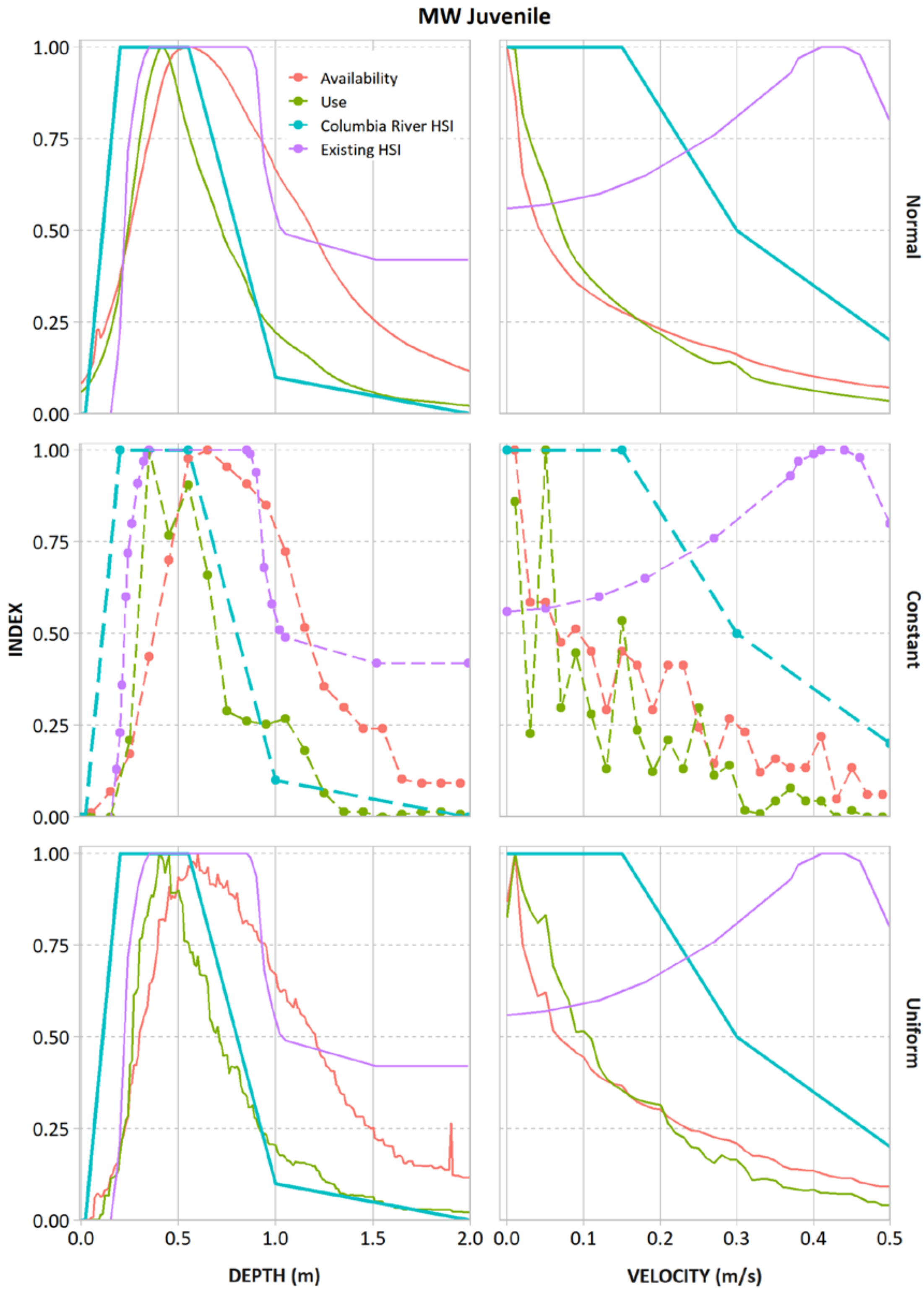


Figure 8. Continued.

d) Rainbow Trout juveniles

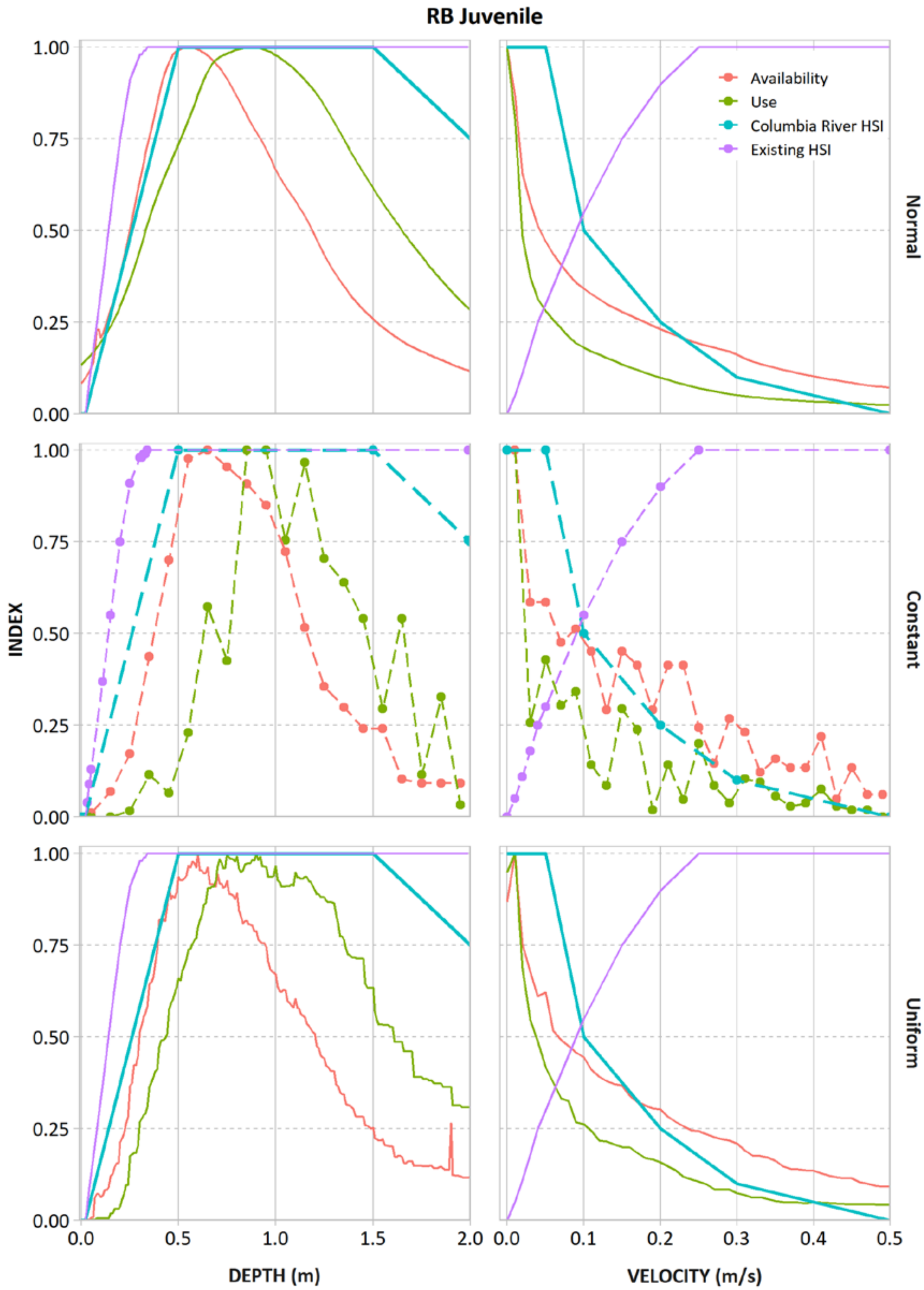
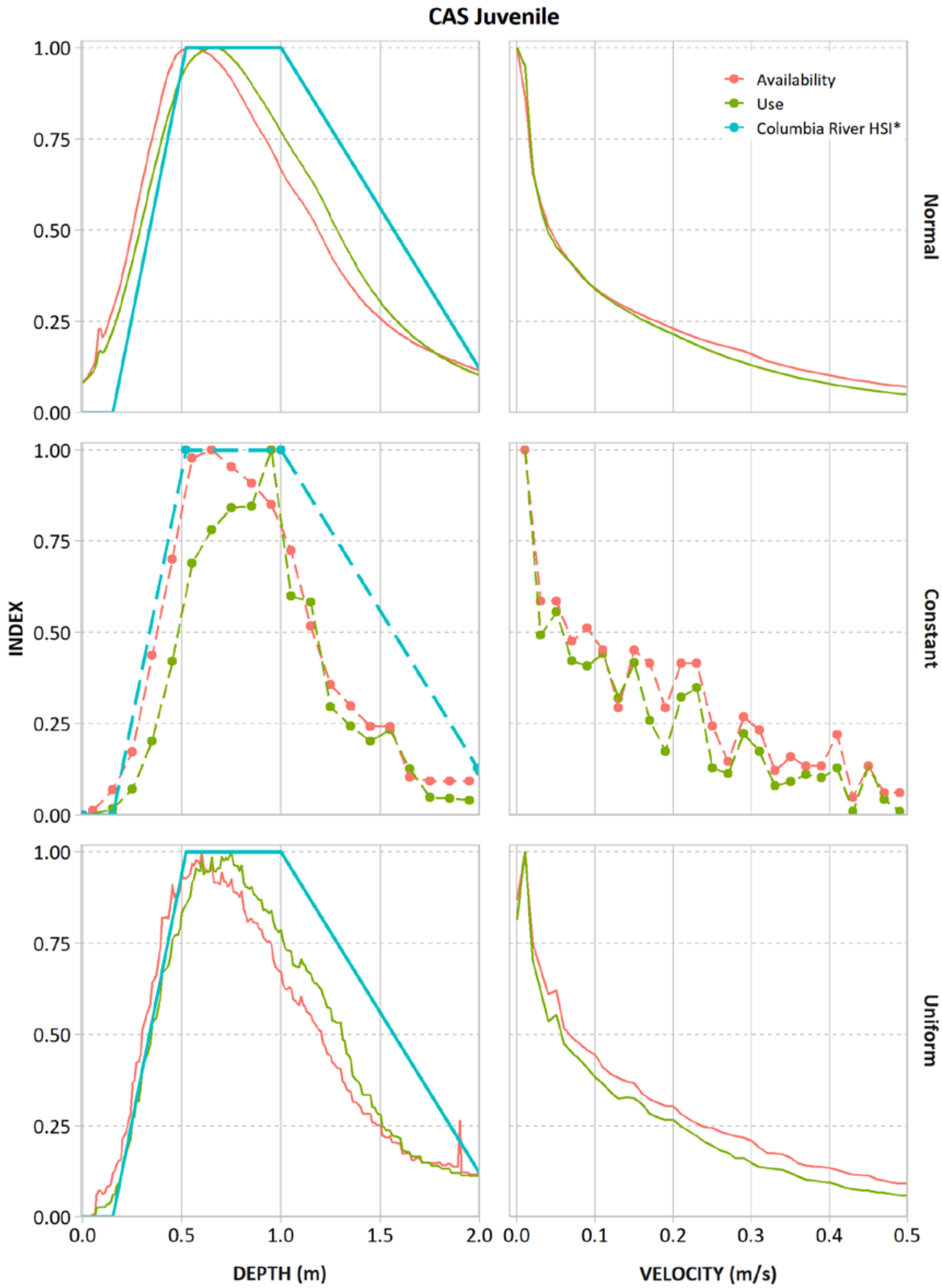


Figure 8. Continued.

e) Prickly Sculpin juveniles



*Habitat use not driven by velocity preference.

Figure 8. Continued.

f) Redside Shiner juveniles

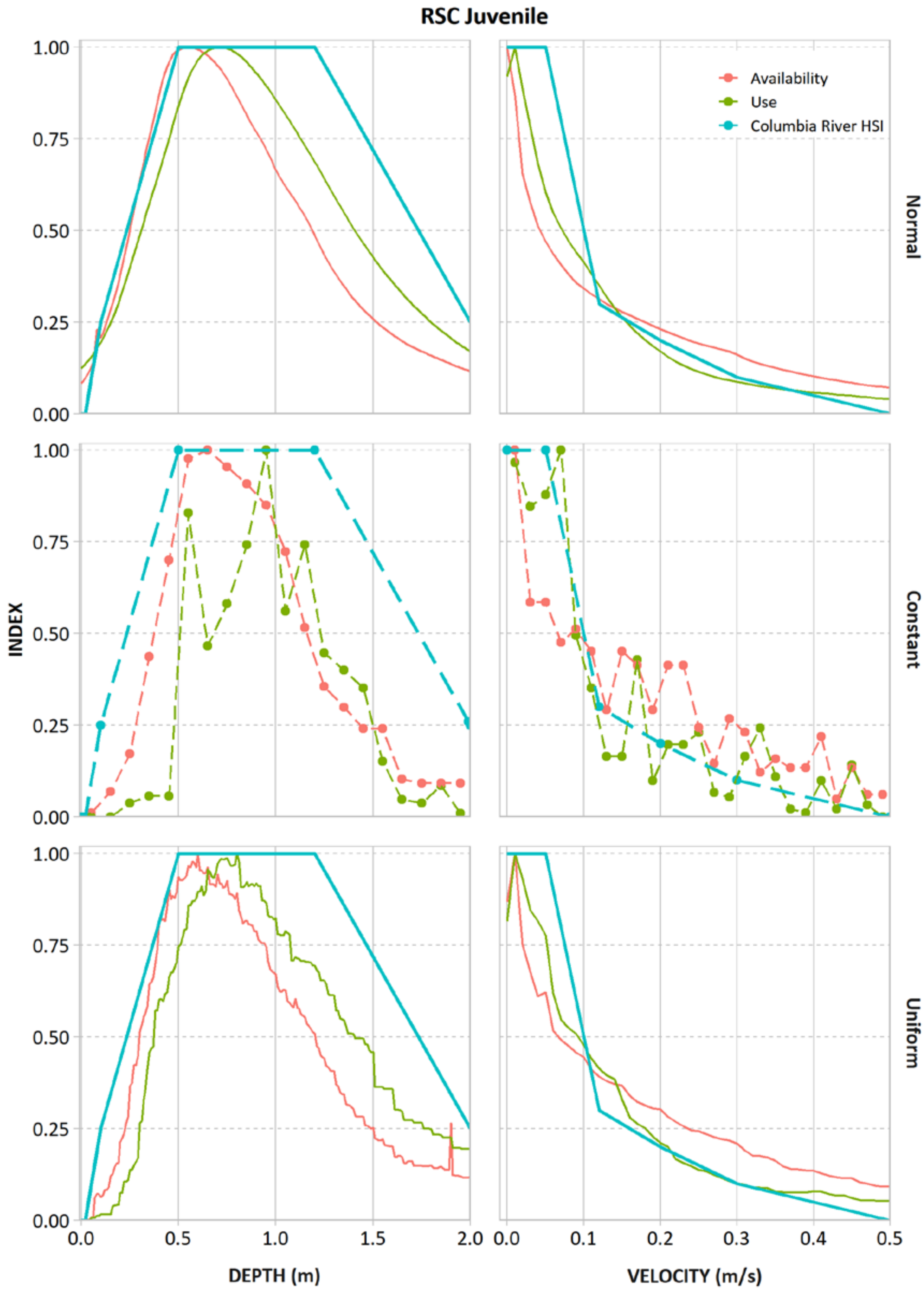


Figure 9. Substrate use, availability, existing HSI, and Middle Columbia River HSI for a) Bull Trout juveniles, b) Mountain Whitefish fry, c) Mountain Whitefish juveniles, d) Rainbow Trout juveniles, e) Prickly Sculpin juveniles, f) Redside Shiner juveniles.

a) Bull Trout juveniles

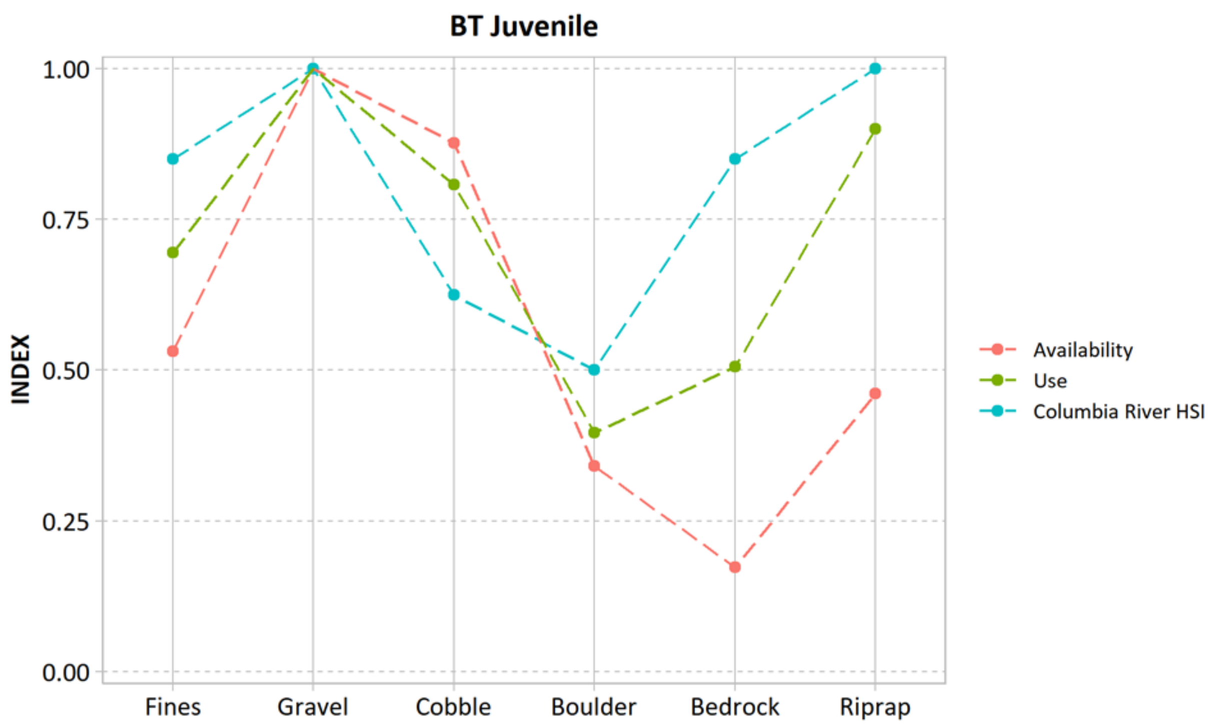
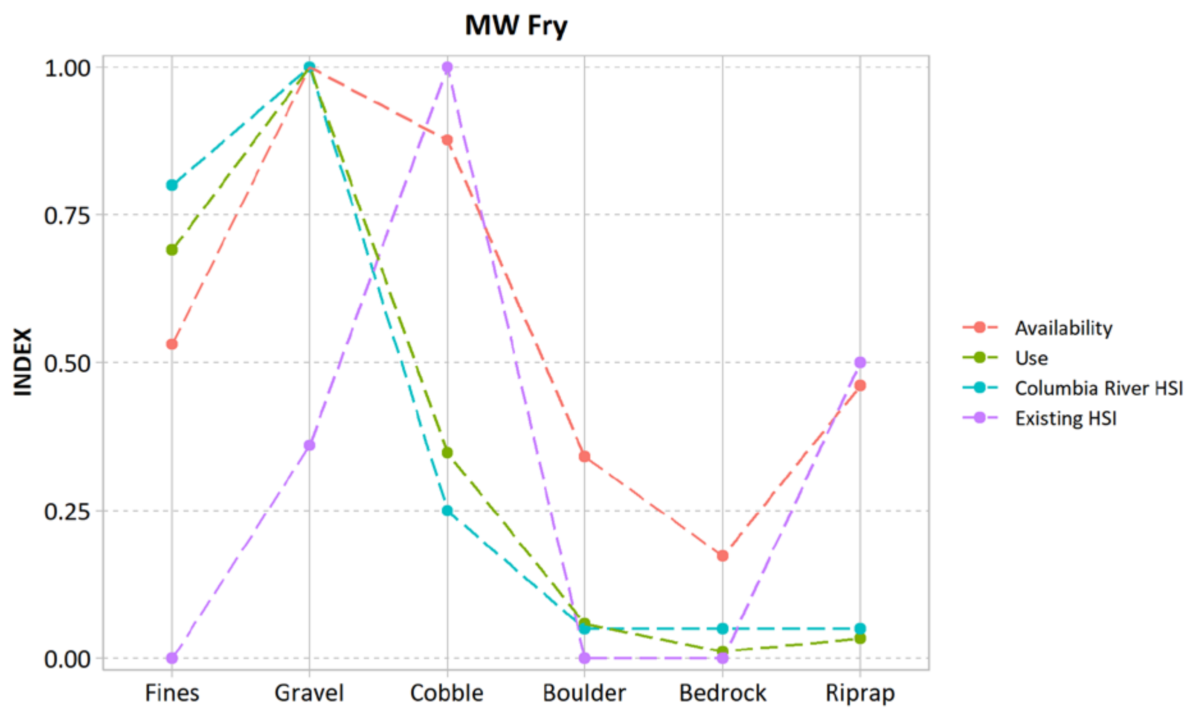


Figure 8. Continued.

b) Mountain Whitefish fry



c) Mountain Whitefish juveniles

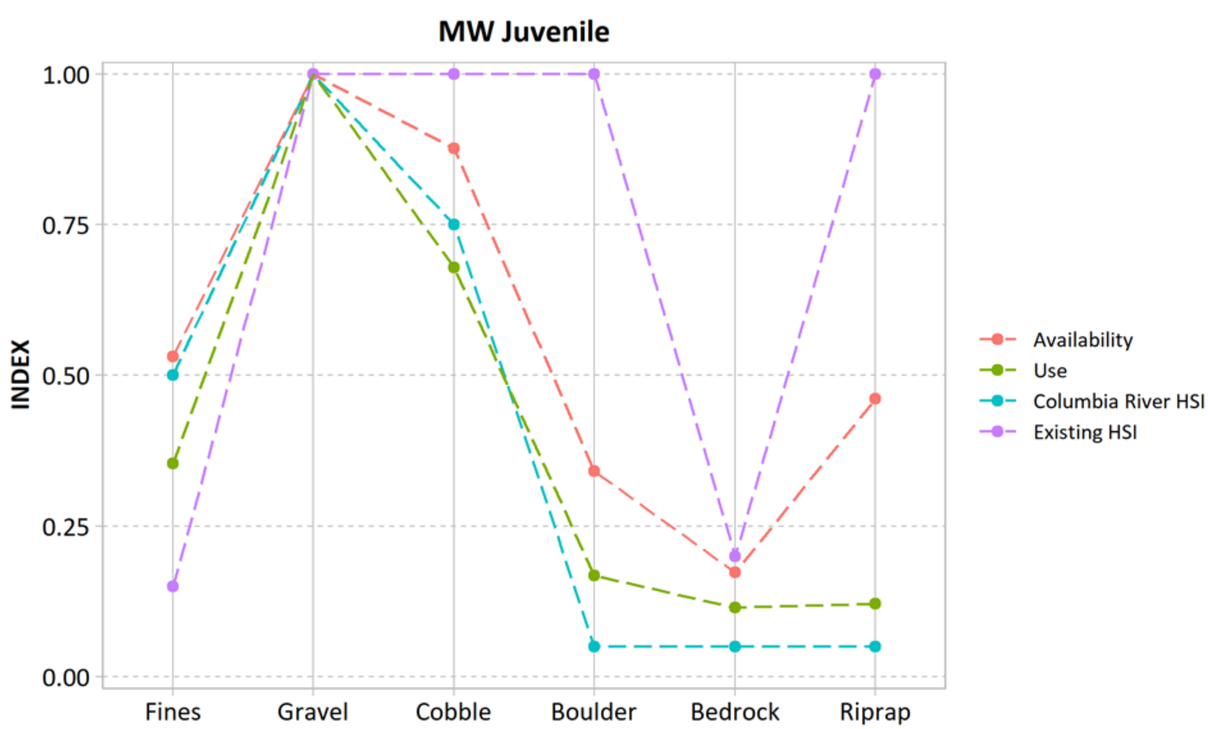
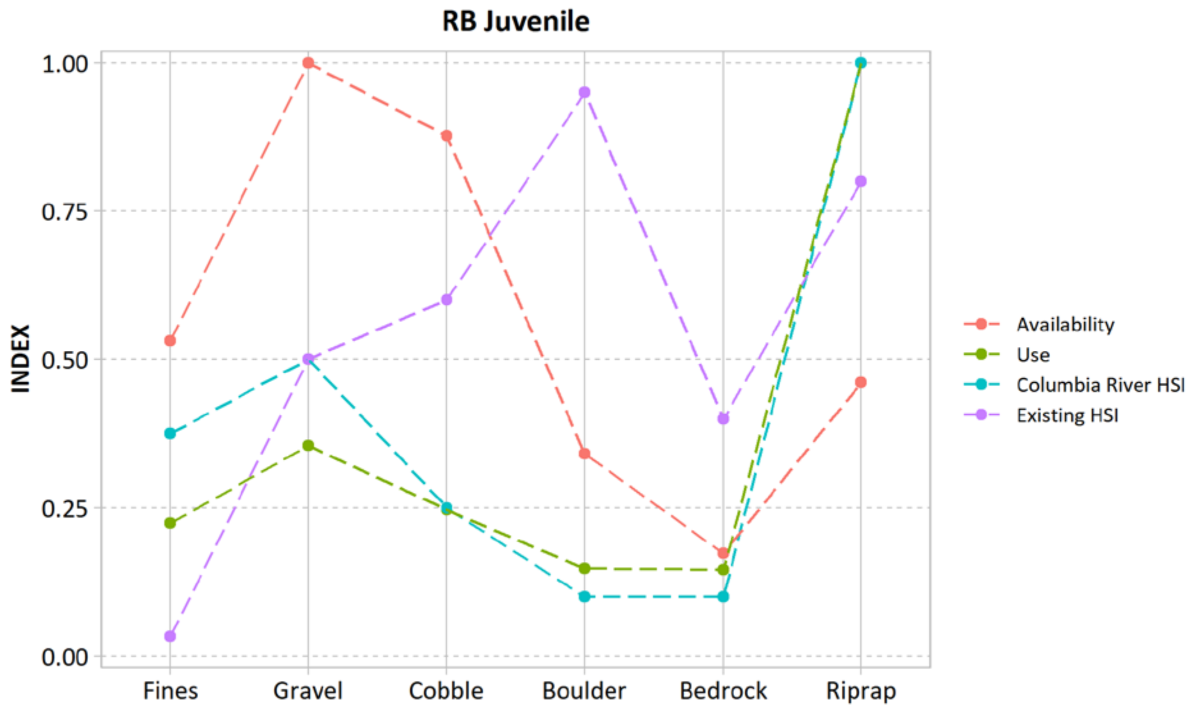


Figure 8. Continued.

d) Rainbow Trout juveniles



e) Prickly Sculpin juveniles

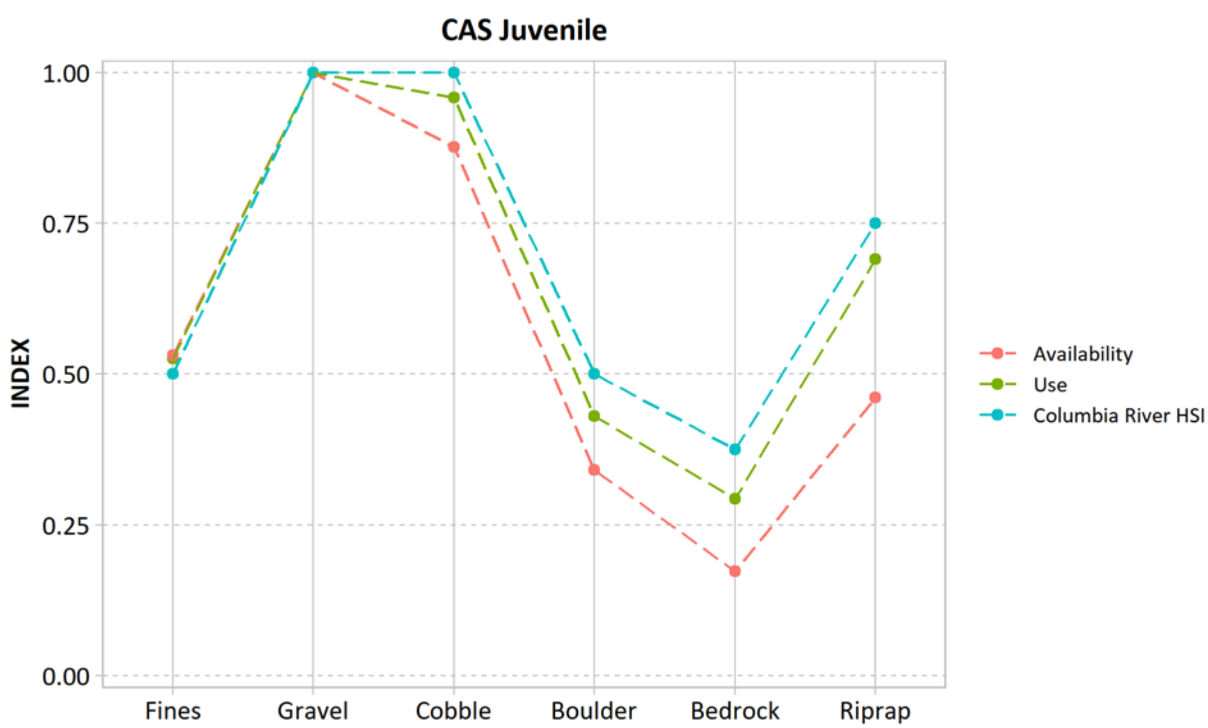


Figure 8. Continued.

f) Redside Shiner juveniles

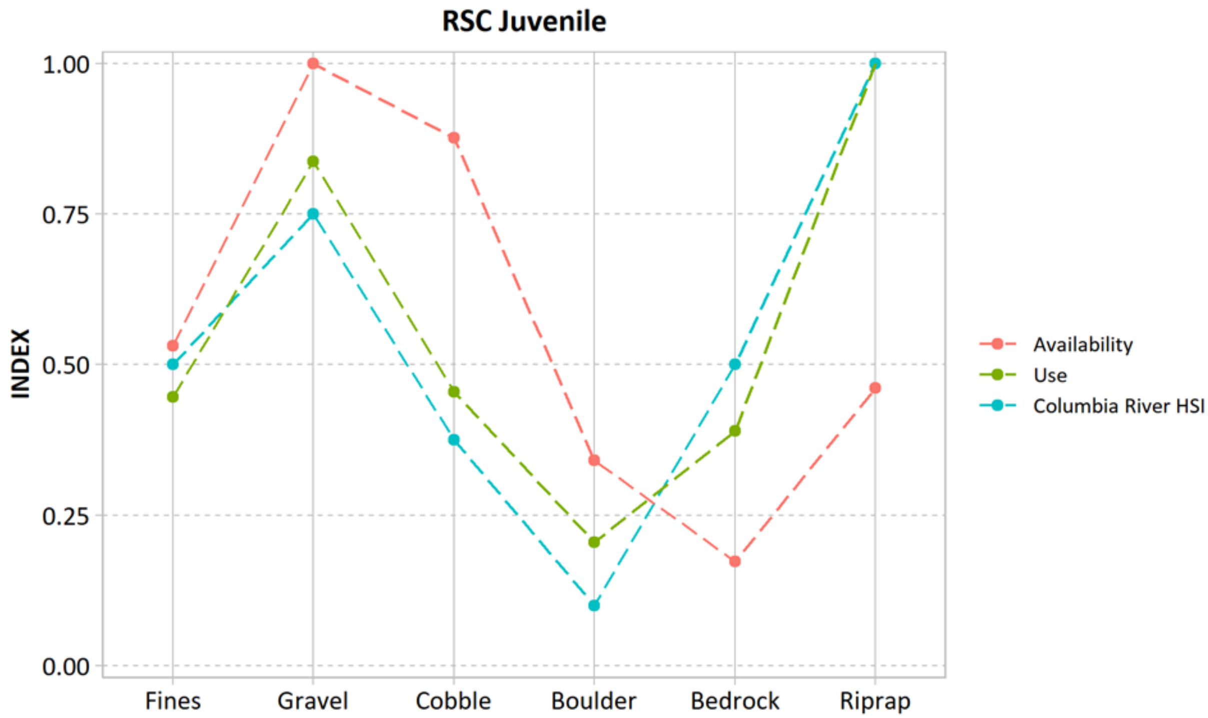
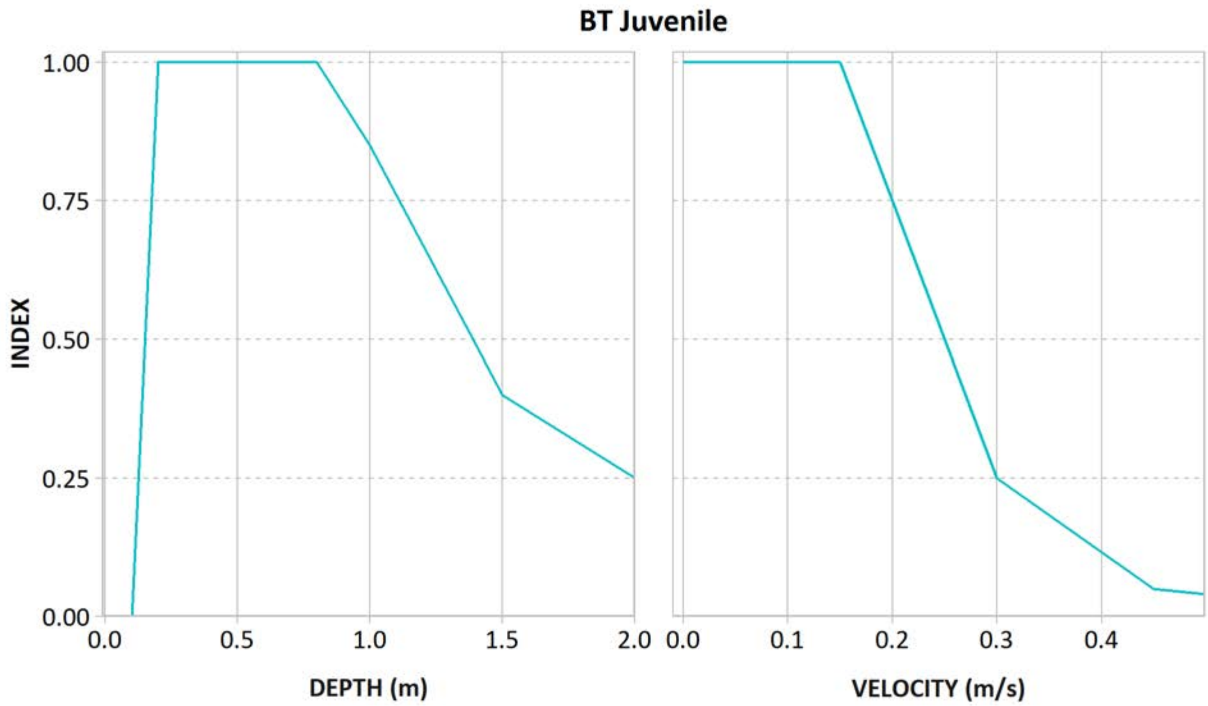


Figure 10. Middle Columbia River depth and velocity HSI for a) Bull Trout juveniles, b) Mountain Whitefish fry, c) Mountain Whitefish juveniles, d) Rainbow Trout juveniles, e) Prickly Sculpin juveniles, f) Redside Shiner juveniles.

a) Bull Trout juveniles



b) Mountain Whitefish fry

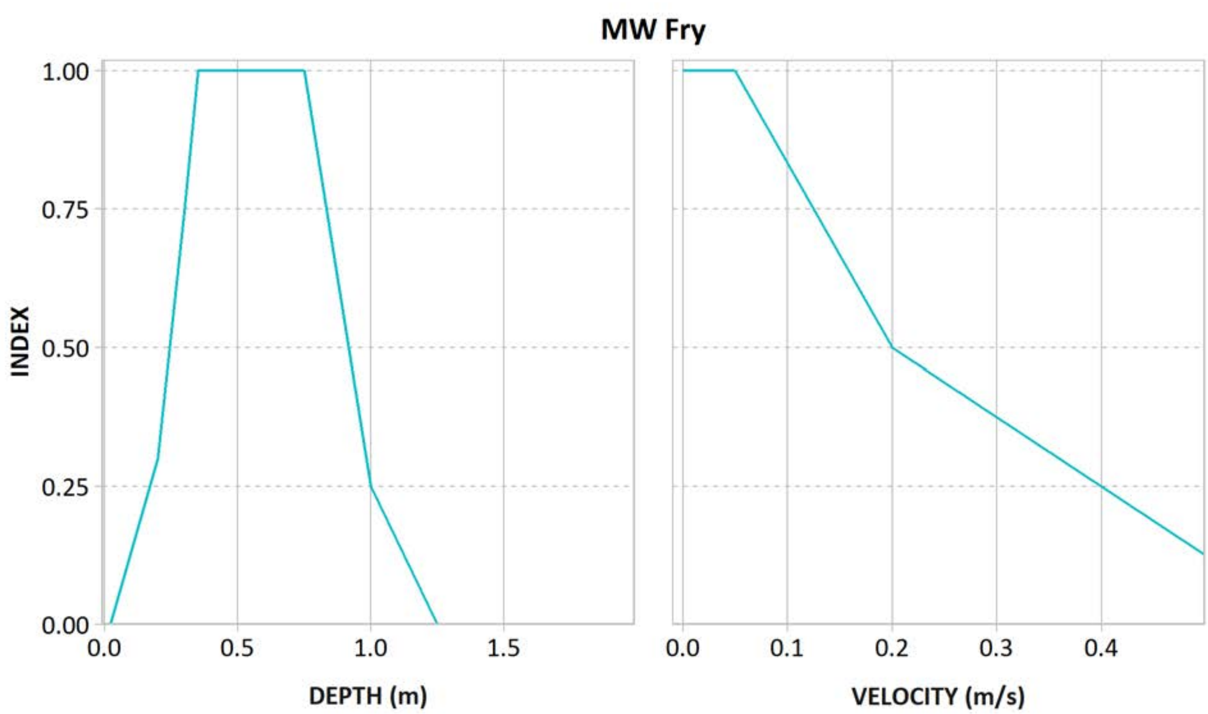
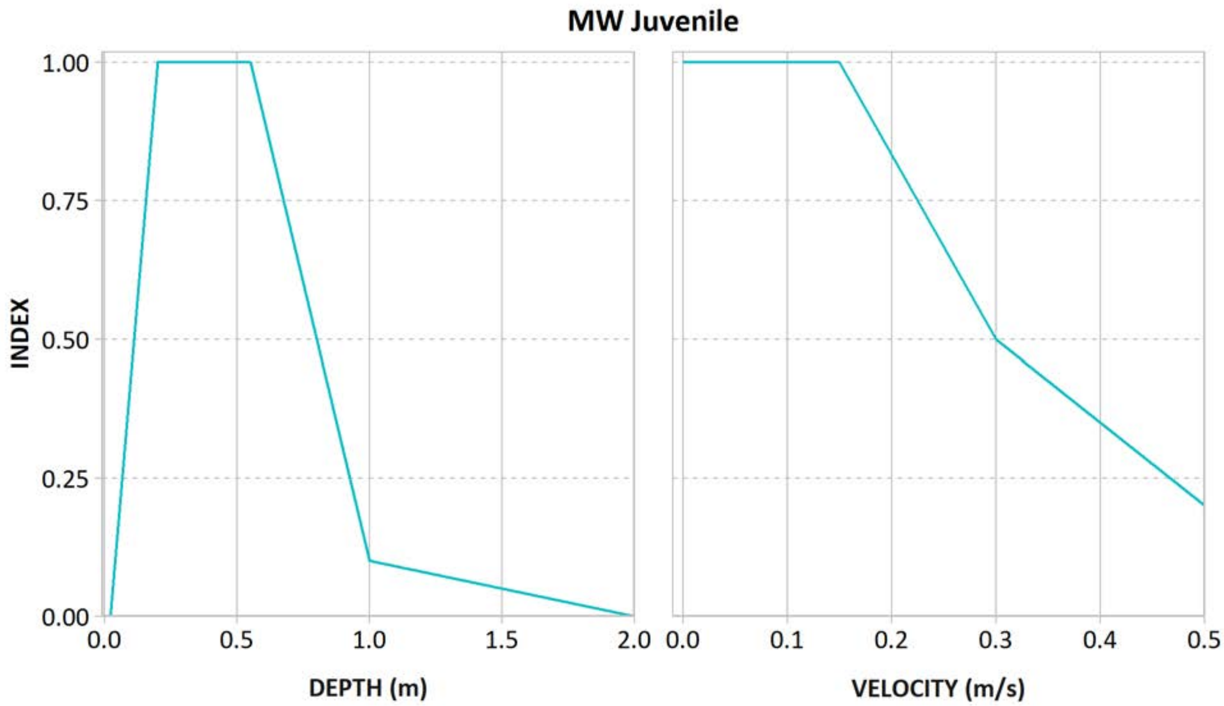


Figure 10. Continued.

c) Mountain Whitefish juveniles



d) Rainbow Trout juveniles

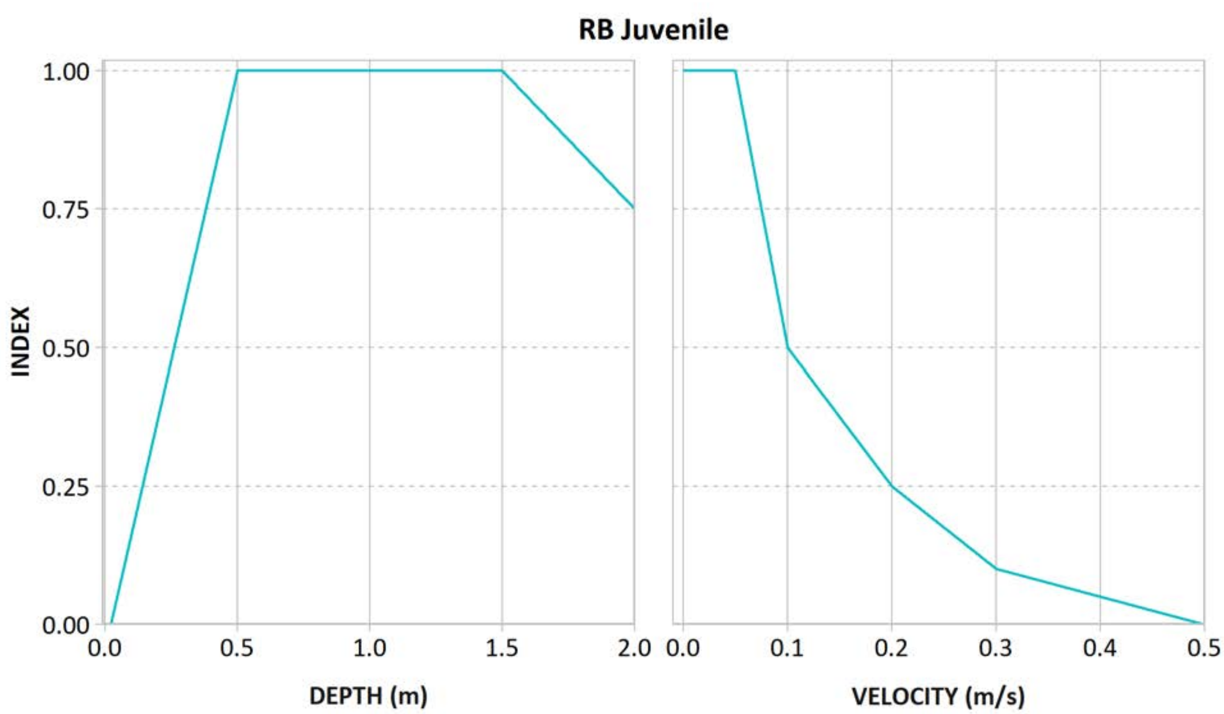
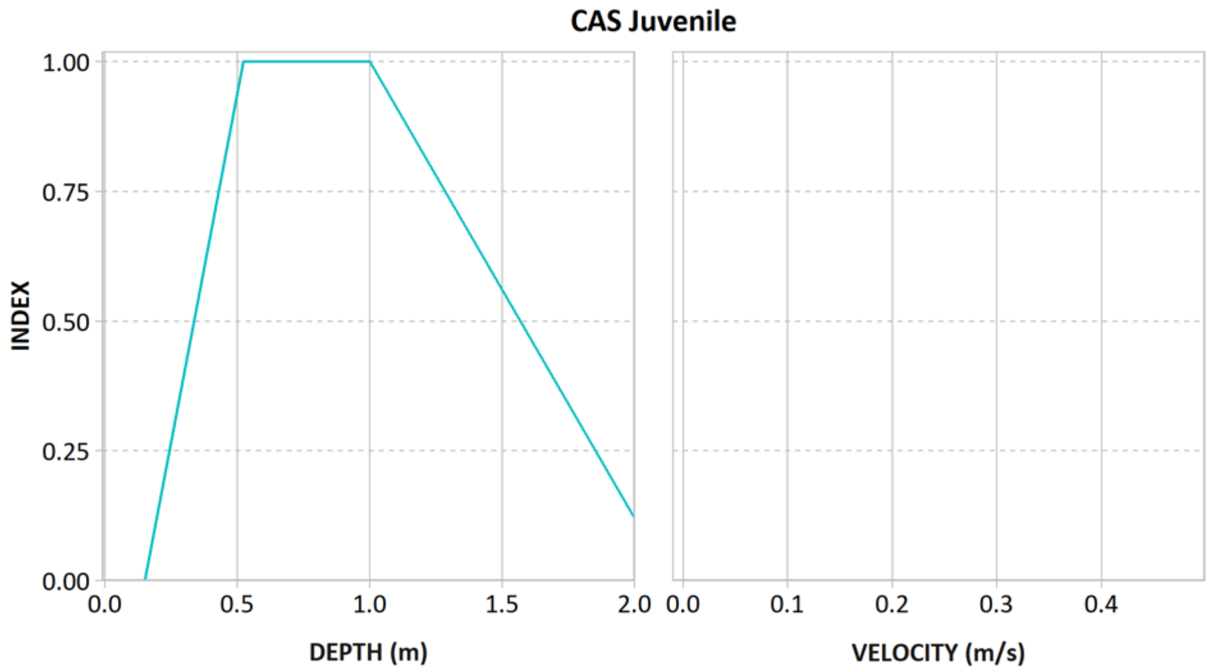


Figure 10. Continued.

e) Prickly Sculpin juveniles



*Habitat use not driven by velocity preference.

f) Redside Shiner juveniles

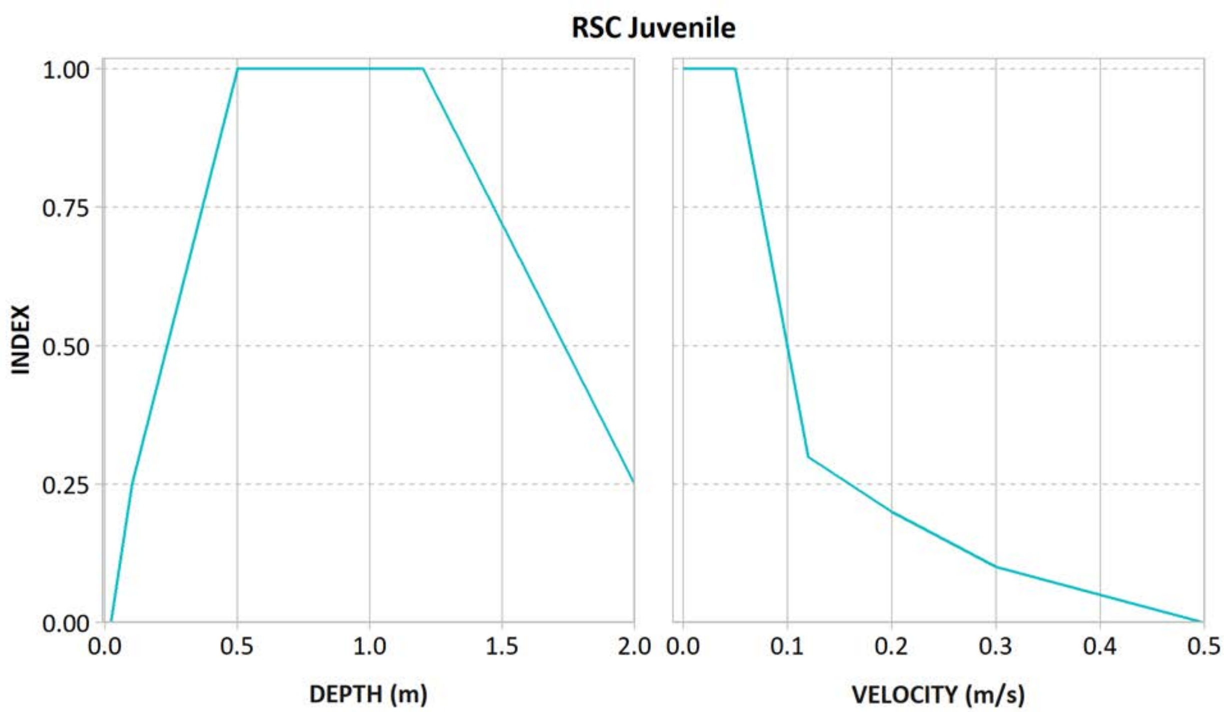
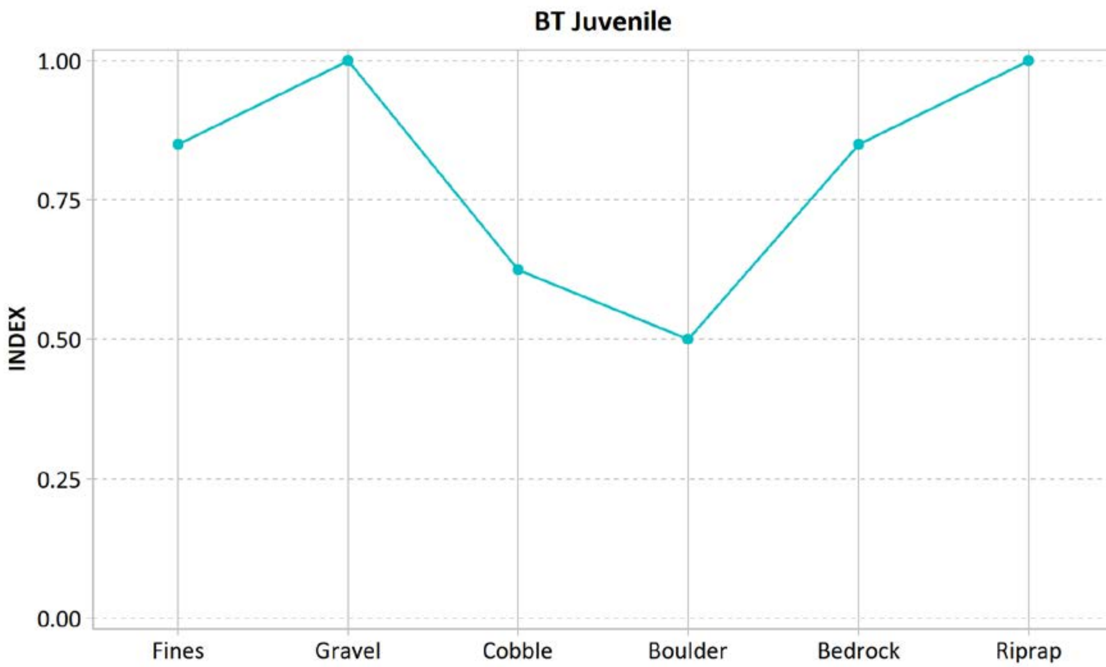


Figure 11. Middle Columbia River substrate HSI for a) Bull Trout juveniles, b) Mountain Whitefish fry, c) Mountain Whitefish juveniles, d) Rainbow Trout juveniles, e) Prickly Sculpin juveniles, f) Redside Shiner juveniles.

a) Bull Trout juveniles



b) Mountain Whitefish fry

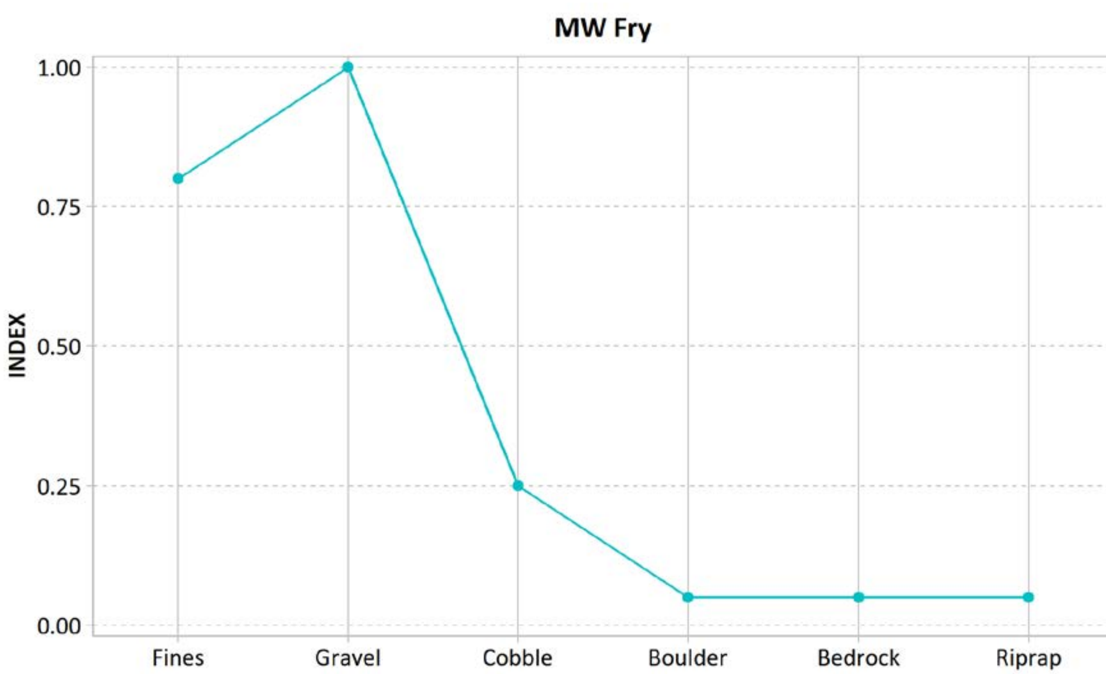
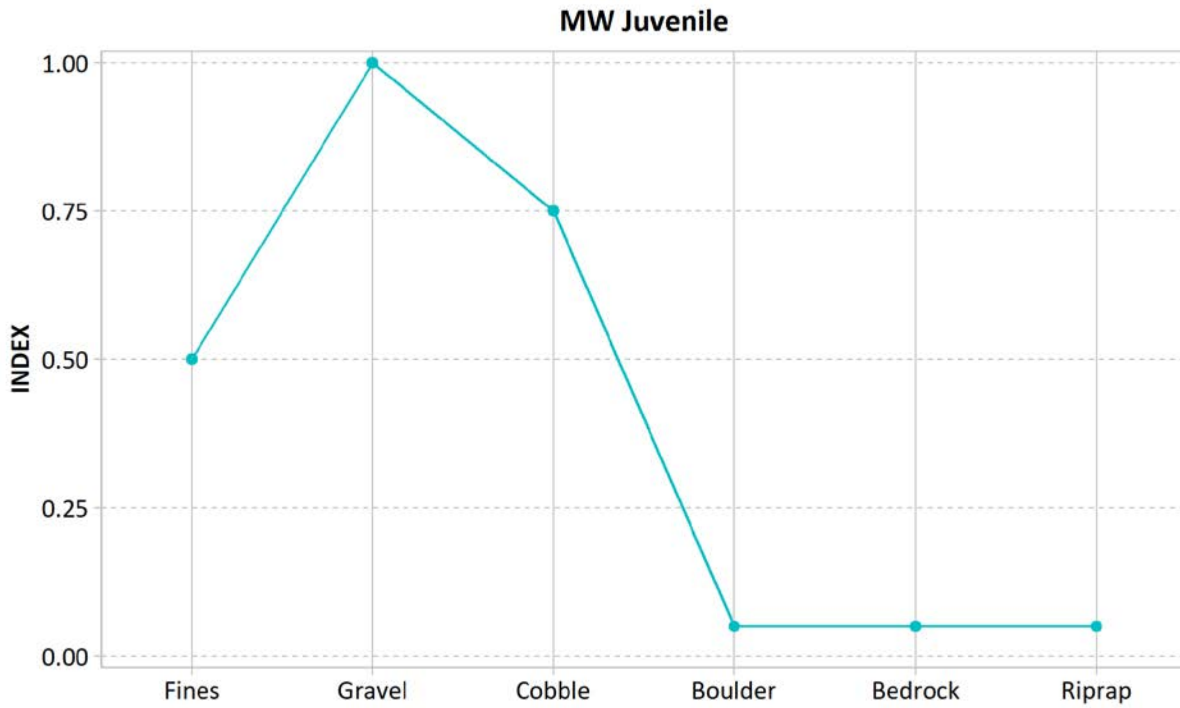


Figure 11. Continued.

c) Mountain Whitefish juveniles



d) Rainbow Trout juveniles

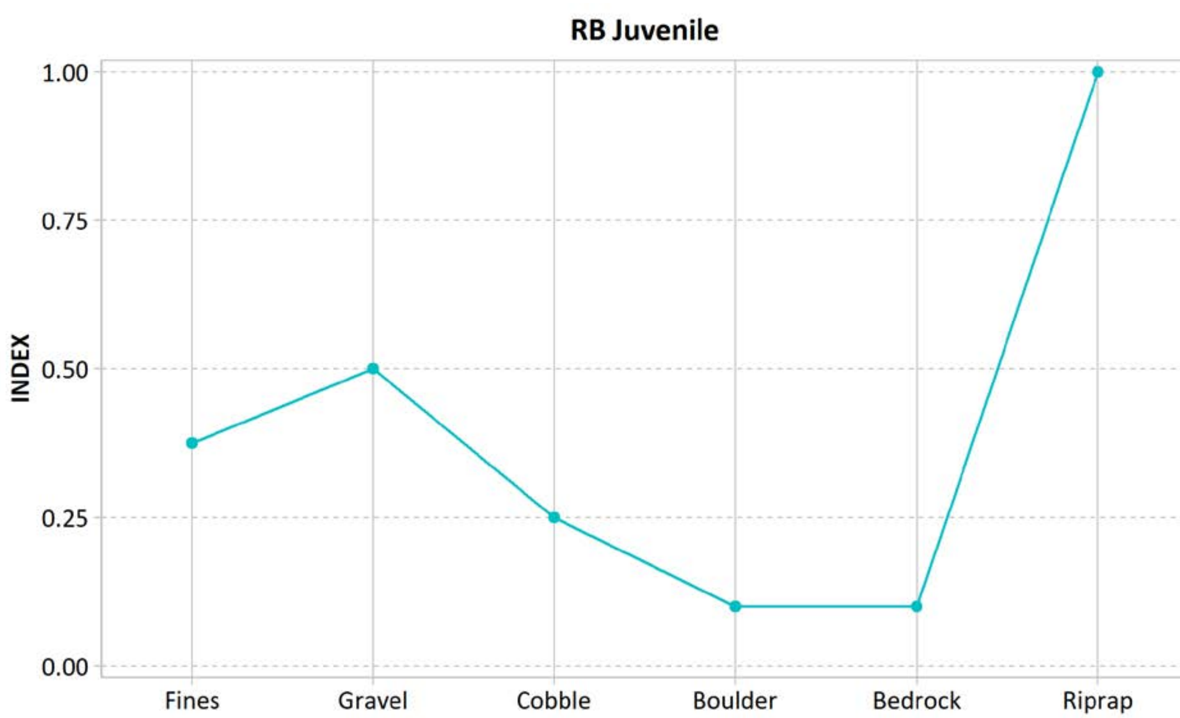
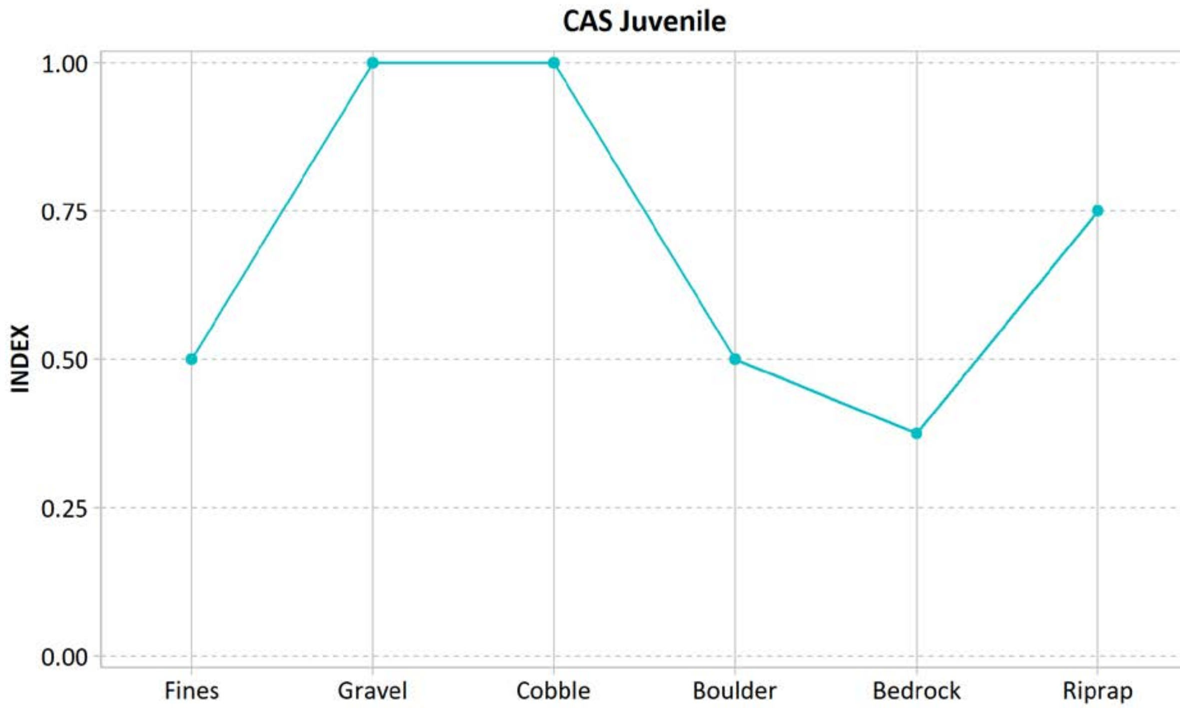
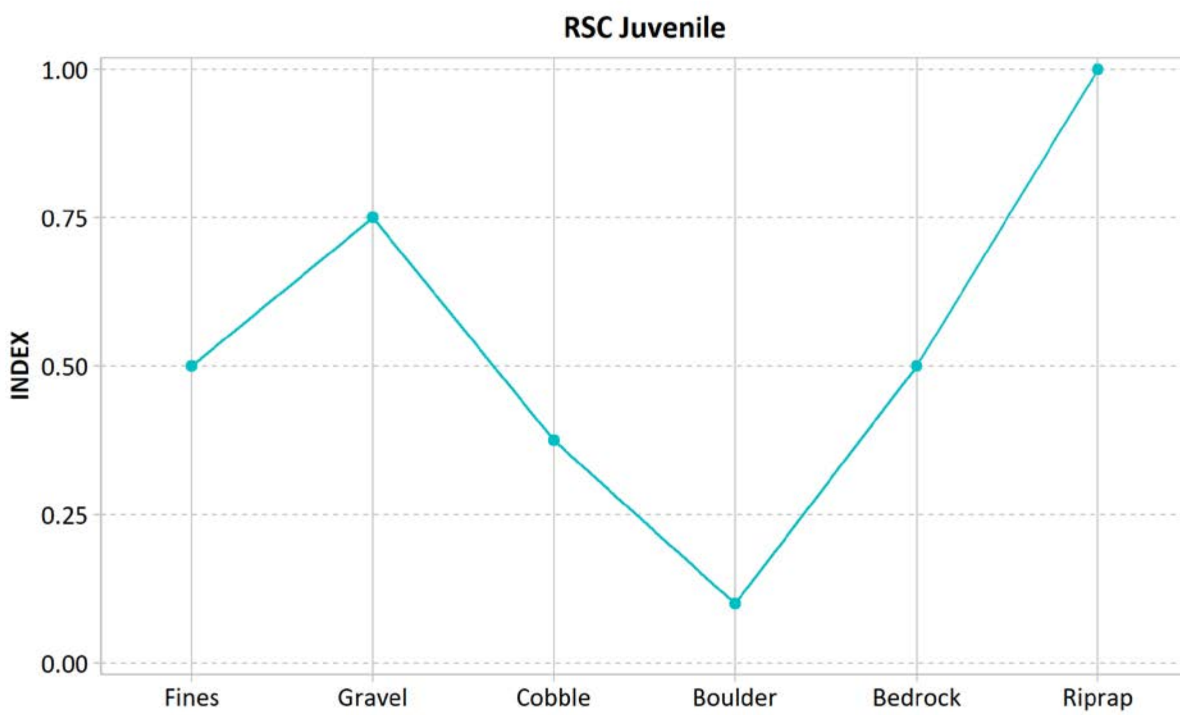


Figure 11. Continued.

e) Prickly Sculpin juveniles



f) Redside Shiner juveniles



3.2. Integration with 2-D Hydraulic Model

3.2.1. HSI Validation

The locations of fish surveys with the greatest counts under the validation flow condition (High ALR, Rev discharge ~296 m^3/s) are shown in Appendix A. These fish observations are overlain with the HSI. It is important to note that the fish survey locations are shown as a single point, while in reality the survey took place along ~100 m of shoreline, and the precise location of the observed fish is unknown. Inset maps are presented to provide additional detail around the fish survey sites, and the scale within each inset map can be used to determine the proximity to highly suitable habitat. A discrepancy is present between the fish survey data and the HSI if highly suitable habitat is not present within 100 m (upstream or downstream) of the fish location.

In all cases, there is highly suitable habitat (SI > 0.50) within 100 m of the survey waypoints. The maps demonstrate that the accuracy of the waypoints may be limited; for example, the waypoint data suggest that 2 Bull Trout juveniles were observed on the Revelstoke Golf Club (Map 1 in Appendix A), and the data show Mountain Whitefish observations ~50-100 m from shore (Map 2 and Map 3 in Appendix A), which is inconsistent with the sampling methodology. These errors in the spatial data suggest limited accuracy and hence limit our ability to validate the HSI.

Given that there were no obvious contradictions between the predicted habitat suitability for the subset of fish data considered, the HSI were retained. These are attached in a Microsoft Excel spreadsheet (Appendix C).

3.2.2. Calculate Weighted Usable Area

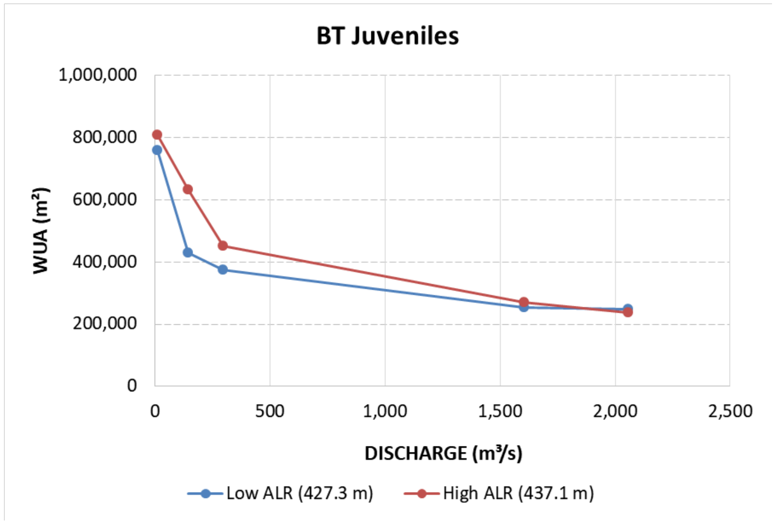
Weighted usable areas (WUA, m^2) generated using the HSI for each of the model runs are summarized in Table 5 and Figure 12.

Table 5. Weighted usable area (WUA) calculated from the Telemac2D output.

Species / Life Stage	Low ALR (427.3 m)					High ALR (437.1 m)				
	8.5 m³/s	142 m³/s	296 m³/s	1603 m³/s	2057 m³/s	8.5 m³/s	142 m³/s	296 m³/s	1603 m³/s	2057 m³/s
Bull Trout Juveniles	759,390	429,410	375,234	255,165	248,034	807,922	631,825	452,339	271,170	237,144
Mountain Whitefish Fry	445,924	271,708	245,344	148,374	133,677	341,793	286,056	220,471	146,788	127,129
Mountain Whitefish Juveniles	591,815	386,753	346,736	186,299	179,727	370,344	337,249	287,860	187,916	169,942
Rainbow Trout Juveniles	623,869	326,644	298,787	255,904	245,177	1,292,394	762,359	382,801	270,840	240,154
Prickly Sculpin Fry	790,827	889,718	781,320	606,531	430,326	675,694	645,329	566,021	452,580	353,606
Redside Shiner Juveniles	529,948	297,201	275,651	230,873	199,680	798,649	513,663	283,192	212,999	178,494

Figure 12. Weighted usable area (WUA) calculated for a) Bull Trout juveniles, b) Mountain Whitefish fry, c) Mountain Whitefish juveniles, d) Rainbow Trout juveniles, e) Prickly Sculpin juveniles, f) Redside Shiner juveniles.

a) Bull Trout juveniles



b) Mountain Whitefish fry

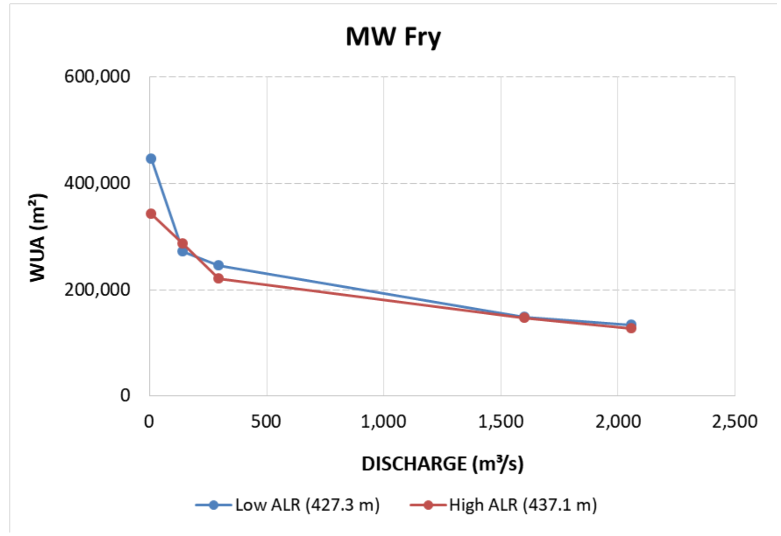
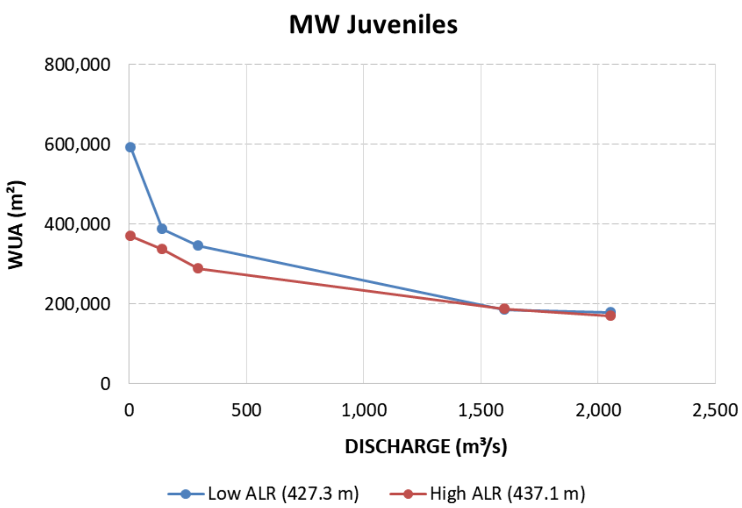


Figure 12. Continued.

c) Mountain Whitefish juveniles



d) Rainbow Trout juveniles

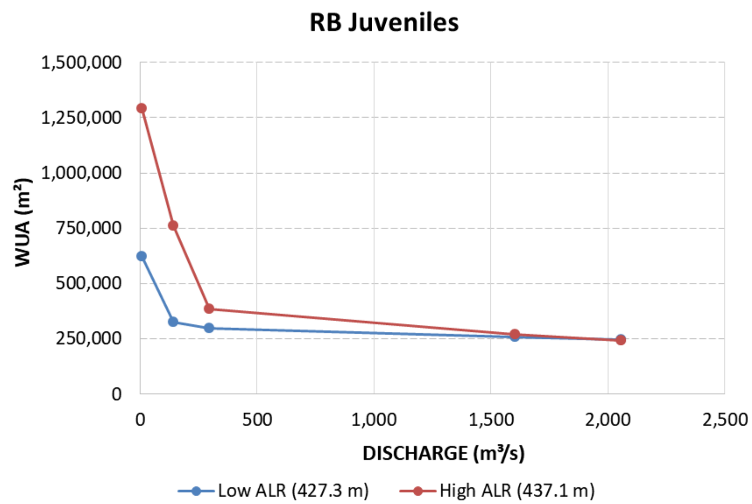
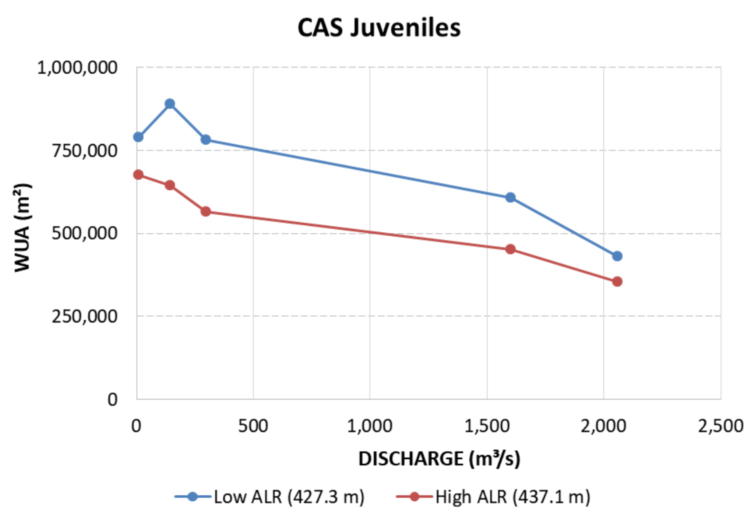
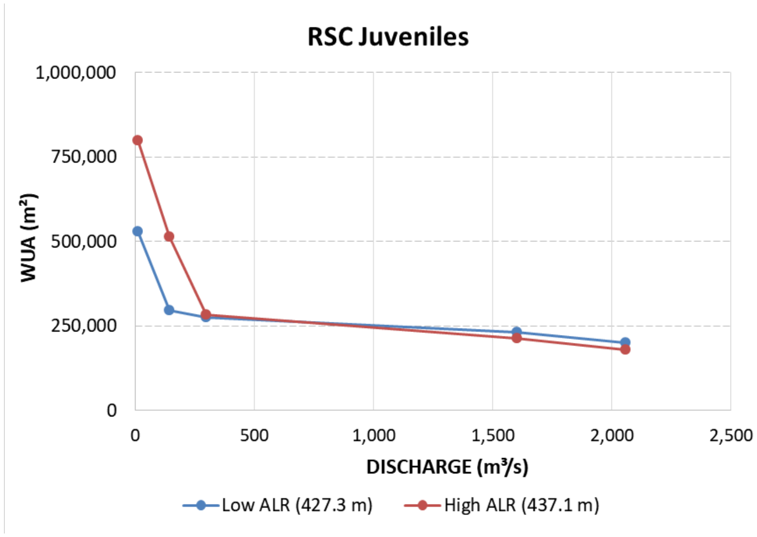


Figure 12. Continued.

e) Prickly Sculpin juveniles



f) Redside Shiner juveniles



3.3. Evaluation of Flow Scenarios

3.3.1. Selection of Flow Scenarios

Flow Frequency Analysis

Base and peak discharge conditions for numerical modelling were selected based on the flow frequency analysis. This analysis was completed with the objective of identifying ~4 flow rates for modelling.

Review of the Revelstoke Dam flow frequency analysis (Figure 13a) revealed that the typical pre-REV5 minimum daily discharge was near 0 m^3/s, consistent with expectations. For the majority of seasons (June to March), the typical post-REV5 base flow is ~296 m^3/s, and the 142 m^3/s minimum flow is frequently present during April-May (spring/fry emergence). Based on this information, we recommended three flow scenarios for modelling REV base flow: 0 m^3/s, 142 m^3/s and 296 m^3/s (Table 6). For the flow scenario of 0 m^3/s, the model actually used 8.5 m^3/s to account for outflow due to seepage (Table 8).

Maximum daily discharge at REV is more variable than the minimum daily discharge, as it is determined by BC Hydro operational objectives. For the purpose of modelling and creating a reasonable contrast with base flow conditions, we selected the 90th percentile maximum daily discharge for modelling. Pre-Rev5, the 90th percentile maximum daily discharge is ~1,603 m^3/s (Figure 13b). Since Rev5 came online, the 90th percentile maximum daily discharge has not changed much during the fall and spring, but has increased in the summer and over the winter, to ~2,057 m^3/s. These two flow rates (1603 m^3/s and 2057 m^3/s) were selected for modelling peak flow conditions (Table 6).

Water levels in ALR are similar pre and post-Rev5 (Table 7, Figure 13c). To represent free-flowing conditions in the study reach, we selected the 10th percentile ALR level for modelling (excluding summer, when backwatering is frequent). To represent a high pool (backwatering) condition, we selected the 90th percentile ALR level (excluding spring/fry emergence, when backwatering is infrequent). The ALR levels selected for modelling low pool and high pool are 427.3 m and 437.1 m, respectively, and are expected to produce a reasonable contrast between free-flowing and backwater conditions.

Table 6. Flow scenarios selected for modelling.

Life Stage	Period	Discharge (m^3/s)			
		Pre Rev5		Post Rev5	
		Base[1]	Peak[2]	Base[1]	Peak[2]
Overwintering	Nov-Mar	0	1,603	296	2,057
Fry Emergence	Apr-May	0	1,603	142	1,603
Summer Rearing	Jun-Aug	0	1,603	296	2,057
Fall Rearing	Sept-Oct	0	1,603	296	1,603

[1]Approximately equivalent to the 50th percentile minimum daily discharge

[2]Approximately equivalent to the 90th percentile maximum daily discharge

Table 7. Water levels in ALR pre and post Rev5. The average 10th and 90th percentile water levels were selected for modelling.

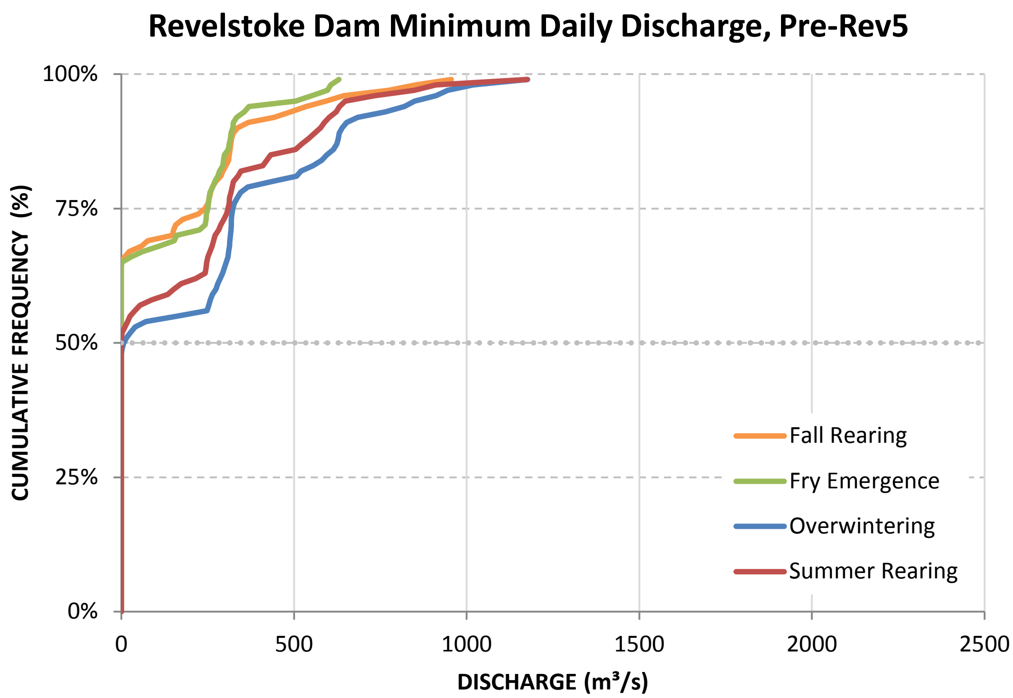
Life Stage	Period	Water Level - Upper Arrow Lake Reservoir (NAK) (m)			
		Pre Rev5		Post Rev5	
		10 percentile	90 percentile	10 percentile	90 percentile
Overwintering	Nov-Mar	426.6	434.1	424.9	435.5
Fry Emergence	Apr-May	426.8	433.1	427.5	433.6
Summer Rearing	Jun-Aug	433.6	439.2	432.7	439.4
Fall Rearing	Sept-Oct	430.3	437.9	428.0	436.8
Average Low Pool	Sept-May	427.9		426.8	
Average High Pool	Jun-Mar		437.0		437.2

Table 8. Summary of modelled flow scenarios.

Scenario	Rev Outflow (m^3/s)	Jordan Flow (m^3/s)	Illecillewaet Flow (m^3/s)	ALR Level (m)
Base #1 - Low	8.5	22	49	427.3
Base #2 - Low	142	22	49	427.3
Base #3 - Low	296	22	49	427.3
Peak #1 - Low	1,603	22	49	427.3
Peak #2 - Low	2,057	22	49	427.3
Base #1 - High	8.5	22	49	437.1
Base #2 - High	142	22	49	437.1
Base #3 - High	296	22	49	437.1
Peak #1 - High	1,603	22	49	437.1
Peak #2 - High	2,057	22	49	437.1

Figure 13. **Seasonal cumulative frequency of a) Revelstoke Dam minimum discharge, b) maximum discharge, and c) Arrow Lake Reservoir water level (Nakusp).**

a) Revelstoke Dam minimum daily discharge pre-Rev5 (top) and post-Rev5 (bottom)



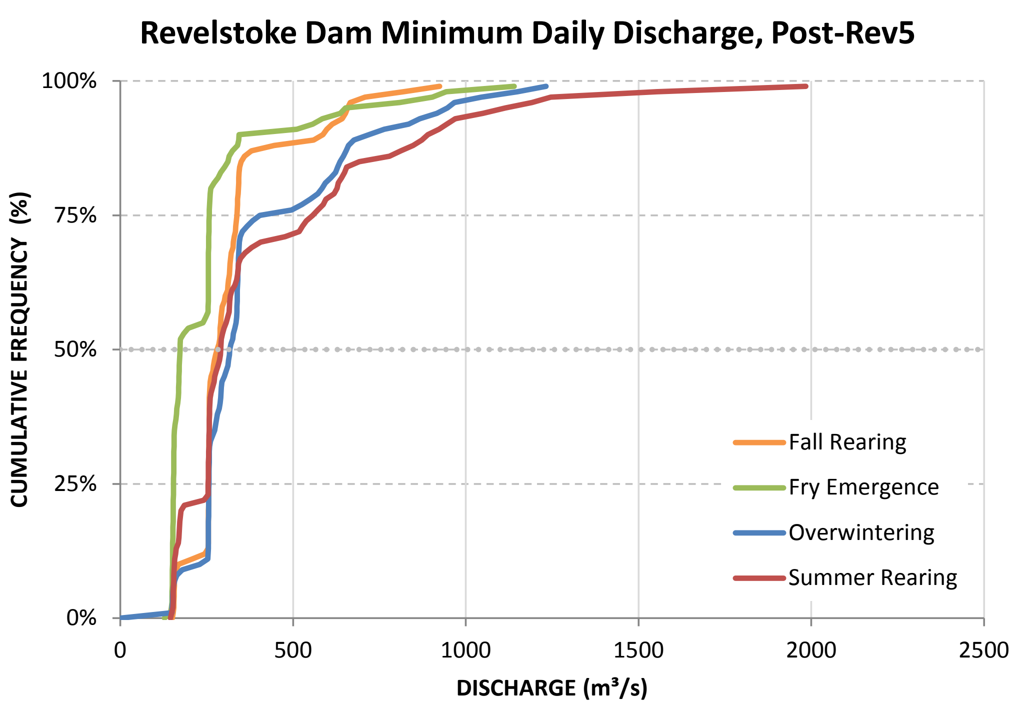
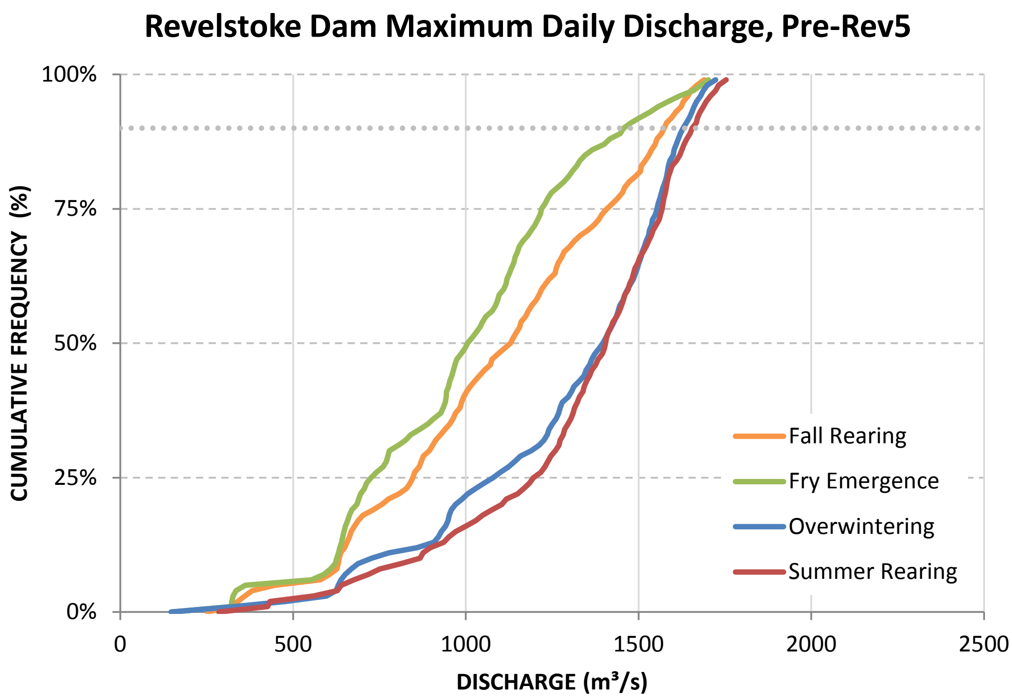


Figure 13. Continued.

b) Revelstoke Dam maximum daily discharge pre-Rev5 (top) and post-Rev5 (bottom)



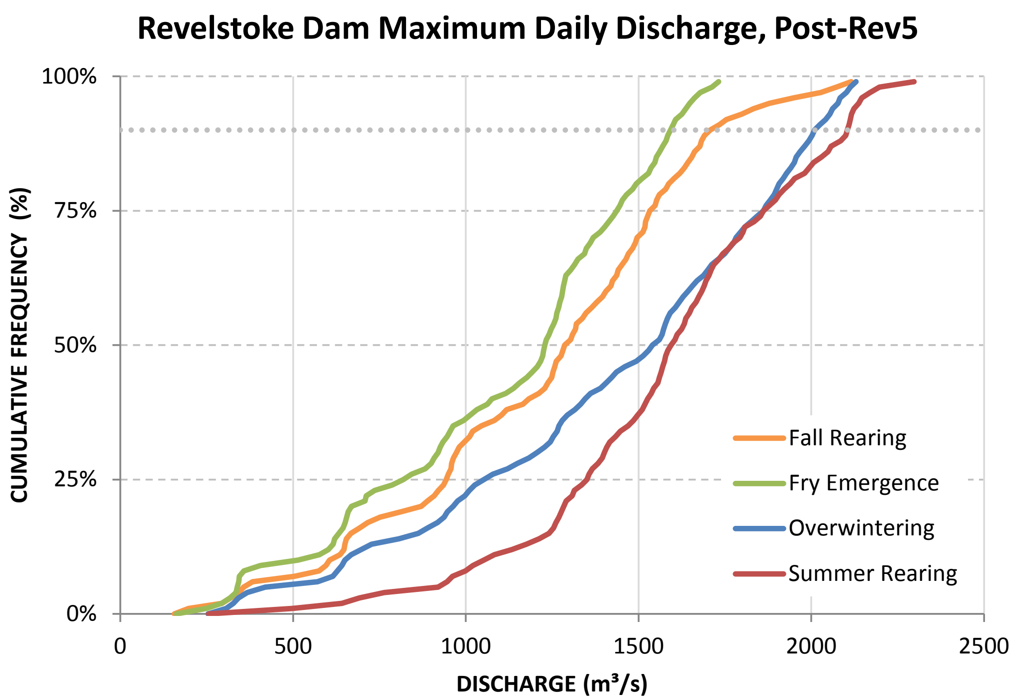
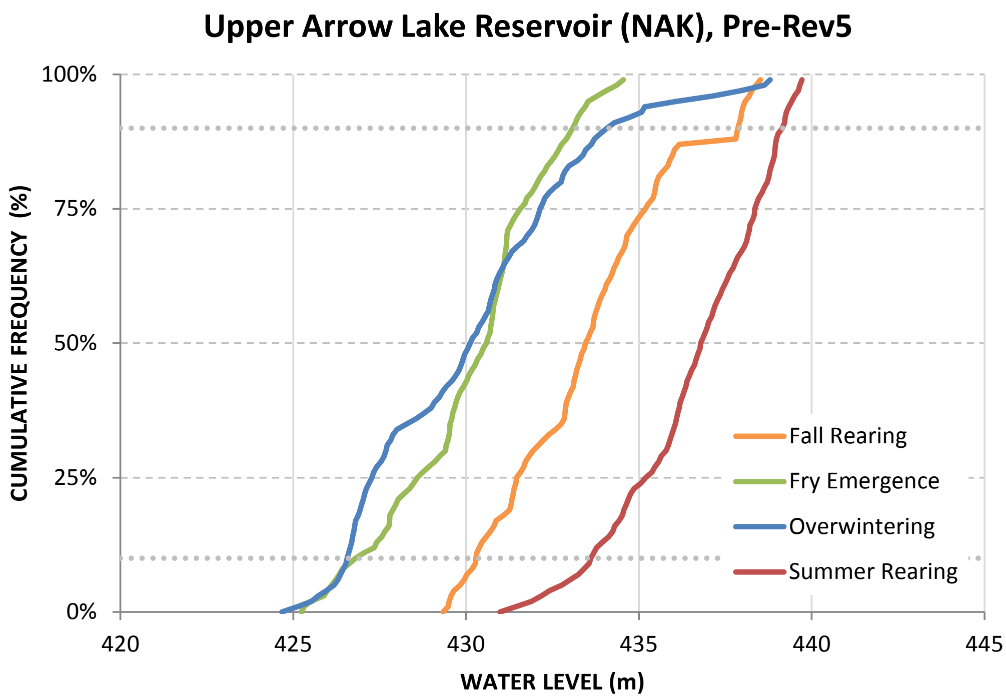
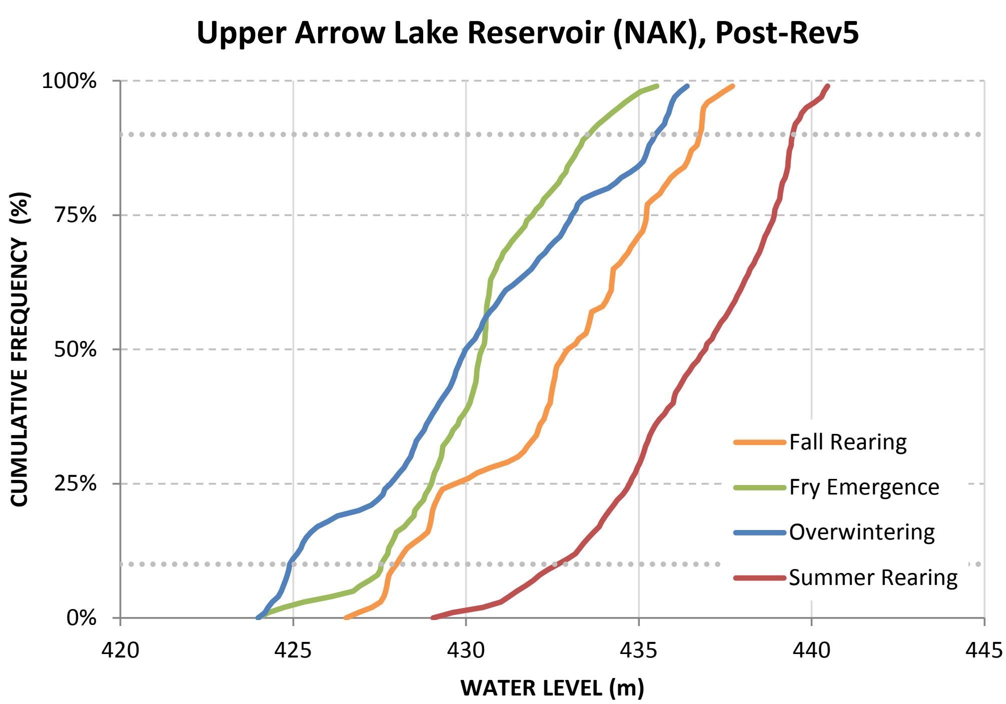


Figure 13. Continued.

c) Arrow Lake Reservoir water level (Nakusp) pre-Rev5 (top) and post-Rev5 (bottom)





3.3.2. Evaluation of Flow Scenarios

The change in weighted usable area by season between the pre- and post-Rev5 flow regime, for each species and life stage, is provided in Table 9 (weighted usable area by season is presented in Appendix D). With the exception of Prickly Sculpin juveniles (during the fry emergence period), habitat under base flow conditions has decreased for all species and life stages under the post-Rev5 flow regime. Habitat under peak flow conditions is generally unchanged in the fall and spring, but has decreased during summer and winter. The difference in habitat between peak and base flow condition has been reduced year-round, reflective of the increase to base flows and preferences of most species/life stages for low water velocity.

Table 9. Change in weighted usable area for study species and life stages between the pre- and post-Rev5 flow regime, under high and low ALR conditions for a) Bull Trout and Rainbow Trout juveniles, b) Mountain Whitefish fry and juveniles, c) Prickly Sculpin and Redside Shiner juveniles.

a) Bull Trout and Rainbow Trout Juveniles

Period	Months	Discharge	BT Juveniles				RB Juveniles			
			ΔWUA (Post - Pre)				ΔWUA (Post - Pre)			
			Low ALR		High ALR		Low ALR		High ALR	
			km^2	%	km^2	%	km^2	%	km^2	%
Overwintering	Nov-Mar	Base	-0.38	-51	-0.36	-44	-0.33	-52	-0.91	-70
		Peak	-0.01	-3	-0.03	-13	-0.01	-4	-0.03	-11
		Peak - Base	0.38	75	0.32	60	0.31	85	0.88	86
Fry Emergence	Apr-May	Base	-0.33	-43	-0.18	-22	-0.30	-48	-0.53	-41
		Peak	0.00	0	0.00	0	0.00	0	0.00	0
		Peak - Base	0.33	65	0.18	33	0.30	81	0.53	52
Summer Rearing	Jun-Aug	Base	-0.38	-51	-0.36	-44	-0.33	-52	-0.91	-70
		Peak	-0.01	-3	-0.03	-13	-0.01	-4	-0.03	-11
		Peak - Base	0.38	75	0.32	60	0.31	85	0.88	86
Fall Rearing	Sept-Oct	Base	-0.38	-51	-0.36	-44	-0.33	-52	-0.91	-70
		Peak	0.00	0	0.00	0	0.00	0	0.00	0
		Peak - Base	0.38	76	0.36	66	0.33	88	0.91	89

Table 9. Continued.

b) Mountain Whitefish fry and juveniles

Period	Months	Discharge	MW Fry				MW Juveniles			
			ΔWUA (Post - Pre)				ΔWUA (Post - Pre)			
			Low ALR		High ALR		Low ALR		High ALR	
			km²	%	km²	%	km²	%	km²	%
Overwintering	Nov-Mar	Base	-0.20	-45	-0.12	-35	-0.25	-41	-0.08	-22
		Peak	-0.01	-10	-0.02	-13	-0.01	-4	-0.02	-10
		Peak - Base	0.19	62	0.10	52	0.24	59	0.06	35
Fry Emergence	Apr-May	Base	-0.17	-39	-0.06	-16	-0.21	-35	-0.03	-9
		Peak	0.00	0	0.00	0	0.00	0	0.00	0
		Peak - Base	0.17	59	0.06	29	0.21	51	0.03	18
Summer Rearing	Jun-Aug	Base	-0.20	-45	-0.12	-35	-0.25	-41	-0.08	-22
		Peak	-0.01	-10	-0.02	-13	-0.01	-4	-0.02	-10
		Peak - Base	0.19	62	0.10	52	0.24	59	0.06	35
Fall Rearing	Sept-Oct	Base	-0.20	-45	-0.12	-35	-0.25	-41	-0.08	-22
		Peak	0.00	0	0.00	0	0.00	0	0.00	0
		Peak - Base	0.20	67	0.12	62	0.25	60	0.08	45

Table 9. Continued.

c) Prickly Sculpin and Redside Shiner juveniles

Period	Months	Discharge	CAS Juveniles				RSC Juveniles			
			ΔWUA (Post - Pre)				ΔWUA (Post - Pre)			
			Low ALR		High ALR		Low ALR		High ALR	
			km²	%	km²	%	km²	%	km²	%
Overwintering	Nov-Mar	Base	-0.01	-1	-0.11	-16	-0.25	-48	-0.52	-65
		Peak	-0.18	-29	-0.10	-22	-0.03	-14	-0.03	-16
		Peak - Base	-0.17	-90	0.01	5	0.22	75	0.48	82
Fry Emergence	Apr-May	Base	0.10	13	-0.03	-4	-0.23	-44	-0.28	-36
		Peak	0.00	0	0.00	0	0.00	0	0.00	0
		Peak - Base	-0.10	-54	0.03	14	0.23	78	0.28	49
Summer Rearing	Jun-Aug	Base	-0.01	-1	-0.11	-16	-0.25	-48	-0.52	-65
		Peak	-0.18	-29	-0.10	-22	-0.03	-14	-0.03	-16
		Peak - Base	-0.17	-90	0.01	5	0.22	75	0.48	82
Fall Rearing	Sept-Oct	Base	-0.01	-1	-0.11	-16	-0.25	-48	-0.52	-65
		Peak	0.00	0	0.00	0	0.00	0	0.00	0
		Peak - Base	0.01	5	0.11	49	0.25	85	0.52	88

4. DISCUSSION

4.1. Management Questions

4.1.1. Effect of REV and ALR Operations on Availability of Preferred Habitat

As noted in Section 2.1, the purpose of this report was to develop HSI for juvenile fish in the Middle Columbia River and address the following management question:

3(i). Do operational strategies for Revelstoke Dam and Arrow Lakes Reservoir impact the availability of preferred habitats?

The comparison of juvenile fish habitat quantity under different operational flow scenarios suggests that the implementation of the new flow regime has affected the quantity of preferred habitats for juvenile fish (Section 3.3.2). Our flow scenario analysis estimates that under base flows there were reductions in habitat quantity with the introduction of the post-Rev5 flow regime for all species and life stages, except for juvenile Prickly Sculpin during fry emergence under low ALR conditions. The increase in habitat quantity for juvenile Prickly Sculpin under base flow and low ALR conditions is related to the increase in depth upon implementation of the post-Rev5 flow regime, and the lack of velocity preference shown by this species, which can hold position on the substrate under a variety of velocities.

The results suggest that under peak flow conditions, habitat quantity for juvenile fish is generally unchanged in the fall and spring, but has decreased during summer and winter under the post-Rev5 flow regime.

The reduced availability of preferred habitats under the new flow regime reflects the preference for shallow, low velocity habitat by juvenile fish in the MCR. Such preferences for shallow, low velocity habitat have also been demonstrated for juvenile fish in other large river systems in the Pacific Northwest, both regulated and unregulated. For example, Branigan *et al.* (2018) found that shallow habitats with low current velocities in the regulated Kootenai River were important for small-bodied native fish, including Mountain Whitefish and Redside Shiners. Similarly, Reinhold *et al.* (2016) demonstrated the use of patches of shallow, slow velocity habitats by small-bodied fish, and the importance of side channel habitat, in the unregulated Yellowstone River.

The preference for shallow, low velocity habitat by juvenile and small-bodied fish in these studies was explained by a number of factors, including: refuge from predation, refuge from high velocities that may displace fish, warmer temperatures, enhanced phytoplankton and zooplankton production, and reduced energy expenditure.

The preference for shallow, slow velocity habitat shown by juvenile and small-bodied fish in other systems supports the HSI developed for juvenile fish in the MCR. The corresponding reduction in habitat quantity for juvenile fish following implementation of the new flow regime must be considered in the context of how the new flow regime has affected other components of the ecosystem (Section 4.1.2).

4.1.2. Juvenile Fish Habitat Changes under New Base Flow Regime

The second management question to be addressed by this project is:

4. What changes in recruitment of juveniles to mainstem rearing habitats result from implementation of the 142 m^3/s minimum flow release (aka the new flow regime)?

The above noted reductions in habitat quantity may be expected to result in a reduction in recruitment of juveniles to mainstem rearing habitats. However, previous studies have found weak or non-existent correlations between WUA and fish density or biomass (e.g., Conder and Annear 1987, Bradford *et al.* 2011) indicating that a reduction in WUA may not necessarily result in reduced productivity.

To assess effects of the new flow regime on juvenile recruitment, other factors in addition to habitat quantity should be considered, including:

- Changes in productivity;
- Changes in growth, condition and survival of juveniles under the new flow regime;
- The ability for juveniles to locate and move between areas of suitable habitat given flow variability;
- Changes in adult abundance, spawning and incubation success;
- Changes in the hydrograph associated with the use of Rev-5;
- Changes in the hydrograph associated with climate change; and
- Changes in water quality/water temperature.

To assess the biological significance of changes in habitat suitability, the results from this study should therefore be considered alongside the other CLBMON studies to address Question #4. For example, the results from this report could be integrated with those from two other monitoring programs, Ecological Productivity Monitoring CLBMON-15B and Fish Population Indexing Surveys CLBMON-16, to evaluate the effects of the new flow regime, and to recommend long-term operational requirements for Revelstoke Dam. In this manner, changes to habitat suitability can be considered in the context of long-term trends in ecological productivity and abundance and condition of juvenile fish.

As discussed in the Fish Population Indexing Surveys CLBMON-16, effects to fish associated with the introduction of a minimum flow cannot be separated from the confounding effects associated with increased maximum discharge related to the use of Rev-5. To separate the effects to fish of the change in the minimum flow from the effects of the change in the maximum flow it would be necessary to conduct experimental manipulations of the minimum flow.

4.2. Discussion of Uncertainty and Limitations

Uncertainties and limitations of the HSI analysis and flow scenario evaluation are identified in the Methods and Results sections above. In this section, we discuss the effects of the uncertainties/limitations on the analysis and the measures taken to address and minimize uncertainty/limitations. Where relevant we also note how these uncertainties and limitations should be considered when reviewing modelling results and making decisions with respect to operations and flow-related changes.

As noted in Section 2.1, no habitat information was collected at the precise location (microhabitat) where fishes were caught. Rather, measurements were taken at nine points at the upstream and downstream end of each sampling area (mesohabitat), and fishes may have occupied any microhabitats within the mesohabitat. To develop HSI it was necessary to make some assumptions regarding the distribution of habitat within each survey, as well as the habitat used by fish. We addressed this limitation by conducting HSI analysis assuming three frequency distributions: uniform distribution of depth/velocity within each survey (and uniform use of this habitat by fish), normal distribution of depth/velocity within each survey (i.e., mean conditions are more frequently present and used by fish), and constant depth/velocity for each survey (i.e., the mean condition was the primary condition present and the habitat condition used by fish). In general, the three distributions generated similar habitat use and availability curves. This sensitivity analysis confirms that HSI developed from the habitat availability and use curves are insensitive to the depth/velocity frequency distribution that was applied.

Of the nine points that were measured within each survey, three were collected at 0 m from the wetted edge, and water depths and velocities were frequently zero (~80% and 90%, respectively). The sensitivity analysis conducted to evaluate inclusion of these data demonstrated that these zero data were skewing habitat use and availability curves toward zero depth and velocity, yielding unrealistic depth habitat curves (e.g., optimal or high habitat use values at 0 m water depth). Removing these shoreline data improved the realism of the depth habitat curves and had little effect on the range of water depths/velocities where habitat use exceeded availability. Based on the results of the sensitivity analysis, it was judged that the improved realism gained from excluding these data provided useful information for the development of HSI, while very little information was lost from excluding shoreline data collected in habitats with vertical banks (the locations where non-zero shore-line water depths and velocities are possible).

There were a number of surveys (13%) where zero velocity was present at all nine measurement locations. Based on the pattern of occurrence, it appeared as if water velocity was not or could not be measured on some dates, and there was no way to distinguish missing data from zero velocity entries. The HSI analysis conducted with and without the velocity data for these surveys showed that removing these data had little effect on the habitat use and availability curves; the main effect of removing these data was a slight reduction in the skew of the velocity curves (though the curves are still positively skewed, i.e., highest values around zero velocity). The removal of these data resulted in a vertical rescaling of the velocity habitat use and availability curves, which was helpful in interpretation of the data during HSI refinement.

Despite the measures to remove bias toward low depths and velocities caused by the survey methodology, it is possible that some bias remains; highly suitable habitat is predicted for all fish species at zero velocity. As a result, maximum habitat is predicted at the lowest flow rate for all species and life stages, and it is unclear if this is truly reflective of habitat preferences (i.e., swimming capability for juvenile fishes, refuge from larger fishes) or is an artifact of deriving HSI from shallow-water sampling. In addition, the majority of sampling (79%) was conducted when at least part of the study reach may have been backwatered. While both habitat use and availability were considered in this analysis, the predictions of high suitability for reservoir conditions may still reflect this sampling bias, i.e., habitat availability during sampling rather than a preference for these habitats.

In addition to these biases, it is challenging in the development and interpretation of HSI to account for interactions between depth, velocity and substrate. For example, the preference for slow water may appear stronger than it is in reality because juvenile fishes may have a strong preference for shallow habitat to avoid predation, and shallow habitat at the margins tends to be slow. The HSI also do not account for the fact that fishes that hold in the water column prefer to hold in slow water adjacent to high flows to optimize energy expenditure and feeding opportunities. Such challenges are likely contributing factors to the observation that field studies often report weak or non-existent correlations between WUA and fish density or biomass (e.g., Conder and Annear 1987, Bradford *et al.* 2011). Predictions made via modelled habitat changes should therefore not be considered a substitute for monitoring change in physical and biological components of the aquatic ecosystem associated with the flow regime change.

Finally, environmental variability during sampling introduces some uncertainty into the HSI. Overall habitat use and availability curves were obtained by aggregating curves from individual surveys collected over multiple years and seasons and over various hydraulic conditions. Ideally, the data would all be collected under similar environmental conditions to avoid introducing bias and uncertainty into the habitat curves. This uncertainty could be quantitatively evaluated by conducting a seasonal analysis (e.g., excluding data sets collected early in the season prior to fry emergence), excluding hydraulic conditions which occur infrequently (e.g., REV discharge in excess of 2,000 m^3/s), or by examining the dataset for specific hydraulic conditions (e.g., no ALR influence). However, each type of analysis would reduce the number of fish observations in the data set, and any improvements in the HSI may be offset by a lower sample size, i.e., uncertainty introduced by environmental variability would be exchanged for uncertainty introduced by a smaller sample size. In summary, uncertainties and biases in the data have been considered both qualitatively and quantitatively and we believe that the relevant information regarding juvenile fish habitat use in the MCR has been extracted from the data to the extent possible. Nevertheless, when interpreting predicted habitat changes calculated using these HSI, it is important to consider that the HSI were derived using fish sampling data collected at night and across multiple seasons.

The evaluation of flow scenarios was completed by selecting representative REV discharge rates and ALR levels for each season. Base flow conditions were selected in direct consideration of Management Question #4, however, peak flows and ALR levels were selected based on a frequency analysis. As described above, the specific REV peak discharge and ALR conditions vary depending on BC Hydro operations, and hence the specific hydraulic conditions modelled may be present infrequently. However, the flow scenarios selected are expected to provide sufficient information to evaluate the effectiveness of the base flow regime (alongside other lines of evidence; Management Question #4), and a reasonable contrast between habitat under pre-Rev5 and post-Rev5 flow regimes.

5. RECOMMENDATIONS

This report has developed HSI for five species of juvenile fish based on habitat preferences shown by fish captured in the MCR. Despite the biases and limitations of the study outlined above, we consider the HSI developed to be the most reasonable representation of juvenile habitat preferences in the study reach. We therefore recommend that future assessments of potential alternative flow regimes in the MCR adopt the juvenile HSI derived herein, and evaluate the expected changes to juvenile habitat in conjunction with projected changes to adult fish habitat and ecological productivity under alternative flow regimes.

To test the sensitivity of predicted habitat change results to the use of different HSI when assessing alternative flow regimes, habitat modelling could also be completed using other HSI. This is particularly important when considering species and life stages where the MCR juvenile HSI developed herein resulted in significant changes from existing HSI (e.g., velocity preferences for juvenile Rainbow Trout and Mountain Whitefish). In such cases, a comparison of the results using the MCR juvenile HSI compared to other relevant HSI (e.g., the Category III suitability curves developed for Mountain Whitefish in the Kootenai River; Hoffman *et al.* 2002) may be insightful when making management decisions. However, any such evaluation would need to consider the limitations and biases in developing the MCR HSI as well as those associated with development of the other HSI modelled.

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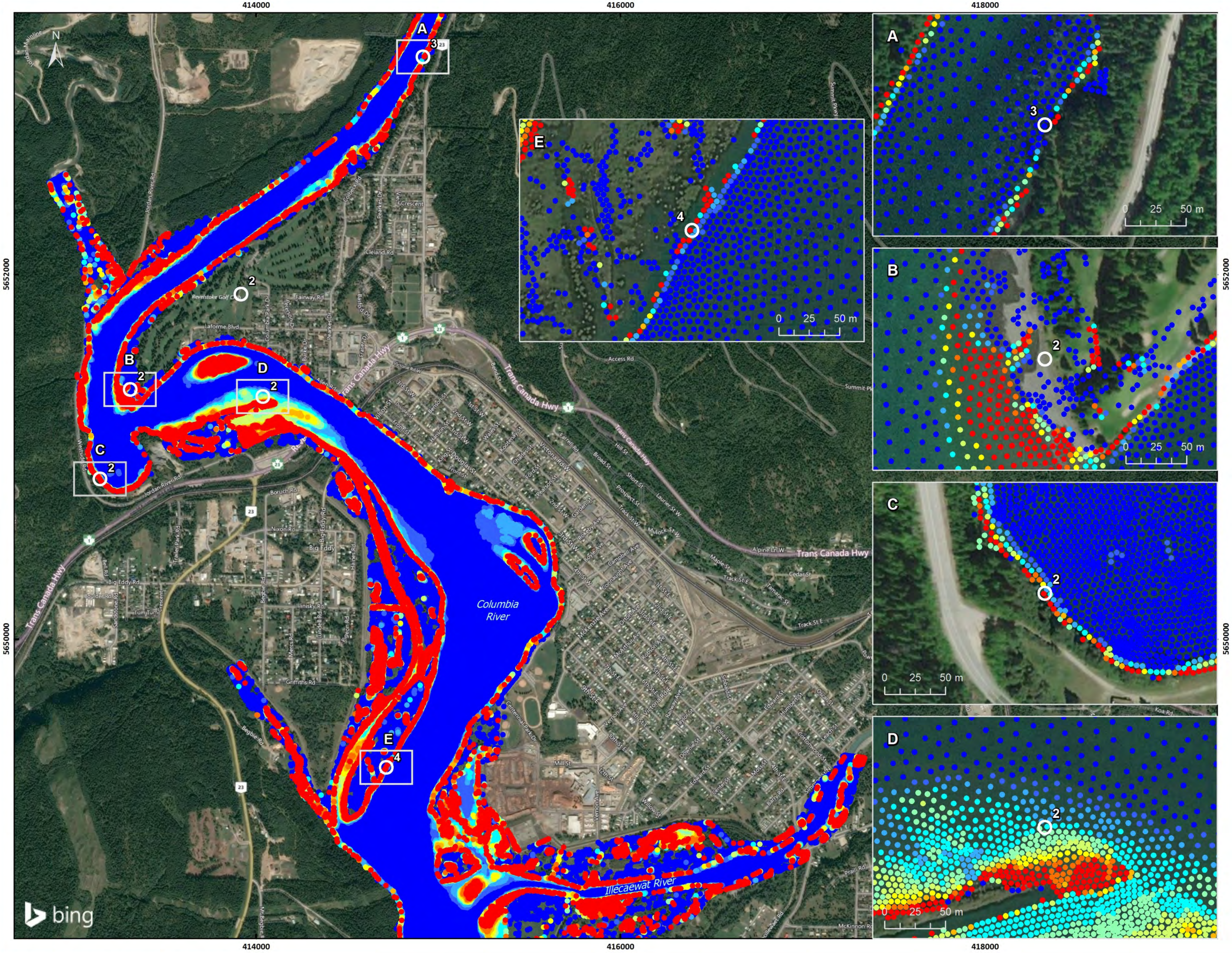
APPENDICES

Appendix A. Maps for Validation of Habitat Suitability Criteria

TABLE OF MAPS



CLBMON17 COLUMBIA RIVER WATER USE PLAN

Bull Trout (Juvenile) Suitability Index

Legend

Bull Trout (Juvenile) Suitability Index

- 0.9 - 1.0
- 0.8 - 0.9
- 0.7 - 0.8
- 0.6 - 0.7
- 0.5 - 0.6
- 0.4 - 0.5
- 0.3 - 0.4
- 0.2 - 0.3
- 0.1 - 0.2
- 0.0 - 0.1
- Fish Data (numbers represent fish captured in sampling sites ~100 m long)

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 100 200 400 600 800 1,000 Meters

Scale: 1:20,000

NO.	DATE	REVISION	BY
1	23/07/2018	1210_BullTrout_Juv_SI_2018Jul06	
2			
3			
4			
5			

Date Saved: 23/07/2018
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 1

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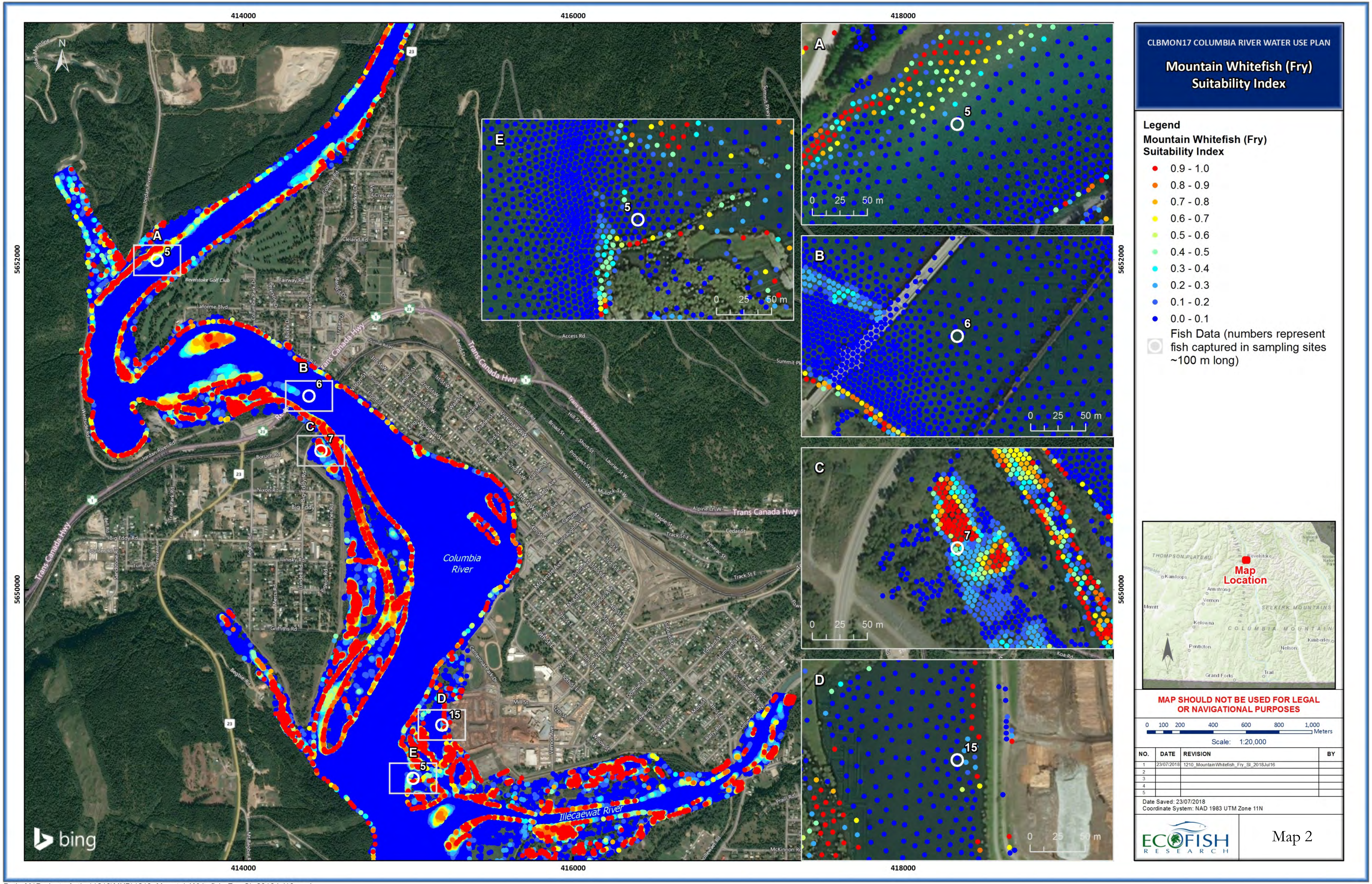
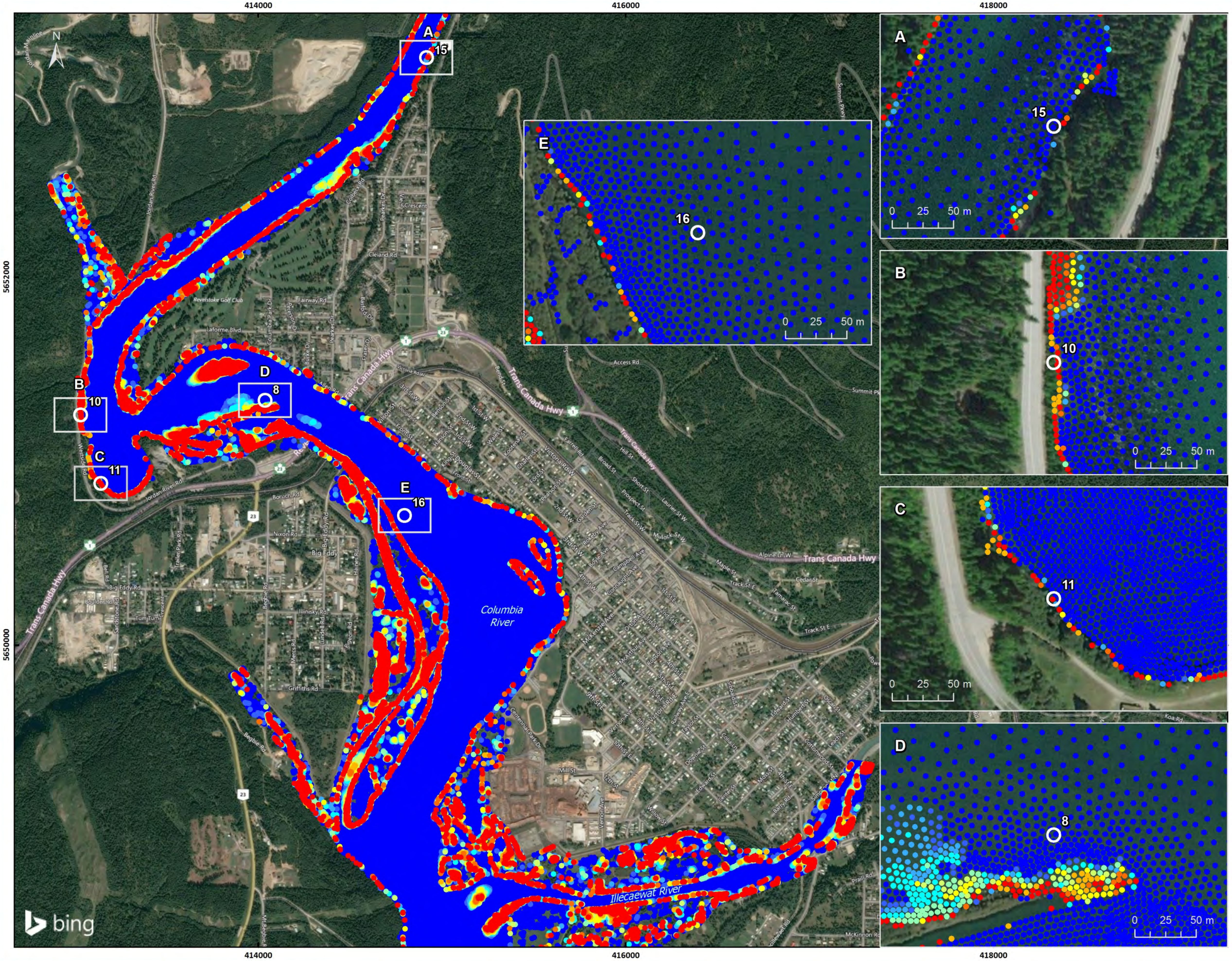


Path: M:\Projects-Active\1210\MXD\1210_MountainWhitefish_Fry_SI_2018Jul16.mxd

CLBMON17 COLUMBIA RIVER WATER USE PLAN

Mountain Whitefish (Juvenile) Suitability Index



Legend

Mountain Whitefish (Juvenile) Suitability Index

- 0.9 - 1.0
- 0.8 - 0.9
- 0.7 - 0.8
- 0.6 - 0.7
- 0.5 - 0.6
- 0.4 - 0.5
- 0.3 - 0.4
- 0.2 - 0.3
- 0.1 - 0.2
- 0.0 - 0.1
- Fish Data (numbers represent fish captured in sampling sites ~100 m long)

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 100 200 400 600 800 1,000 Meters

Scale: 1:20,000

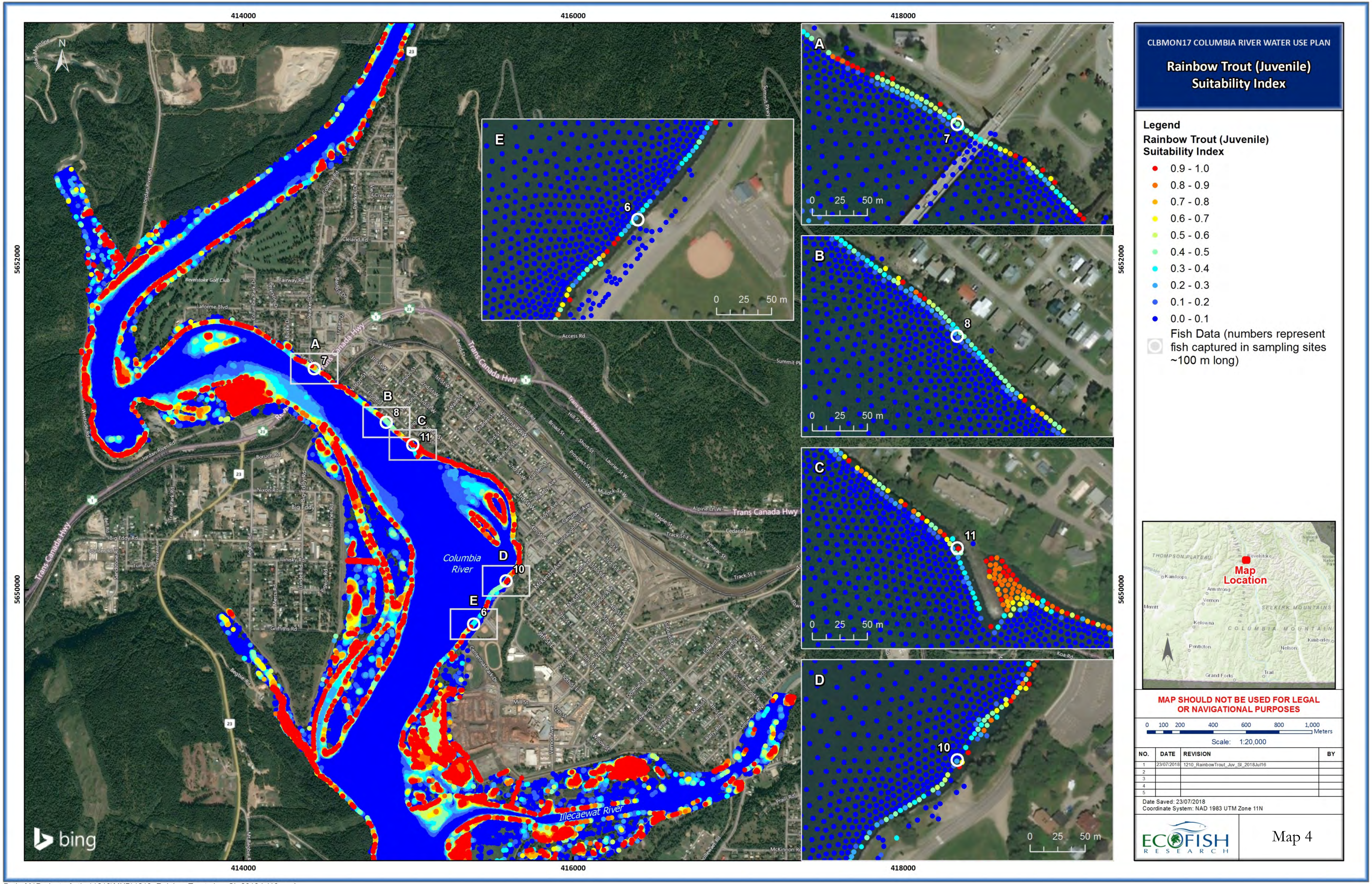
NO.	DATE	REVISION	BY
1	23/07/2018	1210_MountainWhitefish_Juv_SI_2018Jul16	
2			
3			
4			
5			

Date Saved: 23/07/2018
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 3

Path: M:\Projects-Active\1210\MXD\1210_MountainWhitefish_Juv_SI_2018Jul16.mxd



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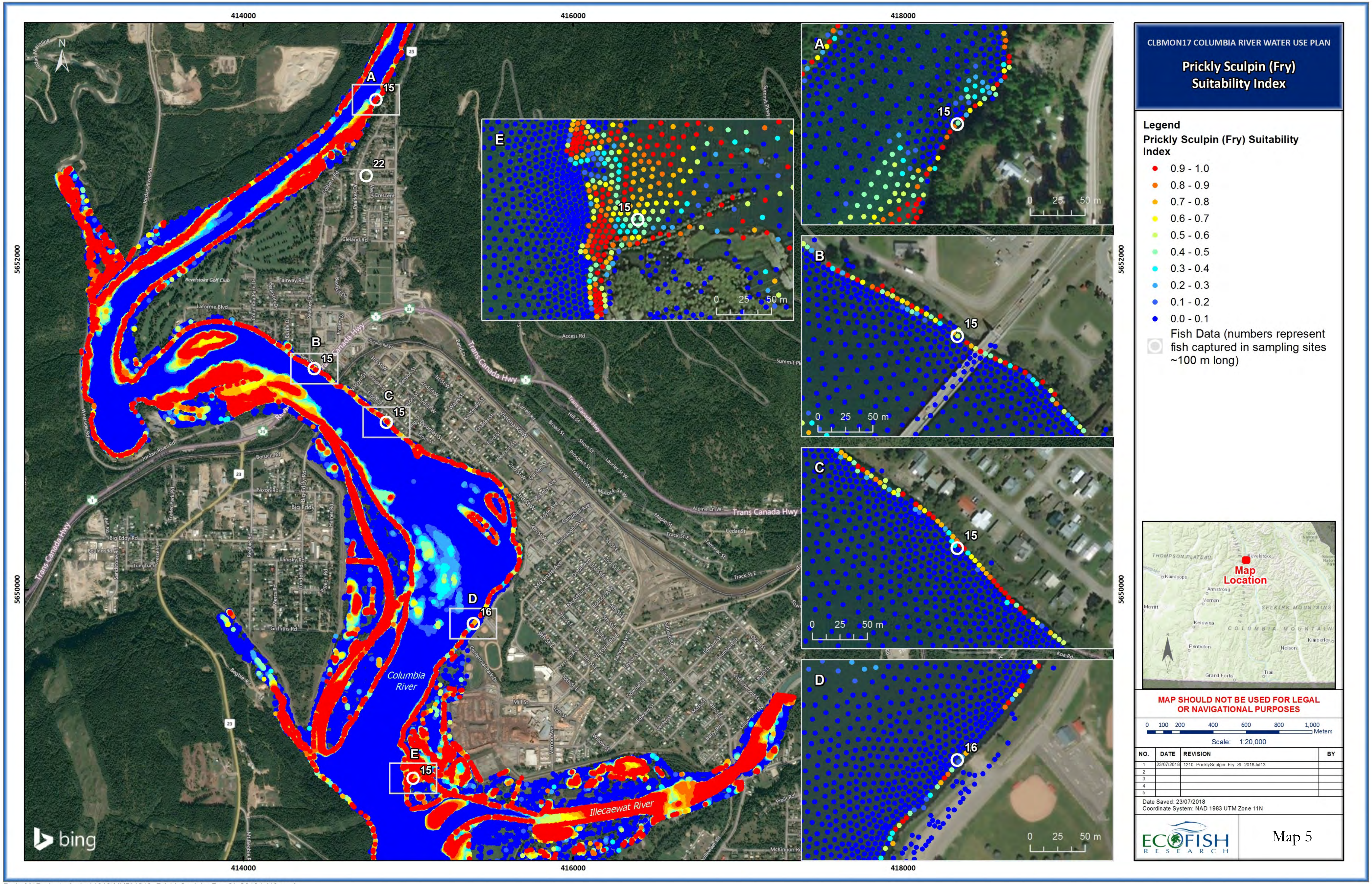

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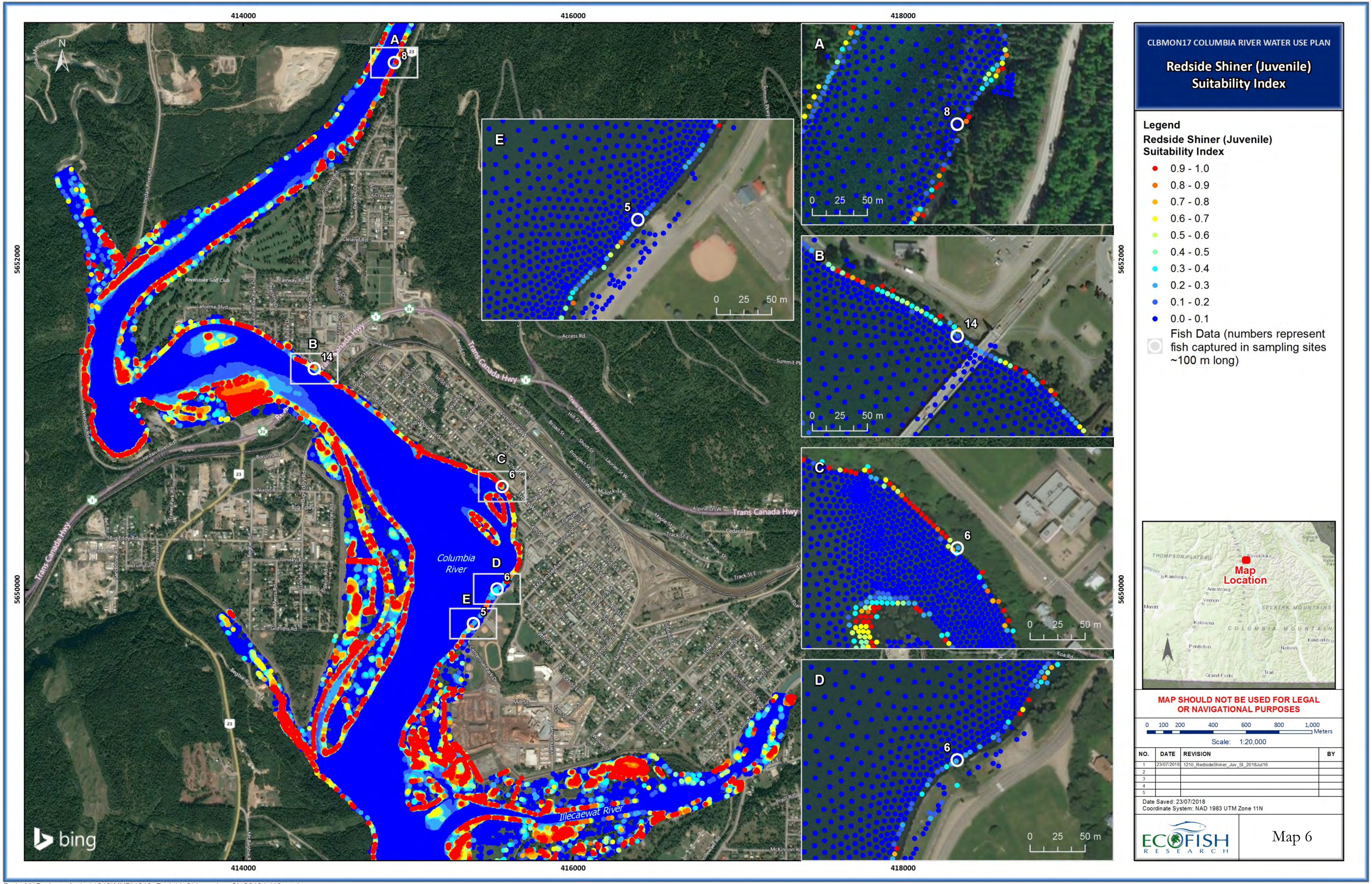
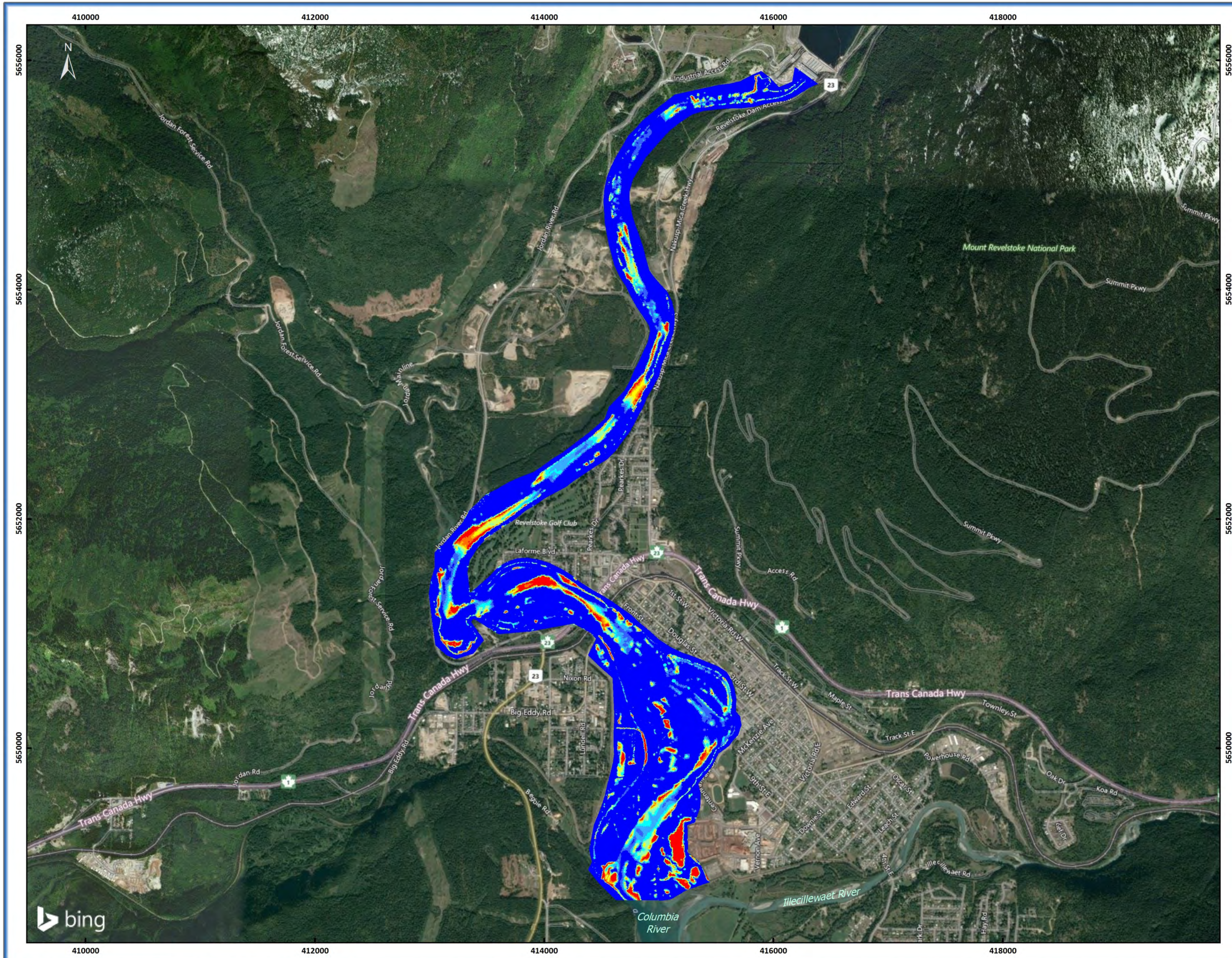


Path: M:\Projects-Active\1210\MXD\1210_RedsideShiner_Juv_SI_2018Jul16.mxd

Appendix B. Maps of Rainbow Trout Juvenile Suitability

TABLE OF MAPS



CLBMON17 COLUMBIA RIVER WATER USE PLAN

Rainbow Trout Juvenile Suitability Index Rev Outflow 8.5 m³/s, ALR Level 427.3 m

Legend

Rainbow Trout (Juvenile) Suitability Index

- 0.9 - 1.0
- 0.8 - 0.9
- 0.7 - 0.8
- 0.6 - 0.7
- 0.5 - 0.6
- 0.4 - 0.5
- 0.3 - 0.4
- 0.2 - 0.3
- 0.1 - 0.2
- 0.0 - 0.1

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 100 200 400 600 800 1,000 Meters

Scale: 1:31,523

NO.	DATE	REVISION	BY
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2			
3			
4			
5			

Date Saved: 14/09/2018
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 1

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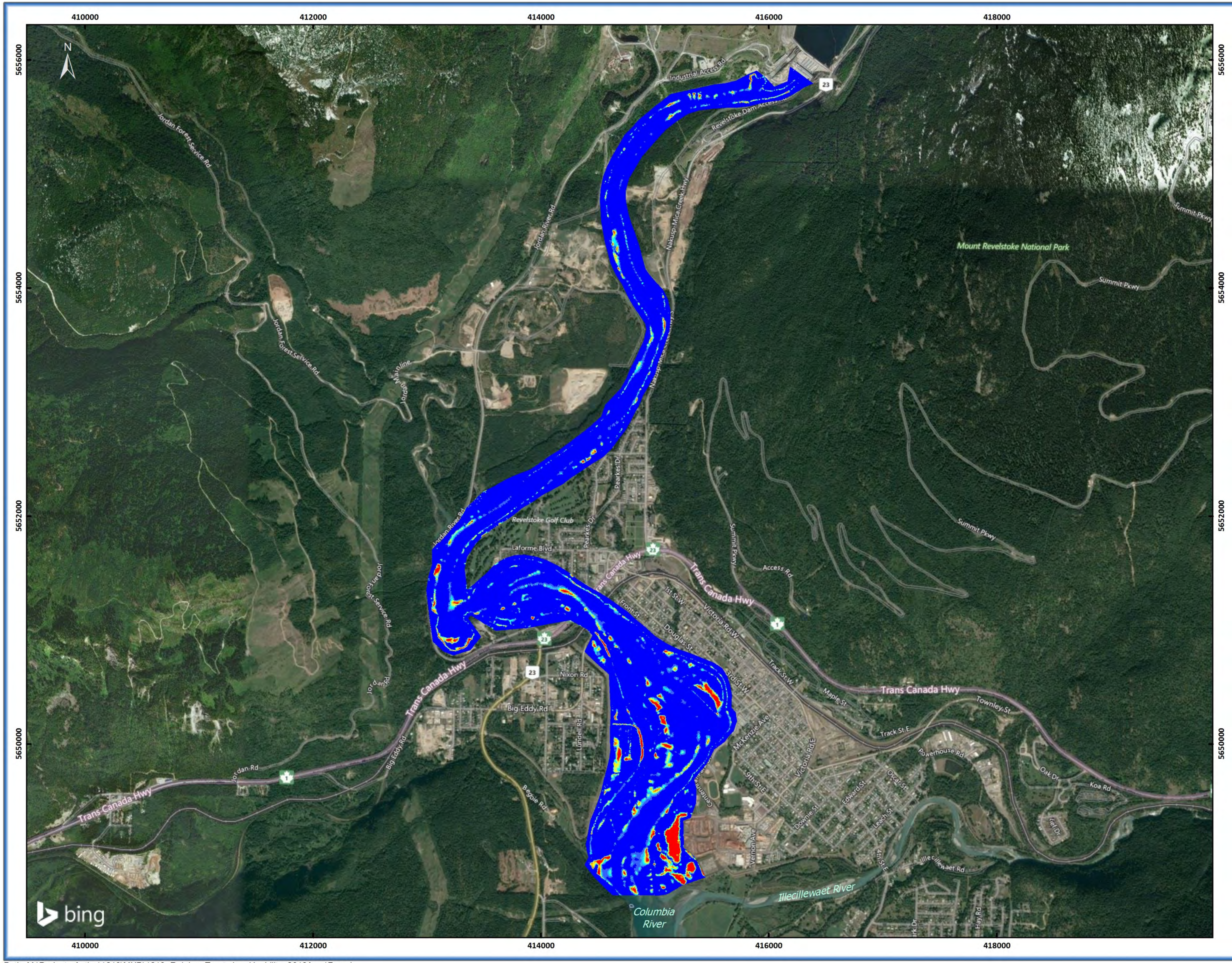


CLBMON17 COLUMBIA RIVER WATER USE PLAN

Rainbow Trout Juvenile Suitability Index Rev Outflow 142 m³/s, ALR Level 427.3 m

Legend

Rainbow Trout (Juvenile) Suitability Index

- 0.9 - 1.0
- 0.8 - 0.9
- 0.7 - 0.8
- 0.6 - 0.7
- 0.5 - 0.6
- 0.4 - 0.5
- 0.3 - 0.4
- 0.2 - 0.3
- 0.1 - 0.2
- 0.0 - 0.1

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 100 200 400 600 800 1,000 Meters

Scale: 1:31,523

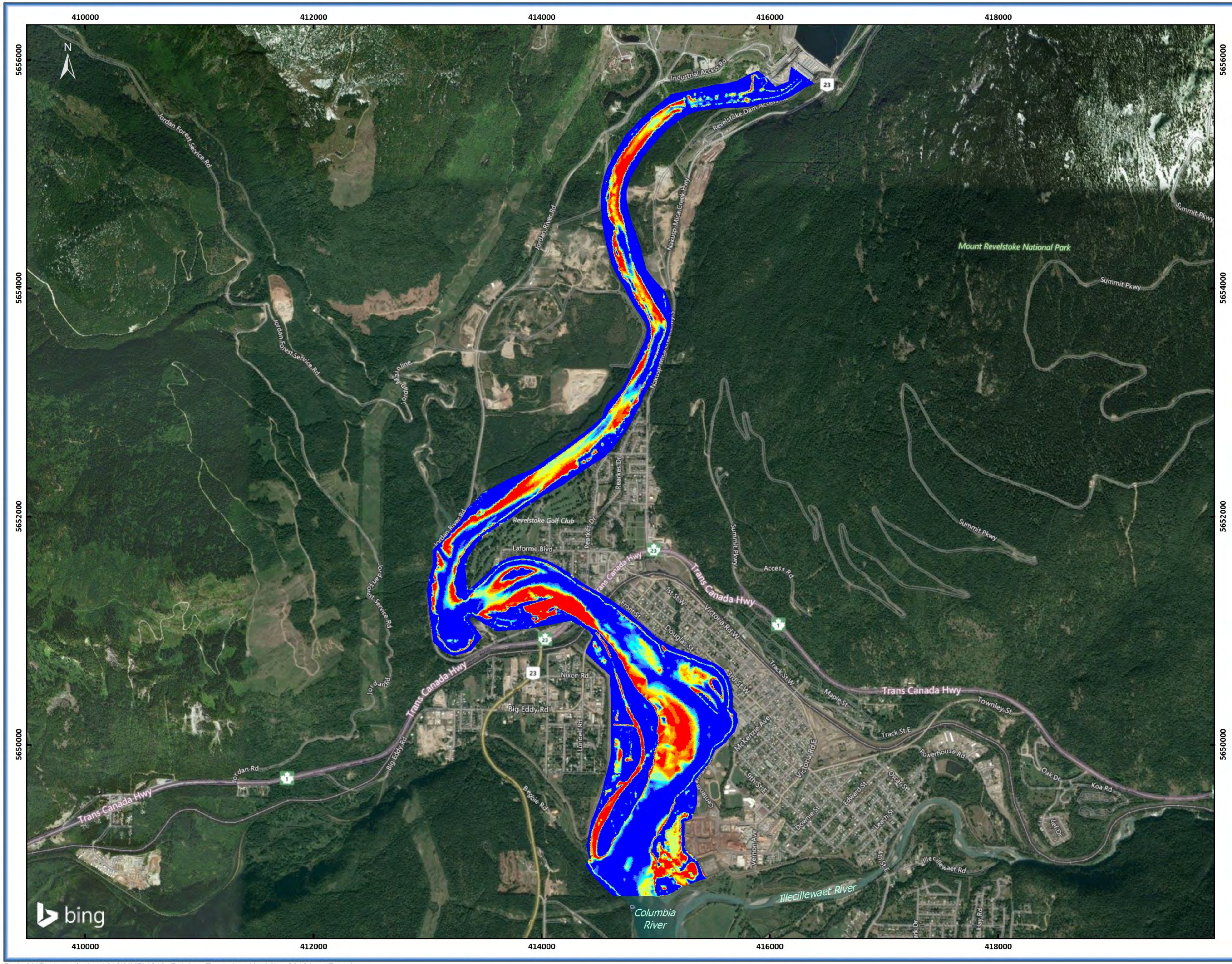
NO.	DATE	REVISION	BY
1	14/09/2018	1210_RainbowTrout_Juv_Usability_2018Aug17	
2			
3			
4			
5			

Date Saved: 14/09/2018
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 2

Path: M:\Projects-Active\1210\MXD\1210_RainbowTrout_Juv_Usability_2018Aug17.mxd



CLBMON17 COLUMBIA RIVER WATER USE PLAN

Rainbow Trout Juvenile Suitability Index Rev Outflow 8.5 m³/s, ALR Level 437.1 m

Legend

Rainbow Trout (Juvenile) Suitability Index

- 0.9 - 1.0
- 0.8 - 0.9
- 0.7 - 0.8
- 0.6 - 0.7
- 0.5 - 0.6
- 0.4 - 0.5
- 0.3 - 0.4
- 0.2 - 0.3
- 0.1 - 0.2
- 0.0 - 0.1

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 100 200 400 600 800 1,000 Meters

Scale: 1:31,523

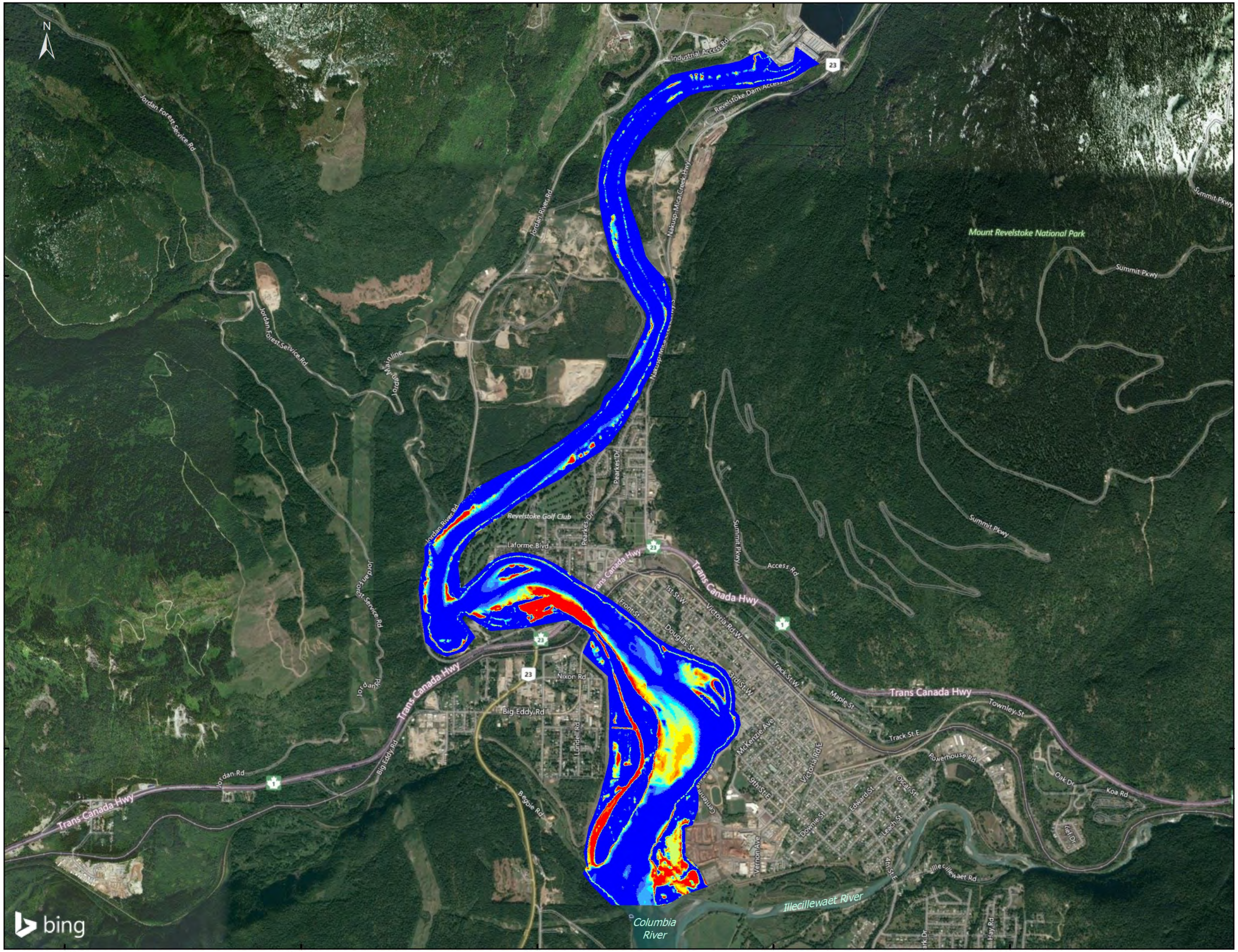
NO.	DATE	REVISION	BY
1	14/09/2018	1210_RainbowTrout_Juv_Usability_2018Aug17	
2			
3			
4			
5			

Date Saved: 14/09/2018
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 3

Path: M:\Projects-Active\1210\MXD\1210_RainbowTrout_Juv_Usability_2018Aug17.mxd



CLBMON17 COLUMBIA RIVER WATER USE PLAN

Rainbow Trout Juvenile Suitability Index Rev Outflow 142 m³/s, ALR Level 437.1 m

Legend

Rainbow Trout (Juvenile) Suitability Index

- 0.9 - 1.0
- 0.8 - 0.9
- 0.7 - 0.8
- 0.6 - 0.7
- 0.5 - 0.6
- 0.4 - 0.5
- 0.3 - 0.4
- 0.2 - 0.3
- 0.1 - 0.2
- 0.0 - 0.1

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 100 200 400 600 800 1,000 Meters

Scale: 1:31,523

NO.	DATE	REVISION	BY
1	14/09/2018	1210_RainbowTrout_Juv_Usability_2018Aug17	
2			
3			
4			
5			

Date Saved: 14/09/2018
Coordinate System: NAD 1983 UTM Zone 11N

ECOFISH RESEARCH

Map 4

Path: M:\Projects-Active\1210\MXD\1210_RainbowTrout_Juv_Usability_2018Aug17.mxd

Appendix C. Habitat Suitability Indices for the Middle Columbia River

LIST OF TABLES

Table 1. Habitat Suitability Indices

Depth (cm)	RB Juvenile	MW Fry	MW Juvenile	BT Juvenile	CAS Fry	RSC Juvenile	Velocity (cm/s)	RB Juvenile	MW Fry	MW Juvenile	BT Juvenile	CAS Fry	RSC Juvenile
0	0	0	0	0	0	0	0	1	1	1	1	1	1
1	0	0	0	0	0	0	1	1	1	1	1	1	1
2	0	0	0	0	0	0	2	1	1	1	1	1	1
3	0.020833333	0.016666667	0.055555556	0	0	0.03125	3	1	1	1	1	1	1
4	0.041666667	0.033333333	0.111111111	0	0	0.0625	4	1	1	1	1	1	1
5	0.0625	0.05	0.166666667	0	0	0.09375	5	1	1	1	1	1	1
6	0.083333333	0.066666667	0.222222222	0	0	0.125	6	0.9	0.966666667	1	1	1	0.9
7	0.104166667	0.083333333	0.277777778	0	0	0.15625	7	0.8	0.933333333	1	1	1	0.8
8	0.125	0.1	0.333333333	0	0	0.1875	8	0.7	0.9	1	1	1	0.7
9	0.145833333	0.116666667	0.388888889	0	0	0.21875	9	0.6	0.866666667	1	1	1	0.6
10	0.166666667	0.133333333	0.444444444	0	0	0.25	10	0.5	0.833333333	1	1	1	0.5
11	0.1875	0.15	0.5	0.1	0	0.26875	11	0.475	0.8	1	1	1	0.4
12	0.208333333	0.166666667	0.555555556	0.2	0	0.2875	12	0.45	0.766666667	1	1	1	0.3
13	0.229166667	0.183333333	0.611111111	0.3	0	0.30625	13	0.425	0.733333333	1	1	1	0.2875
14	0.25	0.2	0.666666667	0.4	0	0.325	14	0.4	0.7	1	1	1	0.275
15	0.270833333	0.216666667	0.722222222	0.5	0	0.34375	15	0.375	0.666666667	1	1	1	0.2625
16	0.291666667	0.233333333	0.777777778	0.6	0.027027027	0.3625	16	0.35	0.633333333	0.966666667	0.95	1	0.25
17	0.3125	0.25	0.833333333	0.7	0.054054054	0.38125	17	0.325	0.6	0.933333333	0.9	1	0.2375
18	0.333333333	0.266666667	0.888888889	0.8	0.081081081	0.4	18	0.3	0.566666667	0.9	0.85	1	0.225
19	0.354166667	0.283333333	0.944444444	0.9	0.108108108	0.41875	19	0.275	0.533333333	0.866666667	0.8	1	0.2125
20	0.375	0.3	1	1	0.135135135	0.4375	20	0.25	0.5	0.833333333	0.75	1	0.2
21	0.395833333	0.345	1	1	0.162162162	0.45625	21	0.235	0.4875	0.8	0.7	1	0.19
22	0.416666667	0.39	1	1	0.189189189	0.475	22	0.22	0.475	0.766666667	0.65	1	0.18
23	0.4375	0.435	1	1	0.216216216	0.49375	23	0.205	0.4625	0.733333333	0.6	1	0.17
24	0.458333333	0.48	1	1	0.243243243	0.5125	24	0.19	0.45	0.7	0.55	1	0.16
25	0.479166667	0.525	1	1	0.27027027	0.53125	25	0.175	0.4375	0.666666667	0.5	1	0.15
26	0.5	0.57	1	1	0.297297297	0.55	26	0.16	0.425	0.633333333	0.45	1	0.14
27	0.520833333	0.615	1	1	0.324324324	0.56875	27	0.145	0.4125	0.6	0.4	1	0.13
28	0.541666667	0.66	1	1	0.351351351	0.5875	28	0.13	0.4	0.566666667	0.35	1	0.12
29	0.5625	0.705	1	1	0.378378378	0.60625	29	0.115	0.3875	0.533333333	0.3	1	0.11
30	0.583333333	0.75	1	1	0.405405405	0.625	30	0.1	0.375	0.5	0.25	1	0.1
31	0.604166667	0.8	1	1	0.432432432	0.64375	31	0.095	0.3625	0.485	0.236666667	1	0.095
32	0.625	0.85	1	1	0.459459459	0.6625	32	0.09	0.35	0.47	0.223333333	1	0.09
33	0.645833333	0.9	1	1	0.486486486	0.68125	33	0.085	0.3375	0.455	0.21	1	0.085
34	0.666666667	0.95	1	1	0.513513514	0.7	34	0.08	0.325	0.44	0.196666667	1	0.08
35	0.6875	1	1	1	0.540540541	0.71875	35	0.075	0.3125	0.425	0.183333333	1	0.075
36	0.708333333	1	1	1	0.567567568	0.7375	36	0.07	0.3	0.41	0.17	1	0.07
37	0.729166667	1	1	1	0.594594595	0.75625	37	0.065	0.2875	0.395	0.156666667	1	0.065

Table 1. Continued.

Depth (cm)	RB Juvenile	MW Fry	MW Juvenile	BT Juvenile	CAS Fry	RSC Juvenile	Velocity (cm/s)	RB Juvenile	MW Fry	MW Juvenile	BT Juvenile	CAS Fry	RSC Juvenile
38	0.75	1	1	1	0.621621622	0.775	38	0.06	0.275	0.38	0.143333333	1	0.06
39	0.770833333	1	1	1	0.648648649	0.79375	39	0.055	0.2625	0.365	0.13	1	0.055
40	0.791666667	1	1	1	0.675675676	0.8125	40	0.05	0.25	0.35	0.116666667	1	0.05
41	0.8125	1	1	1	0.702702703	0.83125	41	0.045	0.2375	0.335	0.103333333	1	0.045
42	0.833333333	1	1	1	0.72972973	0.85	42	0.04	0.225	0.32	0.09	1	0.04
43	0.854166667	1	1	1	0.756756757	0.86875	43	0.035	0.2125	0.305	0.076666667	1	0.035
44	0.875	1	1	1	0.783783784	0.8875	44	0.03	0.2	0.29	0.063333333	1	0.03
45	0.895833333	1	1	1	0.810810811	0.90625	45	0.025	0.1875	0.275	0.05	1	0.025
46	0.916666667	1	1	1	0.837837838	0.925	46	0.02	0.175	0.26	0.048	1	0.02
47	0.9375	1	1	1	0.864864865	0.94375	47	0.015	0.1625	0.245	0.046	1	0.015
48	0.958333333	1	1	1	0.891891892	0.9625	48	0.01	0.15	0.23	0.044	1	0.01
49	0.979166667	1	1	1	0.918918919	0.98125	49	0.005	0.1375	0.215	0.042	1	0.005
50	1	1	1	1	0.945945946	1	50	0	0.125	0.2	0.04	1	0
51	1	1	1	1	0.972972973	1	51	0	0.1125	0.186666667	0.038	1	0
52	1	1	1	1	1	1	52	0	0.1	0.173333333	0.036	1	0
53	1	1	1	1	1	1	53	0	0.0875	0.16	0.034	1	0
54	1	1	1	1	1	1	54	0	0.075	0.146666667	0.032	1	0
55	1	1	1	1	1	1	55	0	0.0625	0.133333333	0.03	1	0
56	1	1	0.98	1	1	1	56	0	0.05	0.12	0.028	1	0
57	1	1	0.96	1	1	1	57	0	0.0375	0.106666667	0.026	1	0
58	1	1	0.94	1	1	1	58	0	0.025	0.093333333	0.024	1	0
59	1	1	0.92	1	1	1	59	0	0.0125	0.08	0.022	1	0
60	1	1	0.9	1	1	1	60	0	0	0.066666667	0.02	1	0
61	1	1	0.88	1	1	1	61	0	0	0.053333333	0.018733333	1	0
62	1	1	0.86	1	1	1	62	0	0	0.04	0.017466667	1	0
63	1	1	0.84	1	1	1	63	0	0	0.026666667	0.0162	1	0
64	1	1	0.82	1	1	1	64	0	0	0.013333333	0.014933333	1	0
65	1	1	0.8	1	1	1	65	0	0	0	0.013666667	1	0
66	1	1	0.78	1	1	1	66	0	0	0	0.0124	1	0
67	1	1	0.76	1	1	1	67	0	0	0	0.011133333	1	0
68	1	1	0.74	1	1	1	68	0	0	0	0.009866667	1	0
69	1	1	0.72	1	1	1	69	0	0	0	0.0086	1	0
70	1	1	0.7	1	1	1	70	0	0	0	0.007333333	1	0
71	1	1	0.68	1	1	1	71	0	0	0	0.006066667	1	0
72	1	1	0.66	1	1	1	72	0	0	0	0.0048	1	0
73	1	1	0.64	1	1	1	73	0	0	0	0.003533333	1	0
74	1	1	0.62	1	1	1	74	0	0	0	0.002266667	1	0

Table 1. Continued.

Depth (cm)	RB Juvenile	MW Fry	MW Juvenile	BT Juvenile	CAS Fry	RSC Juvenile	Velocity (cm/s)	RB Juvenile	MW Fry	MW Juvenile	BT Juvenile	CAS Fry	RSC Juvenile
75	1	1	0.6	1	1	1	75	0	0	0	0.001	1	0
76	1	0.97	0.58	1	1	1	76	0	0	0	0.00096	1	0
77	1	0.94	0.56	1	1	1	77	0	0	0	0.00092	1	0
78	1	0.91	0.54	1	1	1	78	0	0	0	0.00088	1	0
79	1	0.88	0.52	1	1	1	79	0	0	0	0.00084	1	0
80	1	0.85	0.5	1	1	1	80	0	0	0	0.0008	1	0
81	1	0.82	0.48	0.9925	1	1	81	0	0	0	0.00076	1	0
82	1	0.79	0.46	0.985	1	1	82	0	0	0	0.00072	1	0
83	1	0.76	0.44	0.9775	1	1	83	0	0	0	0.00068	1	0
84	1	0.73	0.42	0.97	1	1	84	0	0	0	0.00064	1	0
85	1	0.7	0.4	0.9625	1	1	85	0	0	0	0.0006	1	0
86	1	0.67	0.38	0.955	1	1	86	0	0	0	0.00056	1	0
87	1	0.64	0.36	0.9475	1	1	87	0	0	0	0.00052	1	0
88	1	0.61	0.34	0.94	1	1	88	0	0	0	0.00048	1	0
89	1	0.58	0.32	0.9325	1	1	89	0	0	0	0.00044	1	0
90	1	0.55	0.3	0.925	1	1	90	0	0	0	0.0004	1	0
91	1	0.52	0.28	0.9175	1	1	91	0	0	0	0.00036	1	0
92	1	0.49	0.26	0.91	1	1	92	0	0	0	0.00032	1	0
93	1	0.46	0.24	0.9025	1	1	93	0	0	0	0.00028	1	0
94	1	0.43	0.22	0.895	1	1	94	0	0	0	0.00024	1	0
95	1	0.4	0.2	0.8875	1	1	95	0	0	0	0.0002	1	0
96	1	0.37	0.18	0.88	1	1	96	0	0	0	0.00016	1	0
97	1	0.34	0.16	0.8725	1	1	97	0	0	0	0.00012	1	0
98	1	0.31	0.14	0.865	1	1	98	0	0	0	8E-05	1	0
99	1	0.28	0.12	0.8575	1	1	99	0	0	0	4E-05	1	0
100	1	0.25	0.1	0.85	1	1	100	0	0	0	0	1	0

Table 1. Continued.

Depth (cm)	RB Juvenile	MW Fry	MW Juvenile	BT Juvenile	CAS Fry	RSC Juvenile
101	1	0.24	0.099	0.841	0.9912	1
102	1	0.23	0.098	0.832	0.9824	1
103	1	0.22	0.097	0.823	0.9736	1
104	1	0.21	0.096	0.814	0.9648	1
105	1	0.2	0.095	0.805	0.956	1
106	1	0.19	0.094	0.796	0.9472	1
107	1	0.18	0.093	0.787	0.9384	1
108	1	0.17	0.092	0.778	0.9296	1
109	1	0.16	0.091	0.769	0.9208	1
110	1	0.15	0.09	0.76	0.912	1
111	1	0.14	0.089	0.751	0.9032	1
112	1	0.13	0.088	0.742	0.8944	1
113	1	0.12	0.087	0.733	0.8856	1
114	1	0.11	0.086	0.724	0.8768	1
115	1	0.1	0.085	0.715	0.868	1
116	1	0.09	0.084	0.706	0.8592	1
117	1	0.08	0.083	0.697	0.8504	1
118	1	0.07	0.082	0.688	0.8416	1
119	1	0.06	0.081	0.679	0.8328	1
120	1	0.05	0.08	0.67	0.824	1
121	1	0.04	0.079	0.661	0.8152	0.990625
122	1	0.03	0.078	0.652	0.8064	0.98125
123	1	0.02	0.077	0.643	0.7976	0.971875
124	1	0.01	0.076	0.634	0.7888	0.9625
125	1	0	0.075	0.625	0.78	0.953125
126	1	0	0.074	0.616	0.7712	0.94375
127	1	0	0.073	0.607	0.7624	0.934375
128	1	0	0.072	0.598	0.7536	0.925
129	1	0	0.071	0.589	0.7448	0.915625
130	1	0	0.07	0.58	0.736	0.90625
131	1	0	0.069	0.571	0.7272	0.896875
132	1	0	0.068	0.562	0.7184	0.8875
133	1	0	0.067	0.553	0.7096	0.878125
134	1	0	0.066	0.544	0.7008	0.86875
135	1	0	0.065	0.535	0.692	0.859375
136	1	0	0.064	0.526	0.6832	0.85
137	1	0	0.063	0.517	0.6744	0.840625
138	1	0	0.062	0.508	0.6656	0.83125
139	1	0	0.061	0.499	0.6568	0.821875
140	1	0	0.06	0.49	0.648	0.8125
141	1	0	0.059	0.481	0.6392	0.803125
142	1	0	0.058	0.472	0.6304	0.79375
143	1	0	0.057	0.463	0.6216	0.784375
144	1	0	0.056	0.454	0.6128	0.775
145	1	0	0.055	0.445	0.604	0.765625
146	1	0	0.054	0.436	0.5952	0.75625
147	1	0	0.053	0.427	0.5864	0.746875
148	1	0	0.052	0.418	0.5776	0.7375
149	1	0	0.051	0.409	0.5688	0.728125
150	1	0	0.05	0.4	0.56	0.71875

Table 1. Continued.

Depth (cm)	RB Juvenile	MW Fry	MW Juvenile	BT Juvenile	CAS Fry	RSC Juvenile
151	0.995	0	0.049	0.397	0.5512	0.709375
152	0.99	0	0.048	0.394	0.5424	0.7
153	0.985	0	0.047	0.391	0.5336	0.690625
154	0.98	0	0.046	0.388	0.5248	0.68125
155	0.975	0	0.045	0.385	0.516	0.671875
156	0.97	0	0.044	0.382	0.5072	0.6625
157	0.965	0	0.043	0.379	0.4984	0.653125
158	0.96	0	0.042	0.376	0.4896	0.64375
159	0.955	0	0.041	0.373	0.4808	0.634375
160	0.95	0	0.04	0.37	0.472	0.625
161	0.945	0	0.039	0.367	0.4632	0.615625
162	0.94	0	0.038	0.364	0.4544	0.60625
163	0.935	0	0.037	0.361	0.4456	0.596875
164	0.93	0	0.036	0.358	0.4368	0.5875
165	0.925	0	0.035	0.355	0.428	0.578125
166	0.92	0	0.034	0.352	0.4192	0.56875
167	0.915	0	0.033	0.349	0.4104	0.559375
168	0.91	0	0.032	0.346	0.4016	0.55
169	0.905	0	0.031	0.343	0.3928	0.540625
170	0.9	0	0.03	0.34	0.384	0.53125
171	0.895	0	0.029	0.337	0.3752	0.521875
172	0.89	0	0.028	0.334	0.3664	0.5125
173	0.885	0	0.027	0.331	0.3576	0.503125
174	0.88	0	0.026	0.328	0.3488	0.49375
175	0.875	0	0.025	0.325	0.34	0.484375
176	0.87	0	0.024	0.322	0.3312	0.475
177	0.865	0	0.023	0.319	0.3224	0.465625
178	0.86	0	0.022	0.316	0.3136	0.45625
179	0.855	0	0.021	0.313	0.3048	0.446875
180	0.85	0	0.02	0.31	0.296	0.4375
181	0.845	0	0.019	0.307	0.2872	0.428125
182	0.84	0	0.018	0.304	0.2784	0.41875
183	0.835	0	0.017	0.301	0.2696	0.409375
184	0.83	0	0.016	0.298	0.2608	0.4
185	0.825	0	0.015	0.295	0.252	0.390625
186	0.82	0	0.014	0.292	0.2432	0.38125
187	0.815	0	0.013	0.289	0.2344	0.371875
188	0.81	0	0.012	0.286	0.2256	0.3625
189	0.805	0	0.011	0.283	0.2168	0.353125
190	0.8	0	0.01	0.28	0.208	0.34375
191	0.795	0	0.009	0.277	0.1992	0.334375
192	0.79	0	0.008	0.274	0.1904	0.325
193	0.785	0	0.007	0.271	0.1816	0.315625
194	0.78	0	0.006	0.268	0.1728	0.30625
195	0.775	0	0.005	0.265	0.164	0.296875
196	0.77	0	0.004	0.262	0.1552	0.2875
197	0.765	0	0.003	0.259	0.1464	0.278125
198	0.76	0	0.002	0.256	0.1376	0.26875
199	0.755	0	0.001	0.253	0.1288	0.259375
200	0.75	0	0	0.25	0.12	0.25

Table 1. Continued.

Depth (cm)	RB Juvenile	MW Fry	MW Juvenile	BT Juvenile	CAS Fry	RSC Juvenile
201	0.745	0	0	0.249	0.112	0.2375
202	0.74	0	0	0.248	0.104	0.225
203	0.735	0	0	0.247	0.096	0.2125
204	0.73	0	0	0.246	0.088	0.2
205	0.725	0	0	0.245	0.08	0.1875
206	0.72	0	0	0.244	0.072	0.175
207	0.715	0	0	0.243	0.064	0.1625
208	0.71	0	0	0.242	0.056	0.15
209	0.705	0	0	0.241	0.048	0.1375
210	0.7	0	0	0.24	0.04	0.125
211	0.695	0	0	0.239	0.032	0.1125
212	0.69	0	0	0.238	0.024	0.1
213	0.685	0	0	0.237	0.016	0.0875
214	0.68	0	0	0.236	0.008	0.075
215	0.675	0	0	0.235	0	0.0625
216	0.67	0	0	0.234	0	0.05
217	0.665	0	0	0.233	0	0.0375
218	0.66	0	0	0.232	0	0.025
219	0.655	0	0	0.231	0	0.0125
220	0.65	0	0	0.23	0	0
221	0.645	0	0	0.229	0	0
222	0.64	0	0	0.228	0	0
223	0.635	0	0	0.227	0	0
224	0.63	0	0	0.226	0	0
225	0.625	0	0	0.225	0	0
226	0.62	0	0	0.224	0	0
227	0.615	0	0	0.223	0	0
228	0.61	0	0	0.222	0	0
229	0.605	0	0	0.221	0	0
230	0.6	0	0	0.22	0	0
231	0.595	0	0	0.219	0	0
232	0.59	0	0	0.218	0	0
233	0.585	0	0	0.217	0	0
234	0.58	0	0	0.216	0	0
235	0.575	0	0	0.215	0	0
236	0.57	0	0	0.214	0	0
237	0.565	0	0	0.213	0	0
238	0.56	0	0	0.212	0	0
239	0.555	0	0	0.211	0	0
240	0.55	0	0	0.21	0	0
241	0.545	0	0	0.209	0	0
242	0.54	0	0	0.208	0	0
243	0.535	0	0	0.207	0	0
244	0.53	0	0	0.206	0	0
245	0.525	0	0	0.205	0	0
246	0.52	0	0	0.204	0	0
247	0.515	0	0	0.203	0	0
248	0.51	0	0	0.202	0	0
249	0.505	0	0	0.201	0	0
250	0.5	0	0	0.2	0	0

Table 1. Continued.

Depth (cm)	RB Juvenile	MW Fry	MW Juvenile	BT Juvenile	CAS Fry	RSC Juvenile
251	0.495	0	0	0.196	0	0
252	0.49	0	0	0.192	0	0
253	0.485	0	0	0.188	0	0
254	0.48	0	0	0.184	0	0
255	0.475	0	0	0.18	0	0
256	0.47	0	0	0.176	0	0
257	0.465	0	0	0.172	0	0
258	0.46	0	0	0.168	0	0
259	0.455	0	0	0.164	0	0
260	0.45	0	0	0.16	0	0
261	0.445	0	0	0.156	0	0
262	0.44	0	0	0.152	0	0
263	0.435	0	0	0.148	0	0
264	0.43	0	0	0.144	0	0
265	0.425	0	0	0.14	0	0
266	0.42	0	0	0.136	0	0
267	0.415	0	0	0.132	0	0
268	0.41	0	0	0.128	0	0
269	0.405	0	0	0.124	0	0
270	0.4	0	0	0.12	0	0
271	0.395	0	0	0.116	0	0
272	0.39	0	0	0.112	0	0
273	0.385	0	0	0.108	0	0
274	0.38	0	0	0.104	0	0
275	0.375	0	0	0.1	0	0
276	0.37	0	0	0.096	0	0
277	0.365	0	0	0.092	0	0
278	0.36	0	0	0.088	0	0
279	0.355	0	0	0.084	0	0
280	0.35	0	0	0.08	0	0
281	0.345	0	0	0.076	0	0
282	0.34	0	0	0.072	0	0
283	0.335	0	0	0.068	0	0
284	0.33	0	0	0.064	0	0
285	0.325	0	0	0.06	0	0
286	0.32	0	0	0.056	0	0
287	0.315	0	0	0.052	0	0
288	0.31	0	0	0.048	0	0
289	0.305	0	0	0.044	0	0
290	0.3	0	0	0.04	0	0
291	0.295	0	0	0.036	0	0
292	0.29	0	0	0.032	0	0
293	0.285	0	0	0.028	0	0
294	0.28	0	0	0.024	0	0
295	0.275	0	0	0.02	0	0
296	0.27	0	0	0.016	0	0
297	0.265	0	0	0.012	0	0
298	0.26	0	0	0.008	0	0
299	0.255	0	0	0.004	0	0
300	0.25	0	0	0	0	0

Table 1. Continued.

Depth (cm)	RB Juvenile	MW Fry	MW Juvenile	BT Juvenile	CAS Fry	RSC Juvenile
301	0.245	0	0	0	0	0
302	0.24	0	0	0	0	0
303	0.235	0	0	0	0	0
304	0.23	0	0	0	0	0
305	0.225	0	0	0	0	0
306	0.22	0	0	0	0	0
307	0.215	0	0	0	0	0
308	0.21	0	0	0	0	0
309	0.205	0	0	0	0	0
310	0.2	0	0	0	0	0
311	0.195	0	0	0	0	0
312	0.19	0	0	0	0	0
313	0.185	0	0	0	0	0
314	0.18	0	0	0	0	0
315	0.175	0	0	0	0	0
316	0.17	0	0	0	0	0
317	0.165	0	0	0	0	0
318	0.16	0	0	0	0	0
319	0.155	0	0	0	0	0
320	0.15	0	0	0	0	0
321	0.145	0	0	0	0	0
322	0.14	0	0	0	0	0
323	0.135	0	0	0	0	0
324	0.13	0	0	0	0	0
325	0.125	0	0	0	0	0
326	0.12	0	0	0	0	0
327	0.115	0	0	0	0	0
328	0.11	0	0	0	0	0
329	0.105	0	0	0	0	0
330	0.1	0	0	0	0	0
331	0.095	0	0	0	0	0
332	0.09	0	0	0	0	0
333	0.085	0	0	0	0	0
334	0.08	0	0	0	0	0
335	0.075	0	0	0	0	0
336	0.07	0	0	0	0	0
337	0.065	0	0	0	0	0
338	0.06	0	0	0	0	0
339	0.055	0	0	0	0	0
340	0.05	0	0	0	0	0
341	0.045	0	0	0	0	0
342	0.04	0	0	0	0	0
343	0.035	0	0	0	0	0
344	0.03	0	0	0	0	0
345	0.025	0	0	0	0	0
346	0.02	0	0	0	0	0
347	0.015	0	0	0	0	0
348	0.01	0	0	0	0	0
349	0.005	0	0	0	0	0
350	0	0	0	0	0	0

Appendix D. Weighted Usable Area for Study Species and Life Stages

LIST OF TABLES

Table 1. Weighted usable area for study species and life stages for base and peak flows, under high and low ALR conditions for a) Bull Trout juveniles, b) Mountain Whitefish fry, c) Mountain Whitefish juveniles, d) Rainbow Trout juveniles, e) Prickly Sculpin juveniles, f) Redside Shiner juveniles.

a) Bull Trout Juveniles

Period/Process	Months	Discharge	WUA (m²)				Δ WUA (m²) (Post - Pre)	
			Pre Rev5		Post Rev5			
			Low ALR	High ALR	Low ALR	High ALR	Low ALR	High ALR
Overwintering	Nov-Mar	Base	759,390	807,922	375,234	452,339	-384,156	-355,583
		Peak	255,165	271,170	248,034	237,144	-7,131	-34,026
		Peak - Base	-504,225	-536,752	-127,200	-215,195	377,025	321,557
Fry Emergence	Apr-May	Base	759,390	807,922	429,410	631,825	-329,980	-176,097
		Peak	255,165	271,170	255,165	271,170	0	0
		Peak - Base	-504,225	-536,752	-174,245	-360,655	329,980	176,097
Summer Rearing	Jun-Aug	Base	759,390	807,922	375,234	452,339	-384,156	-355,583
		Peak	255,165	271,170	248,034	237,144	-7,131	-34,026
		Peak - Base	-504,225	-536,752	-127,200	-215,195	377,025	321,557
Fall Rearing	Sept-Oct	Base	759,390	807,922	375,234	452,339	-384,156	-355,583
		Peak	255,165	271,170	255,165	271,170	0	0
		Peak - Base	-504,225	-536,752	-120,069	-181,169	384,156	355,583

Table 1. Continued.

b) Mountain Whitefish fry

Period/Process	Months	Discharge	WUA (m²)				Δ WUA (m²) (Post - Pre)	
			Pre Rev5		Post Rev5			
			Low ALR	High ALR	Low ALR	High ALR	Low ALR	High ALR
Overwintering	Nov-Mar	Base	445,924	341,793	245,344	220,471	-200,580	-121,322
		Peak	148,374	146,788	133,677	127,129	-14,697	-19,660
		Peak - Base	-297,550	-195,005	-111,667	-93,342	185,883	101,662
Fry Emergence	Apr-May	Base	445,924	341,793	271,708	286,056	-174,215	-55,737
		Peak	148,374	146,788	148,374	146,788	0	0
		Peak - Base	-297,550	-195,005	-123,335	-139,268	174,215	55,737
Summer Rearing	Jun-Aug	Base	445,924	341,793	245,344	220,471	-200,580	-121,322
		Peak	148,374	146,788	133,677	127,129	-14,697	-19,660
		Peak - Base	-297,550	-195,005	-111,667	-93,342	185,883	101,662
Fall Rearing	Sept-Oct	Base	445,924	341,793	245,344	220,471	-200,580	-121,322
		Peak	148,374	146,788	148,374	146,788	0	0
		Peak - Base	-297,550	-195,005	-96,970	-73,683	200,580	121,322

Table 1. Continued.

c) Mountain Whitefish juveniles

Period/Process	Months	Discharge	WUA (m²)				Δ WUA (m²) (Post - Pre)	
			Pre Rev5		Post Rev5			
			Low ALR	High ALR	Low ALR	High ALR	Low ALR	High ALR
Overwintering	Nov-Mar	Base	591,815	370,344	346,736	287,860	-245,079	-82,484
		Peak	186,299	187,916	179,727	169,942	-6,572	-17,974
		Peak - Base	-405,516	-182,428	-167,009	-117,919	238,507	64,509
Fry Emergence	Apr-May	Base	591,815	370,344	386,753	337,249	-205,062	-33,095
		Peak	186,299	187,916	186,299	187,916	0	0
		Peak - Base	-405,516	-182,428	-200,454	-149,333	205,062	33,095
Summer Rearing	Jun-Aug	Base	591,815	370,344	346,736	287,860	-245,079	-82,484
		Peak	186,299	187,916	179,727	169,942	-6,572	-17,974
		Peak - Base	-405,516	-182,428	-167,009	-117,919	238,507	64,509
Fall Rearing	Sept-Oct	Base	591,815	370,344	346,736	287,860	-245,079	-82,484
		Peak	186,299	187,916	186,299	187,916	0	0
		Peak - Base	-405,516	-182,428	-160,437	-99,944	245,079	82,484

Table 1. Continued.

d) Rainbow Trout juveniles

Period/Process	Months	Discharge	WUA (m²)				Δ WUA (m²) (Post - Pre)	
			Pre Rev5		Post Rev5			
			Low ALR	High ALR	Low ALR	High ALR	Low ALR	High ALR
Overwintering	Nov-Mar	Base	623,869	1,292,394	298,787	382,801	-325,082	-909,593
		Peak	255,904	270,840	245,177	240,154	-10,726	-30,687
		Peak - Base	-367,965	-1,021,553	-53,610	-142,647	314,356	878,906
Fry Emergence	Apr-May	Base	623,869	1,292,394	326,644	762,359	-297,225	-530,035
		Peak	255,904	270,840	255,904	270,840	0	0
		Peak - Base	-367,965	-1,021,553	-70,741	-491,518	297,225	530,035
Summer Rearing	Jun-Aug	Base	623,869	1,292,394	298,787	382,801	-325,082	-909,593
		Peak	255,904	270,840	245,177	240,154	-10,726	-30,687
		Peak - Base	-367,965	-1,021,553	-53,610	-142,647	314,356	878,906
Fall Rearing	Sept-Oct	Base	623,869	1,292,394	298,787	382,801	-325,082	-909,593
		Peak	255,904	270,840	255,904	270,840	0	0
		Peak - Base	-367,965	-1,021,553	-42,884	-111,961	325,082	909,593

Table 1. Continued.

e) Prickly Sculpin juveniles

Period/Process	Months	Discharge	WUA (m²)				Δ WUA (m²) (Post - Pre)	
			Pre Rev5		Post Rev5			
			Low ALR	High ALR	Low ALR	High ALR	Low ALR	High ALR
Overwintering	Nov-Mar	Base	790,827	675,694	781,320	566,021	-9,508	-109,672
		Peak	606,531	452,580	430,326	353,606	-176,205	-98,974
		Peak - Base	-184,296	-223,114	-350,994	-212,416	-166,698	10,698
Fry Emergence	Apr-May	Base	790,827	675,694	889,718	645,329	98,890	-30,365
		Peak	606,531	452,580	606,531	452,580	0	0
		Peak - Base	-184,296	-223,114	-283,186	-192,749	-98,890	30,365
Summer Rearing	Jun-Aug	Base	790,827	675,694	781,320	566,021	-9,508	-109,672
		Peak	606,531	452,580	430,326	353,606	-176,205	-98,974
		Peak - Base	-184,296	-223,114	-350,994	-212,416	-166,698	10,698
Fall Rearing	Sept-Oct	Base	790,827	675,694	781,320	566,021	-9,508	-109,672
		Peak	606,531	452,580	606,531	452,580	0	0
		Peak - Base	-184,296	-223,114	-174,788	-113,442	9,508	109,672

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Table 1. Continued.

f) Redside Shiner juveniles

Period/Process	Months	Discharge	WUA (m²)				Δ WUA (m²) (Post - Pre)	
			Pre Rev5		Post Rev5			
			Low ALR	High ALR	Low ALR	High ALR	Low ALR	High ALR
Overwintering	Nov-Mar	Base	529,948	798,649	275,651	283,192	-254,298	-515,457
		Peak	230,873	212,999	199,680	178,494	-31,194	-34,505
		Peak - Base	-299,075	-585,650	-75,971	-104,698	223,104	480,952
Fry Emergence	Apr-May	Base	529,948	798,649	297,201	513,663	-232,747	-284,986
		Peak	230,873	212,999	230,873	212,999	0	0
		Peak - Base	-299,075	-585,650	-66,328	-300,664	232,747	284,986
Summer Rearing	Jun-Aug	Base	529,948	798,649	275,651	283,192	-254,298	-515,457
		Peak	230,873	212,999	199,680	178,494	-31,194	-34,505
		Peak - Base	-299,075	-585,650	-75,971	-104,698	223,104	480,952
Fall Rearing	Sept-Oct	Base	529,948	798,649	275,651	283,192	-254,298	-515,457
		Peak	230,873	212,999	230,873	212,999	0	0
		Peak - Base	-299,075	-585,650	-44,777	-70,193	254,298	515,457