Fisheries and Oceans Canada
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REVIEW OF THE APPLICABILITY OF HABITAT SUITABILITY INDEX (HSI) MODEL AND HABITAT ASSESSMENT TOOL (HAT) FOR ASSESSMENT OF WESTSLOPE CUTTHROAT TROUT HABITAT CHARACTERISTICS AND ASSOCIATED PRODUCTIVITY

1.0 Context

Teck Coal Limited (hereafter the Proponent) has proposed the development of three new coal mining areas, which would expand the existing operating areas of Line Creek, Coal Mountain, and Fording River, all located near Sparwood, BC. The Provincial Environmental Assessment (EA) for the Line Creek Phase II Expansion is complete, with construction underway. The Fording River and Coal Mountain Phase II Expansions are currently under Federal and/or Provincial EA review. The majority of the proposed developments occur within the Dry Creek, Lake Mountain Creek, and Wheeler Creek drainages, respectively. The Proponent currently has two existing *Fisheries Act* Authorizations associated with the Line Creek Operations, which require "offsetting" to be identified to counterbalance serious harm to fish that are considered a part of a commercial, recreational or Aboriginal (CRA) fishery. One of the key species considered a part of a CRA fishery in the Fording River area is the Westslope Cutthroat Trout, *Oncorhynchus clarkii lewisi*. Westslope Cutthroat Trout (WCT) is a popular freshwater sport fish in western Canada and is a Province of British Columbia managed fish resource. The British Columbia population of Westslope Cutthroat Trout is listed as Species of Special Concern by the Committee of the Status of Endangered Wildlife in Canada (COSEWIC). Westslope Cutthroat Trout is also identified as an indicator species of general ecosystem health, due to their restrictive habitat requirements (COSEWIC 2006).

Proposed offsets for these developments will require assessment of the Fording River and tributaries to develop a greater understanding of Westslope Cutthroat Trout populations and limiting habitats affecting productivity. As a component of this assessment, the Proponent has developed and submitted a Habitat Suitability Index (HSI) model and a Habitat Assessment Tool (HAT) model which is being reviewed by the Fisheries Protection Program (FPP). As part of the *Fisheries Act* Authorization process, FPP will review the proposed models to determine whether they are appropriate as tools to evaluate project effects, and potential benefits of offsetting measures.

In general, Habitat Suitability Indices are curves used to quantify and evaluate habitat quality for a specific species, based on the known selection of particular habitat conditions during specific periods of the species' life history (Bovee 1986). The HSI curves are therefore applicable only to the life stages and areas that are specified in the model, and for which field data has been obtained. In the absence of such field data, HSI curves from other regions have been adapted and applied in some cases; but adapted HSI information may not be appropriate for other areas, habitats or species (Larocque et al. 2014). Additionally, the statistical approach used to incorporate individual curves into composite indices for a complete HSI model will produce different estimates of habitat suitability.

The Habitat Assessment Tool is a population model that links changes in abundance of WCT to changes in habitat conditions or management actions. Such models can be used to evaluate the potential impacts of habitat changes on growth, survival rate, fecundity, migration or carrying capacity. Population trends can be projected over time. The model can potentially incorporate HSI models as a means to link habitat characteristics to population processes.

The Province of British Columbia has provided incremental reviews and advice to the Proponent regarding the development and application of both HSI and the HAT models, and the subsequent validations both in informal technical reviews and as participants in the Fording River Operations Swift Project Fish and Fish Habitat Working Group. The HSI and HAT models and an assessment of the models by the BC Ministry of Environment were presented to the Elk Valley Fish and Fish Habitat Committee, which is comprised of the Proponent, Provincial and Federal regulators, and the Ktunaxa First Nations.

FPP is requesting Science Branch assistance to further assess the HSI for its suitability as a tool to quantify habitat quality and the HAT as a tool to predict the response of CRA fisheries species to various potential management strategies, in the context of Fisheries and Oceans Canada's (DFO's) regulatory obligation to consider impacts to fish and fish habitat of a CRA fishery. The purpose of this Science Response is to review information provided with respect to the above mentioned modelling in "Westslope Cutthroat Trout Suitability Model Validation" (Golder Associates), and "Habitat Assessment Tool for the Upper Fording Westslope Cutthroat Trout Population" (Ecofish Research Ltd.) to meet the following objectives:

1. Review the inputs, parameters and assumptions of the Habitat Suitability Index (HSI) and provide advice regarding the adequacy of the HSI Version 5 Models as surrogates of fisheries productivity when considering project related impacts to Westslope Cutthroat Trout and their habitats and corresponding offsets. Include a discussion of uncertainties and data gaps.
2. Review the inputs, parameters and assumptions of the Habitat Assessment Tool (HAT) and provide advice regarding the adequacy of the HAT to determine limiting habitats and to assess the population response of the Upper Fording Westslope Cutthroat Trout population from potential management and strategies and offset actions. Include a discussion of uncertainties and data gaps.
3. Provide a summary of recommendations and advice consistent with recent National guidance regarding the use of these tools as a suitable proxy for future projects to determine fisheries productivity when considering impacts to fish and fish habitat of a CRA fishery and corresponding offsetting proposals.

This Science Response Report results from the Science Response Process of August 2015 on the Review of the applicability of Habitat Suitability Index (HSI) Model and Habitat Assessment Tool (HAT) for assessment of Westslope Cutthroat Trout habitat characteristics and associated productivity.

2.0 Background

The Proponent has proposed the development of new coal mining operating areas at Line Creek, Coal Mountain, and Fording River (Figure 1). The proposed developments include expansion adjacent to the north boundary of their existing Line Creek Mine operations by about 1100 hectares, located approximately 22 km northeast of Sparwood in south-eastern British Columbia. The Proponent estimates that the proposed development would produce 52 million metric tons of clean coal over about 20 years (average of 2.6 million tons per year) and would generate approximately 600 million m^3 of waste rock. The majority of the proposed development occurs within the Dry Creek drainage, a tributary of the Fording River.

The proposed Coal Mountain expansion would involve an extension of Coal Mountain operations of 1000 hectares 20 km north of the existing facility which is located approximately 15 km south of Sparwood, BC. The Proponent estimates that the proposed development would produce 76.5 million metric tons of clean coal over about 34 years (average of 2.25 million tons per year) and would generate approximately 510 million m^3 of waste rock. The majority of the proposed development occurs within the Wheeler Creek drainage, a tributary of Michel Creek.

In addition, the Proponent has proposed to develop a new operating area adjacent to existing Fording River Operations, an expansion of 1200 hectares approximately 20 km northeast of Elkford, south-eastern British Columbia. The Proponent estimates that the proposed development would produce 175 million metric tons of clean coal over 25 years, and would generate approximately 1500 million m^3 of waste rock. The majority of the proposed development occurs within Fording Creek drainage, a tributary of the Elk River.

Westslope Cutthroat Trout are known to inhabit the Fording River and Michel Creek (tributaries to the Elk River), and their respective tributaries which include Line Creek, Dry Creek, Swift Creek, Kilmarnock Creek, Henretta Creek, Fish Pond Creek, Clode Creek, Lake Mountain Creek Wheeler Creek, and Snowslide Creek. The Proponent's Environmental Assessment Certificate Application for Fording River Operations notes that the primary pathways in which the projects have the potential to affect fish and fish habitat are:

- *"Potential destruction or permanent alteration of tributary fish habitat associated with implementation of surface water management, open pit development and waste rock placement and;*
- *Potential changes to flows and levels [in affected watercourses] associated with surface water management, open pit development and waste rock placement, which can affect Westslope Cutthroat Trout habitat quantity, suitability or connectivity." (Preface and Executive Summary p. 159).*

The potential impacts to fish and fish habitat as a result of the proposed developments, as well as the proposed offsets for these developments, have been determined in part from the descriptions of habitat suitability and quantity derived from the HSI and HAT models used by the Proponent. The HSI model was subsequently validated through the collection of field survey data to assess how well the model Suitability Index curves represent the habitat suitability relationships in streams in this watershed.

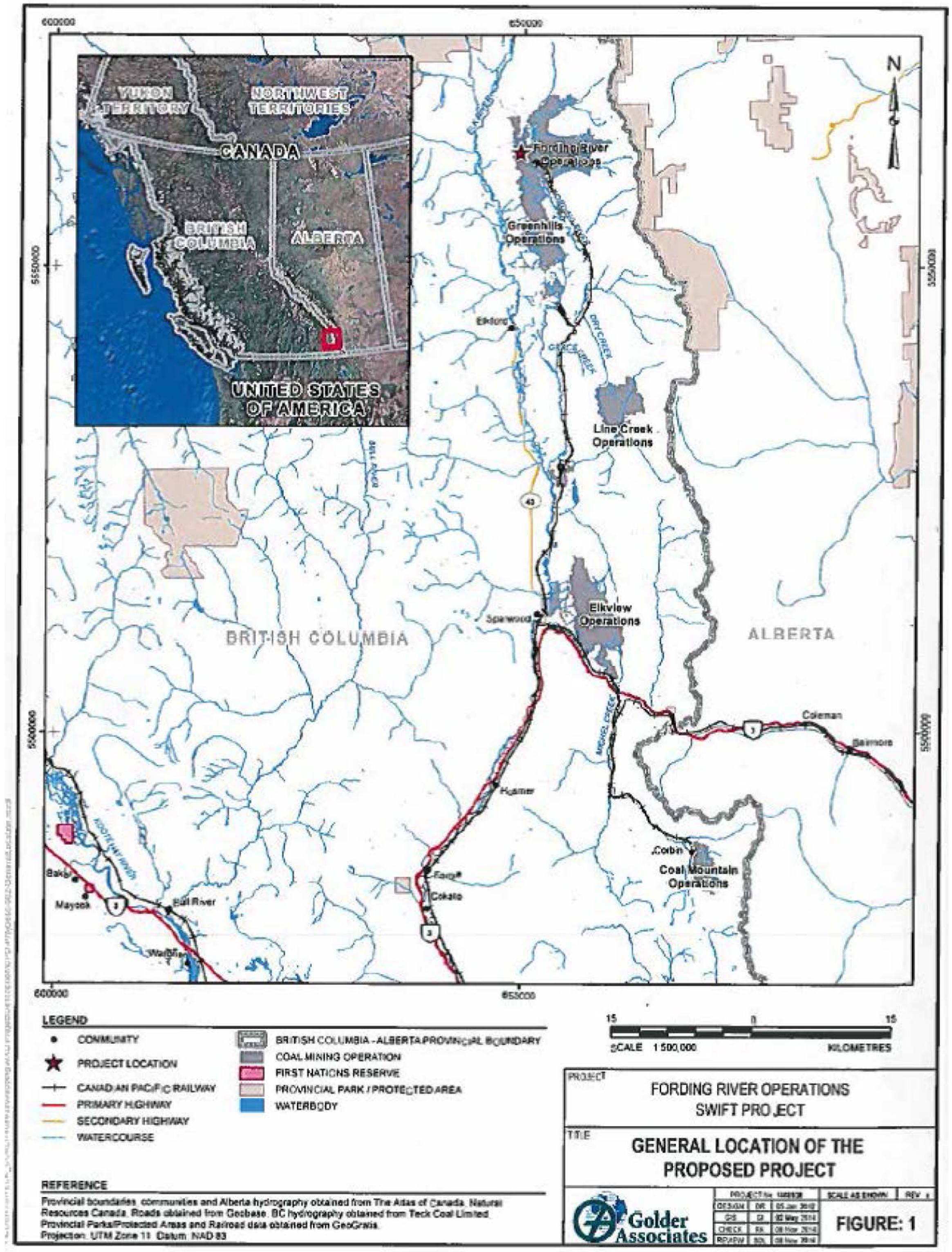

Figure 1. General locations of Teck Coal Ltd's proposed expansions of the existing operating areas of Line Creek, Fording River and Coal Mountain. From the "Environmental Assessment Certificate Application submitted by Teck Coal Limited for the proposed Fording River Operations Swift Project"; available on the [Province of British Columbia's Environmental Assessment Office website](#).

3.0 Analysis and Response

DFO Science Branch responses to the three review objectives posed by DFO FPP (see Context above) are detailed below. To prepare this response, the following documents from the Proponent were reviewed:

- Results of 2012-2014 Westslope Cutthroat Trout Habitat Suitability Model Validation, Report # 1412994, Golder Associates, June 2015. Hereafter the "Validation Report".
- Smyth, E., M. Sparling, and T. Hatfield. Habitat Assessment Tool for the Upper Fording Westslope Cutthroat Trout Population. Consultant's report prepared for Teck Coal Limited by Ecofish Research Ltd., August 22, 2014. Hereafter the "HAT Report".

The Fisheries Productivity Investment Policy (DFO 2013) provides guidance on developing offsetting measures when there is unavoidable serious harm to fish. Residual serious harm to fish is determined after all avoidance and mitigation measures have been applied. By understanding the nature of the residual serious harm to fish, it is possible to estimate the consequences on fisheries productivity and, in turn, to characterize the contribution of relevant fish to the ongoing productivity of commercial, recreational or Aboriginal fisheries (Paragraph 6(a) of the Fisheries Act). The residual *serious harm to fish* is the loss that must be counterbalanced by the proposed offsetting measures.

Science advice on how to characterize serious harm to fish in the context of fisheries productivity and for the development of offset measures has been provided (Bradford et al. 2013, Randall et al. 2013, Clarke and Bradford 2014, Bradford et al. unpublished manuscript[1]). Serious harm to fish has been categorized as impacts that have effect on habitat quantity, habitat quality, and those that cause ecosystem transformations. For projects where the serious harm is localized and the proposed offsetting measures are designed to replace the productivity lost in the immediate area of the project's impacts, changes in habitat quantity or quality can be assessed by habitat-based measures. If the offset habitat is the same as that affected by the project, a simple evaluation of habitat area may be sufficient to determine offset requirements. In other cases, the function or capacity of the habitat to produce fish may need to be assessed, and a habitat suitability index in relation to a quantitative habitat model can be used to compute weighted useable area (WUA) as recommended by Bradford et al. (unpublished manuscript[1]). The key consideration in these cases is that the offset measures are being designed to directly offset the serious harm by providing benefits to the same fish affected by the project's impacts.

For situations where offset measures are out-of-kind, or will benefit other populations than those exposed to the residual serious harm, a population rather than habitat-based focus may be required to evaluate the offset, and to determine if the proposed measures can be considered equivalent, in terms of fisheries productivity, to the serious harm.

Ecosystem transformation refers to situations where whole ecosystems are being significantly changed, either through destruction, significant alteration, or transformation to another type (e.g., river to reservoir). In these cases, impacts are expected to affect significant proportions of populations, and the assessment of effects should consider changes in fisheries productivity (or a related surrogate) through an evaluation of the changes in population processes that affect productivity. In some cases, a relatively simple habitat-production relation may be sufficient, but

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[1] Bradford, M.J., Smokorowski, K.E. Clarke, K.D., Keatley, B.E., and Wong, M.C. (2015). Equivalency metrics for the determination of offset requirements for the Fisheries Protection Program. DFO Can. Sci. Advis. Sec. Res. Unpublished manuscript.

in others a population model that accounts for the effects of the project on fish vital rates (growth, survival, migration and reproduction) is required. Such a model may be qualitative (e.g., influence diagrams) or quantitative (numerical analysis or simulation). The choices of species or communities to be considered in the analysis will be guided by fisheries management objectives for the region (DFO 2013).

Guidance on the use of models for habitat management is provided in De Kerkhove et al. (2008), Minns et al. (2011), and Poesch et al. (2012). Because most projects will affect habitat, establishing the link between habitats and fish production is critical for the successful application of population models. The most precise models will use site-specific information on habitat, fish abundance, and other life history information to estimate changes in fish populations associated with development, and make predictions of the benefits of proposed offsetting measures. Models with fewer site-specific data will need to make use of regional or larger-scale information and will have lower precision; in these cases the offsetting requirements may be increased as a result of the greater uncertainty (DFO 2013).

3.1 Evaluation of the Habitat Suitability Index (HSI) Model

3.1.1 Background on HSI

The habitat suitability index (HSI) is a commonly used index to describe fish habitat quality (Bovee 1986). HSI can be obtained through professional judgment or from life history studies in the literature (Category I), habitat use data based on frequency of occurrence of actual habitat conditions used by different species and life stages in a stream (Category II), or habitat preference data that combines the category II frequency analysis with additional information on the habitat availability in the sampling reaches (Category III).

HSI curves can be created for a variety of different abiotic habitat variables such as water depth, velocity, substrate, temperature, dissolved oxygen, etc. For a particular habitat variable, the HSI curve represents the degree of preference displayed by fish over the complete range of environmental conditions found in a river reach. Generally, data for these variables is obtained in focal positions where fish were present and absent, as determined through visual observations (e.g., snorkeling). Subsequently, a HSI is calculated as the ratio of percent utilization (percentage of fish observed that used this range of variable) to percent availability (percentage of the surface area of the river characterized by this range of variable) of these environmental conditions (Vadas and Orth 2001). Values of HSI generally range from 0 (poor habitat) to 1 (excellent habitat). In the absence of such field data, expert opinion may be used or HSI curves from other regions are applied (adapted HSI). However, adapted HSI information may not be appropriate for other areas, habitats, species or life stages (Larocque et al. 2014).

After establishing the individual HSI curve for different abiotic habitat variables, normally a composite HSI is calculated (Figure 2), using a variety of different statistical approaches (Ahmadi-Nedushan et al. 2006). This composite HSI is subsequently used in combination with habitat and hydrological models (e.g., Physical Habitat Simulation Model (PHABSIM), River2D) to create habitat quality maps, and to calculate weighted useable area (WUA). Estimated WUAs may later be incorporated in the Instream Flow Incremental Methodology (IFIM) and used to predict habitat gains or losses due to project developments or water withdrawals (Stalnaker et al. 1995).

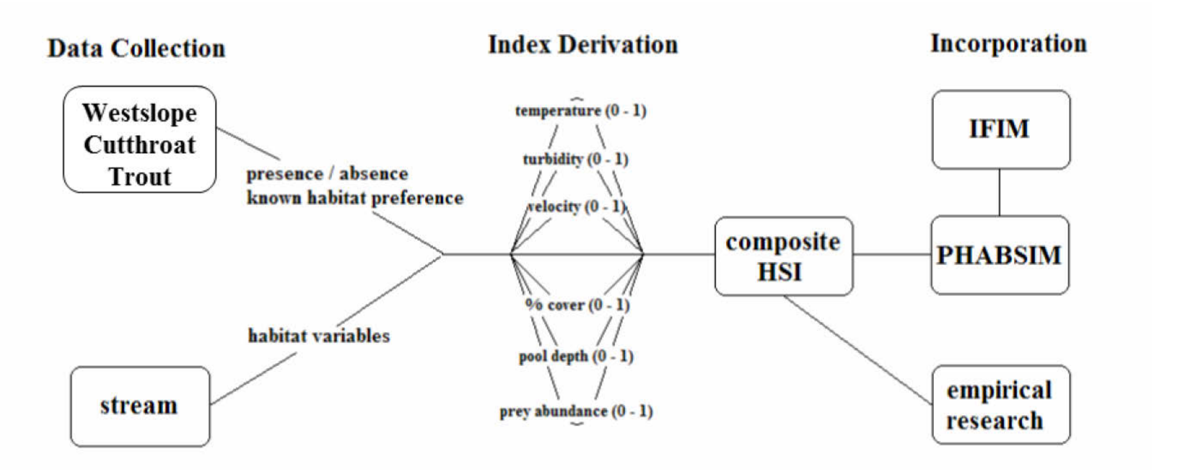

Figure 2. A generalized process for developing and using habitat suitability indices and incorporating them into other environmental assessment tools after De Kerckhove et al. (2008).

HSI is a useful tool for spatial modelling and ecosystem simulation by linking a biological value to physical habitat features. HSI models are widely used to assess the risk of habitat losses to a population or individual (Stalnaker et al. 1995). However, without verification of the model predictions, models have little merit. Therefore, the validation of the HSI model is an important step. The validation may include, in a first approach, the verification of the individual HSI curves, but more importantly an evaluation of the composite HSI and the WUA against independent data of actual fish occurrences should be conducted.

3.1.2 Review of the data inputs, parameters, and assumptions of the HSI curves and discussion of their adequacy as surrogates of fisheries productivity

Although the HSI curves developed by the Proponent have been subject to several reviews, some of the major points of concern raised by regulators and First Nations, as well as the Fish and Fish Habitat Working Group Subcommittee still remain in regards to the results presented in the Validation Report. Key deficiencies in the validation are described below.

The Validation Report does not clearly describe how the information from the HSI curves will be applied to quantify habitat losses and determine offsetting. The Validation Report states that the HSI was developed as a tool to describe fish habitat and suitability, and predict habitat losses and gains. The preferable method to achieve this, as described above, would be to develop a composite HSI, and, using a combination of empirical data and habitat and hydrological models, incorporate the information into habitat quality maps and calculate weighted useable areas, which would then be validated.

It seems likely that the intent is instead to feed the individual habitat suitability indices directly into the HAT. However, the Validation Report describes the validation of individual habitat suitability curves only, and does not articulate how the individual curves will be incorporated to describe fish habitat and suitability toward predicting habitat losses and gains. The lack of detail with respect to the specific next steps for the individual HSI curves hampers the assessment of the adequacy of the HSI curves.

There are key limitations associated with the use of HSI that are not identified in the Validation Report. For example, an HSI model does not consider the connectivity between and the importance of tributary and mainstem habitat for different life stages in a mobile fish species such as WCT (Anderson et al. 2006). It is likely that different life stages of WCT in the Elk River watershed use different habitats, situated in tributary streams, and in the mainstem river. Consequently, the destruction of a tributary stream may affect the overall WCT population, as habitat features lost in the tributary may not be replaceable in the mainstem. There is no indication in the Validation Report that this limitation has been considered or will be considered in the future.

The timing of field program and the site selection may not be adequate. With respect to *timing* of the field sampling, October appears relatively late to adequately describe parr and adult rearing habitat in this geographical area, based on data provided by the BC Ministry of Environment that suggests that water temperatures are declining in October. The decline in water temperature likely results in behavioral changes of juvenile WCT from diurnal to nocturnal, and a habitat shift from rearing to sheltering (Heggenes et al. 1993). Therefore, October may be inappropriate to describe summer rearing habitat.

Modelling of habitat suitability requires, on one hand, HSI curves for the different life stages of key species and, on the other hand, the timing of Biologically Significant Periods (BSP) in which these life stages occur (Geer 1987). BSPs, which are periods of time when a given life stage is present or active in a particular habitat, and for which habitat modelling of that life stage is relevant, have not been identified for WCT in the Elk River watershed. A typical periodicity chart of a species includes the BSP and the dates of the period for which the modelling of habitat is relevant for a given life stage of interest (Table 1). A periodicity chart to articulate the time periods for Westslope Cutthroat Trout BSPs is required to determine if October is an appropriate sampling period to describe parr rearing habitat.

Table 1. Generalized species periodicity chart highlighting the timing of Biologically Significant Periods (BSP) for the life stages of interest.

				Life stage		
		Spawning		**Rearing**		**Overwintering**
BSP	Date		Fry	Parr	Adult	
1	*n/a*	x				
2	*n/a*		x			
3	*n/a*			x	x	
4	*n/a*					x

With respect to *site selection*, very little information is provided on the criteria used in the site selection process. For example, the description of site selection did not identify if there were sites selected in areas that are expected to be permanently altered by the development, or if there were reference sites chosen. Highlighted uncertainties in the timing and the site selection are reducing the confidence in the pertinence of the data acquisition and relevance of the acquired data to validate the HSI curves.

HSI models, as described by the Proponent, may not be an appropriate surrogate of fisheries productivity when considering project related impacts to Westslope Cutthroat Trout and their habitats. For the assessment of environmental impacts, HSI models are generally considered an appropriate metric to quantify fish habitat (Bradford et al. unpublished manuscript[1]); however, the link to equate fish habitat quantity or quality to productivity is less established (Hayes et al. 2009). Although the importance of habitat for the sustainability of fish populations is widely recognized, and the protection and restoration of habitat are common components of fisheries management programs, the question of how much (if any) habitat can be lost before there is a recognizable effect on the fisheries productivity remains an open question. Because further research is needed at this time to quantify the link between habitat conditions and metrics of productivity, to develop predictive models, the HSI model as described by the proponent should acknowledge the limitations associated with its ability to predict productivity and population responses to habitat change.

Recent legislative changes to the *Fisheries Act* focus on conservation, sustainability, and the ongoing productivity of Canada's commercial, recreational, and Aboriginal fisheries, rather than the specific protection of fish habitat. Whereas the methods to evaluate the quantity and quality of fish habitat based on habitat suitability indices are well established, new methods may be needed to assess the ongoing productivity of fisheries. The use of bioenergetics habitat models to assess habitat quality using the net energetic gain (NEG) of fish has been suggested (De Kerckhove et al. 2008, Larocque et al. 2014). By incorporating not only physical variables, but also biological variables, such as food availability, bioenergetics habitat models improve the ability to quantify habitat quality in comparison to HSI models (Rosenfeld et al. 2005). Furthermore, bioenergetics habitat models are mechanistic models, with causal relationships between variables, rather than the correlative relationships in the HSI models. Consequently, a bioenergetics habitat modelling approach may represent a better proxy for fisheries productivity than HSI models. Although bioenergetics models have been developed to explain habitat use of a variety of aquatic species including Cutthroat Trout (Jenkins and Keeley 2010), the absence of a readily available modelling tool, as well as the high demand of species- and site-specific information, may be seen as prohibitive at this point in time for a wider commercial use of bioenergetics habitat models in environmental impact assessments.

Recommendations

- Calculate a composite HSI that captures the interactions between the preferences for depth, velocity, and substrate, combine HSI with a hydrological model to estimate habitat quality and quantity and validate the model output against field observations.
- Define Biological Significant Periods (BSP) for WCT in the Elk River watershed.
- Provide details on the selection process and criteria for the selected study sites and the particular purpose (e.g., impacted, reference/control) for each selected study site.
- Explore data more relevant to predict fish densities, such as water temperature and dissolved oxygen that was collected during the field program in the data analysis.
- Complex bioenergetics habitat models, with a wider variety of abiotic (water temperature, dissolved oxygen concentration) and biotic (predator density, food availability) input variables, may, in the future, be a more suitable tool to adequately describe habitat quality and its linkage to fish density, fitness, or productivity.

3.1.3 Review of Validation

As the validity of the HSI curves is critical to the accuracy of the model outcome, particular emphasis is given to the validation of the HSI curves and the evaluation of the methodology used in the validation. Key deficiencies in the validation are described below.

There is no validation presented for a composite HSI. Considerable effort was spent on validation of univariate habitat suitability curves as presented in the Validation Report. Over three years, 29 sites that are distributed over a relatively wide geographical range were studied, and in many cases the validation of univariate habitat suitability curves represents an extensive investigative and analytical process. However, the Proponent fails to describe any process by which the individual univariate habitat suitability curves will be incorporated, or how a composite HSI will then be validated. For example; significant effort was invested to determine the exact substrate size by using a "100 particle Wolman pebble count for substrate composition", in which the b-axis (2nd largest) of 100 particles is measured (Harrelson et al. 1994). This data was used to determine the D_{50}, which is the particle size that 50% of the particles are equal to or smaller than (Harrelson et al. 1994).

The validation of univariate habitat suitability curves for velocity, depth, and substrate for different life stages of WCT that were generated based on expert opinion may be considered as a first step in the validation process, however, the Validation Report does not include an HSI model and its validation.

The methodology chosen to validate the curves is not standard (Bovee 1986). There are two key discrepancies associated with the method commonly used to establish and validate HSI curves. *The data acquisition method is not standard*. The method used to generate the input data for the preference curves for fry, juvenile, and adult rearing habitat does not conform to the standardized and accepted approach, i.e., no snorkeling surveys were conducted and no microhabitat data (depth, velocity) were collected (Bovee 1986, 1998). Instead the Proponent conducted three-pass depletion-removal electrofishing with block nets and measured the habitat variables along the cross-section, situated mid-site, or where the field crew identified the most representative conditions in the blocked area. Using the electrofishing approach, it is unlikely that WCT were caught in their exact drift-feeding or sheltering position. In addition, the physical habitat was not measured in the focal fish position.

The data analysis of relating fish density to habitat quality to validate the curves is not standard. Instead of presence/absence data, fish density was used to validate the HSI curves. Although fish density is a valid proxy in some circumstances to describe habitat quality, the presented data analysis is not likely adequate as fish density is affected by a variety of biotic and abiotic factors and, therefore, cannot be accurately predicted by a single biotic variable in the validation process (Table 2). Furthermore, particularly for territorial juvenile salmonids, fish density may not be a reliable proxy for habitat quality because dominant individuals occupy the best quality habitat displacing subordinates into relatively low quality habitat at higher densities (Rosenfeld 2003).

This unproven methodology may potentially introduce biases of unknown magnitude and impact to the habitat suitability as well as habitat quality and quantity predictions. Additionally, although the field program to validate the HSI curves was conducted over three years, using the unconventional method of relating a measure of fish density to mesohabitat characteristics leads to a relatively low number of observations. This relatively small sample size also occurs over a limited hydraulic range, such that the HSI curves can only be partially validated, for example; the spawning HSI curve for water depth could not be corroborated for water depths greater than 0.6 m.

Without a demonstration that this method (fish density on mesohabitat scale) produces the same or similar results as the standard method (fish presence/absence on micro habitat scale), there is limited confidence in the value of the presented data to validate the expert-opinion HSI curves.

Relationship between HSI curves and field data is not statistically evaluated. The association between the individual HSI curves and the corresponding field observations was described (Table 2), but no objective statistical evaluation was conducted to quantify the model fit to the data. With no quantifiable method evaluating the fit of the field observation to the HSI curves presented, the confidence in the values of the results is limited.

Table 2. Accordance of estimated fish densities from field data and the HSI curves for different life stages of WCT.

	HSI curves			
Life stage	Depth	Velocity	Substrate	Cover
Spawning	Some fit but lower than predicted, water depths from 0.6-1.5 m not validated	Discrepancy, data indicated lower preference than predicted by HSI curve	Some fit	n/a
Fry - rearing	Fits but lower than predicted	Fits but lower than predicted	Poor fit	n/a
Parr - rearing	Poor fit	Poor fit	Poor fit	Some fit
Adult - rearing	Poor fit	Poor fit	Poor fit	Poor fit
Overwintering	n/a	n/a	Poor fit	n/a

Weak link between site suitability and fish density. In Section 3.2.1.2 of the Validation Report (Site suitability and fish density), a quantile regression analysis is presented to assess the relationship between the upper limits of fish density and habitat suitability calculated from the weighted useable area. In general, quantile regression is a useful analysis for estimating the effects of limiting factors when ecological responses are highly variable (Milhous and Bartholow 2006). For example, Dunham et al. (2003) used quantile regression analysis to describe density of Cutthroat Trout as a function of physical habitat characteristics. However, the quantile regression analysis presented in Section 3.2.1.2 highlights that the site suitability values for depth, velocity, and substrate on their own are poor predictors for fish density. Fish density is likely to be affected by a variety of other abiotic and biotic variables, which were not considered in the study. Consequently, the quantile regression analysis of fish density versus site suitability per life stage and habitat variable for WCT in the Elk River watershed reveals only four significant relationships. But when accounting for the multiple comparison (Bonferonni correction: $\alpha = 0.05/27 = 0.002$), this number declines to two significant relationships; i.e., the relationships between velocity and fish density at the 0.8 percentile for adult rearing habitat and between substrate and fish density at the 0.95 percentile for overwintering habitat. Little confidence in the data can be gained from the statistical analysis.

Poorly described terms and data analysis. *Weighted useable area* was calculated as follows "For each cell along the transect, the probability of use from the HSI model based on the measured water depth or water velocity of that cell was multiplied by the cross sectional area to represent the usable area within each cell. The sum of the usable areas across the transect was divided by the total cross sectional area and is referred to the site suitability. For substrate, site suitability was calculated as the sum of the products of the proportions of particles from the pebble count in each size category and the Model 5 HSI probabilities for that category."

This approach to calculate WUA is different from the WUA that is the outcome of PHABSIM or the River2D model. Normally, WUA will change depending on the discharge chosen in the model simulation, whereas the WUA presented by the Proponent appears to be a fixed value per study reach, which is an inappropriate assumption. Furthermore, information on the number of cells that were studied per cross-sectional transect is missing and should be added.

Fished surface area was estimated for each survey site, and then numbers of fish caught at each site were converted to a standardized fish density per 100 m^2. This *estimated fish density* was further scaled by dividing fish density at a given site by the maximum fish density observed, referred to as *relative fish density*, which was used as habitat suitability measure. This estimation method is vulnerable to habitat suitability values becoming skewed from the influence of any single outlier in the fish density data set. Normally in the calculation of habitat suitability indices, the observation of individual fish are grouped in categories (intervals of a particular abiotic habitat variable) (Bovee 1986). For example, water depth would be binned in the following categories 0-19 cm, 20-39 cm, 40-59 cm, etc. The multiple observations within each category would consequently minimize the potential influence of one single outlier data point to skew other data points through the scaling process.

Recommendation

- Provide rationales for the use of electrofishing instead of snorkeling to support the use of a non-standard practice.
- Validate HSI curves using field observations of standardized methodology, e.g., frequency microhabitat used by the target fish species.
- As noted in the Validation Report, information at greater water depths and velocities would be required to validate the HSI curves over their complete range and for predictions of habitat quality in deeper river sections.
- Provide formulas next to text description for calculation used in the Validation Report. Depending on how the WUA was calculated, the Proponent may want to change the name of this variable so as to not confuse the reader with the weighted useable area that is the outcome of PHABSIM or the River2D model.
- Group fish density data into different intervals, to ensure that the maximum fish density value would be incorporated into the average with other values in the same velocity or depth interval. A potential outlier would be less influential using this methodology for scaling.

3.2 Evaluation of the Habitat Assessment Tool (HAT)

3.2.1 Background on HAT

The habitat assessment tool (HAT) was designed to “determine limiting factors and to assess the population response from potential management strategies and habitat offset actions” (p.ii of the HAT Report). The authors conclude that the “local population was limited by young adult and adult rearing habitat”. Through various simulations they find that their conclusion was robust and that the population was not sensitive to manipulations of any particular habitat type.

Models such as HAT are tools to quantitatively organize information and thinking about a population and its linkages to habitat. When information is scarce, model outputs are less reliable and might be best viewed as plausible hypotheses to be evaluated with other information, such as field observations, data or expert opinion. As site-specific information becomes increasingly available, it becomes possible to make detailed predictions or prescriptions.

The core population model is a standard Leslie matrix formulation, similar to the WCT model of Hildebrand (2003). Key parameters, survival rates, and fecundities are drawn from a variety of sources. The basic model has no density dependent or compensatory processes, meaning the model population will grow exponentially without limit (if the parameters are set to result in positive population growth). To limit the population, a hard ceiling is imposed at each life stage from young-of-the-year (YOY) to older adults. Ceiling values were from the Area-per-Individual (API) model of Minns (2003) that estimates density of fish communities as a function of body size. The amount of habitat was estimated as the product of the area of habitat for each life stage, and a rating of habitat quality, and this was used in conjunction with the API to estimate the maximum abundance possible based on the habitat for each life stage. Fish movement was modelled to allow adult fish to move among modelled river reaches when carrying capacity was exceeded.

The key result, that adult habitat is limiting the model population, should be examined critically, as it could have a significant impact on management decisions regarding habitat manipulations. For the adult stage to be limiting, the supply of juveniles into the adult stage, and the survival of adults must be large enough such that the density of adults exceeds the estimated carrying capacity. In other cases, the juvenile stages can be limiting when the abundance of juveniles is limited by the habitat carrying capacity and low survival for subsequent stages prevents adults from reaching densities that approach the habitat ceiling for their habitat. Finally, when survival rates are low, populations may never reach the carrying capacity of their environment. Populations with low survival rates may be vulnerable to extirpation (Hildebrand 2003).

3.2.2 Review of the data inputs, parameters, and assumptions of the HAT and discussion of the adequacy of HAT to determine limiting habitats and assess population response of Westslope Cutthroat Trout

The review of the HAT model outlines key deficiencies as described below.

Input Parameters: survival rates appear to be too high. Examination of the input parameters to the base model suggests that the finding of adult habitat limitation may be caused by the use of very high adult population survival rates. The authors used an annual survival rate of 0.81, whereas other authors used values of 0.35 (Hildebrand 2003) or 0.47 (Peterson et al. 2010) in their WCT population models. Direct estimates of adult mortality are available for the Elk River (Wilkinson 2009), and they are in the range of these other studies. It is unclear why estimates from the Elk River were not used as a starting point for the adult population. Use of the high survival rate causes the adult population to be at least threefold larger for a given level of recruitment than would be the case if one of the empirically-based estimates had been used (equation 1.18 of Ricker (1975)). This makes it much more likely that the adult population will exceed the ceiling imposed by the API-habitat calculation.

The matrix model was tuned by adjusting YOY survival rates to achieve a population growth rate of 1.93, which means that the population will nearly double in size in a year when it is below carrying capacity. The value is derived from production/biomass estimates for a brook trout population; however, the life history of brook trout is very different from WCT, based on the data in Randall and Minns (2000). This value seems extremely high for a conservation-listed population, especially if there are anthropogenic factors that may affect survival. By contrast, Hildebrand (2003) and Peterson et al. (2010) developed almost identical models for US WCT populations and adjusted YOY survival to achieve growth rates of 1.008 and 1.06, values which result in very slow population growth.

Recommendation

- The model should be rerun with more appropriate values for both the YOY and adult survival rates. The use of any rate should be justified using best available empirical information, including the current status and trends for the population.

- Scenarios, where the population growth rate ranges from declining, stable or increasing might be useful to set alternative values for YOY or other survival rates (see Peterson et al. (2010) for an example). Population trajectories under different scenarios can be used to establish how sensitive the population is to changing habitat quantity (i.e., carrying capacity) relative to factors that affect survival (habitat quality, water quality or other agents of mortality).
- Sensitivity analysis should be conducted on all major parameters using a simple, deterministic version of the model. The elasticity analysis provided only evaluates the density-independent aspects of population growth.

Model Assumptions: Area-Per-Individual Model incorrectly used. The proponent used the API relation for lakes found in Minns (2003). That relation was derived from Randall et al.'s (1995) compilation of allometric relations between body size and estimated abundance and production, for samples from whole fish communities drawn from around the world. There are separate relations for lakes and rivers in Randall et al. (1995); for a given average fish body size the densities of stream fish communities are 3-5 times higher than that of lakes. Further, there is evidence that the density of individual species is much lower than the community average (Randall and Minns 2003); the density of individual life stages or age classes may be lower still.

Regardless of the level of aggregation of the data, the pattern of decreasing density with increasing size is robust, with a slope of -0.8 to -1.0 for mass-based regressions. It is unclear what affect the use of the lake-based community relation is having on the prediction of maximum densities of individual life stages of a stream salmonid, and its use is not defensible, given the availability of more relevant alternatives.

In the HAT model, it is assumed that the API-derived density is the maximum density (i.e., which would be observed at the carrying capacity) that would occur in optimal habitats. However, no information is available on habitat quality or other population processes that determine abundance for the data compiled by Randall et al. (1995). Observed densities in Randall et al.'s (1995) compilation may be the result of density-dependent limitation in the sampled stages or limitation in one of the earlier life history stages that may not even be available to the sampling gear. Thus, regression estimators based on central tendencies of the data provide estimates of "typical" or observed densities, not necessarily maximum densities in optimal habitats as was assumed by the Proponent.

Recommendation

- Consider using one of the many stream salmonid size-abundance relations (e.g., Allen 1969). Setting stage-specific capacities using stream salmonid data is more justifiable than using parameters derived from large-scale compilations of diverse fish communities.
- Ensure that the modelling of habitat quality is consistent with the data and associated parameters of whatever empirical density relation is being employed. If the data are from a random selection of habitats or locations, this will have to be factored into the habitat rating process. It may be appropriate to use quantile regression to estimate greater than average densities as an approximation of the carrying capacity in optimal habitats.
- Provide a table of the assumed fish body sizes for each stage in the model and the associated density prediction from the API model. It appears that maximum densities for overwintering stages were also used, but their origin is not documented.

- Use sensitivity analysis in deterministic model runs to learn how density ceilings in each stage contribute to population regulation, and how sensitive the findings are to the exact values being chosen.

3.2.4 Review of the spatial model

The spatial model is not credible as presented. Generalized spatially explicit models aid in understanding population processes, provide very broad-based guidance, and generate testable hypotheses. However, they rely on a number of structural assumptions about fish movement patterns and behaviour, and potentially a large number of parameters. A full numerical model, as proposed here, will only be useful for management decisions if there is a solid empirical basis of support for the chosen model structure and the parameters. There should be a way to validate the model against independent data, although this may prove to be difficult.

The authors acknowledge that the role of movements on population productivity is a key uncertainty. Observations of fish moving from a site of tag implantation to spawn elsewhere are interpreted as “homing” (implying a repeatable behaviour), rather than habitat selection. Assumptions about the movements (or lack of movements) are made for each life stage and there are additional assumptions about the role of density-dependent processes affecting movement. These assumptions are all biologically plausible, but which among them are actually relevant to the Fording River population is unknown. No distinction is made regarding the role of key habitats (in particular, tributary streams) on production.

The evaluation is also hampered by a lack of detail in the HAT Report on what processes are being modelled, the parameter values, input population size, model trajectories, length of simulation, and other basic information. For example, there are a series of parameters in Table 6 concerning movement, but no values are provided. In section 2.1.5.1, it states “as redd density reaches the carrying capacity in a section some spawning fish may move to another section”; yet in section 2.2, it states “the model incorporates density dependence at every life stage for each season except spawning” (emphasis added). This lack of clarity and precision in the model description contributes to its lack of credibility.

A generalized spatial model may have value in formalizing thinking about population processes, but it seems unlikely at this time that it can provide credible management advice on specific habitats in the Fording River basin. The spatial model may provide some useful inferences (or generate hypotheses) about what combinations of assumptions and parameters are likely to make major differences to management actions that could be based on, for example, habitat-based methods.

Recommendation

- If this component of the model is to be pursued, it is suggested that the authors clearly and carefully document all components of the model using consistent terminology, symbols, and tables of values for inputs, outputs, and model structure. Equations should replace verbal descriptions of movement rules.
- Stochastic components of the model should be removed. There are so many key uncertainties with model structure and corresponding deterministic parameters that need to be examined before uncertainty/variability is added. Simple deterministic time trends of population abundance (see Hildebrand 2003) are likely all that is needed to assist in understanding the model, and to compare alternative sets of assumptions about movements and habitats. The deterministic model is also most appropriate for determining the most likely effects of the serious harm on fisheries productivity and whether proposed offsetting measures can counterbalance the serious harm.

3.2.5 Review of Population-habitat linkages

Population-habitat linkages are inadequate for managers. Site-specific habitat information and an assessment of the significance of that habitat to population processes are needed in order to evaluate the potential loss of fisheries productivity associated with a habitat alteration, or predictions of gains resulting from offset measures. As identified by members of the Fish and Fish Habitat Working Group Subcommittee, the inconsistency of the qualitative analysis of habitat quality, and the lack of clarity (p. 12 of the HAT Report) regarding how the scoring was incorporated into the model, undermines the utility of this approach. For example, the method used to compute the parameter E that defines the habitat rating (equation 10) is not described in the documentation. Habitat areas for the mainstem Fording River in Appendix E appear to be the full width of the channel for certain mesohabitat types, but it is unclear whether all of this habitat is useable for YOY fish in all seasons, and if all other mesohabitat types are completely unsuitable. Presumably the development of HSI curves will permit a more precise quantification of available habitat.

Recommendation

- As a precursor, and possible replacement for detailed spatial modelling, a thorough analysis of available information on fish and habitat in the study area, supported by inferences on other WCT populations is needed to guide thinking about the significance of specific habitats in the basin on population productivity, and to clearly identify gaps in the current information base.

4.0 Conclusions

Previous reviews and feedback on the HSI and HAT have identified deficiencies, a lack of clarity, and concerns regarding the adequacy of the analyses. This review confirms a number of deficiencies in modelling inputs, parameters, and assumptions in both the validation of the HSI curves and the HAT model.

The following are main observations, conclusions, and recommendations of this review:

- In general, there is a lack of clarity and standardized documentation and inconsistent use of terminology regarding the data inputs, parameters, and assumptions, in both the descriptions of the Habitat Suitability Index and the Habitat Assessment Tool. This diminishes the ability to assess the adequacy of the HSI and the HAT and reduces confidence in their results.
- The description of HSI curves does not adequately outline the method by which the individual HSI curves will be incorporated into an HSI model, or adequately describe how they will be used to calculate an appropriate weighted useable area. Consequently this work does not represent an actual HSI model. This diminishes the ability to evaluate the relevance and adequacy of the HSI curves.
- The method used to validate HSI curves for WCT was unconventional; sampling more data (2012-14) using the same methodology did not increase the confidence level in the data, indicating the presented methodology and results fail to demonstrate a reliable validation of the proposed expert-opinion HSI curves. Without the use of a standard method or a demonstration that the Proponent's method (fish density on mesohabitat scale) produces the same or similar results as the standard method (fish presence / absence on micro habitat scale), there is limited confidence in the validation of the expert-opinion HSI curves or in the recommendations presented in the Proponent's submission.

- The HAT, as presented, is a complex multi-component numerical model. The current model appears to be too complex, given the level of available data and general understanding of WCT in the Fording River area. In spite of the complexity, the HAT does not appear to make use of the best available data and information in its formulation and parameterization. A revised and simplified model should be able to replicate the current status of the WCT population, as is being revealed in concurrent field studies.
- Analysis of population dynamics should include time trends in abundance and estimated densities of each life stage for comparison with field observations. A few scenarios that differ in parameter values or structural assumptions should be developed to span a range of potential conditions. The model can then be used to calculate the change in population associated with manipulations of habitat, using the scenarios to examine the robustness of those conclusions.
- A simple, but carefully conceived, documented, and analysed model of trout population processes can have value in the discussion of impacts and offsets for the Fording River WCT population. A more descriptive or empirical approach, based on habitat quality and observations of fish abundance and distribution, may be more appropriate for management decision making.
- The spatial model may be useful in a supporting role to provide guidance regarding potential implications of fish movement, which in turn provides insight into the efficacy of proposed management actions, but more detailed site-specific information is needed before it can provide direct guidance for management decision making.

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