Reference Model Supporting Documentation
for CABIN Analytical Tools

MODEL NAME: Northeast BC Model 2018

AUTHOR: Shauna Bennett

AFFILIATION: Limnotek Research and Development Inc.

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CONTACT(S): Shauna Bennett sbennett@limnotek.com

1. STUDY DESIGN, SCOPE AND SITE SELECTION

Unconventional oil and gas development (i.e., hydraulic fracturing for shale gas) began in the geological deposit of the Horn River Basin in northeastern British Columbia (B.C.) around 2005, with reported production starting around 2007. Development increased rapidly, with peak drilling activity occurring in 2010. Hydraulic fracturing activity expanded to the adjacent Liard and Cordova Embayment deposits and continued through to 2014. As a result, the B.C. Ministry of Environment and Climate Change Strategy (ENV) had an interest in establishing an aquatic baseline for this area. Environment and Climate Change Canada (ECCC) also began biomonitoring in the area through funding provided by Natural Resources Canada (Pappas et al., 2017). Data collected between 2010 and 2014 were used to develop a preliminary CABIN bioassessment model for the Fort Nelson, Petitot, and Central Liard River Basins in Northeast B.C. (NEBC) in 2016 (Strachan and Pappas, 2016). The model was considered preliminary as it only contained data from 52 reference sites, which is less than the 60-75 sites typically recommended to develop a model (Reynoldson and Wright, 2000). ECCC and ENV sampled new reference sites in 2016 and 2017 to fill spatial gaps identified in the preliminary model and to ensure reference sites covered a greater range of natural variability across NEBC. All data were collected following CABIN field protocols (Environment Canada, 2012) by field certified samplers. Taxonomy data were analyzed following standard CABIN laboratory methods (Environment Canada, 2014) (Appendices A and B).

1.1 Model Purpose

The purpose of the preliminary model was to assess the effects of unconventional oil and gas development on the health of aquatic ecosystems in NEBC. This updated model offers increased sensitivity to evaluate effects of this industry and will also provide a baseline to support bioassessments related to a broader array of human disturbances (e.g., forestry, agriculture, mining, residential/urban development) in this area.

1.2 Spatial and Temporal Scope

The study area includes the Liard and the Fort Nelson/Petitot Basins within NEBC, and encompasses 7 different ecoregions (Boreal Mountains and Plateaus, Hay River Lowlands, Hyland Highlands, Liard Basin, Muskwa Plateau, Northern Alberta Uplands, and Northern Canadian Rocky Mountains) (Figure 1). The watersheds in this region drain north into the Northwest Territories (NWT) and eventually into the Mackenzie River near Fort Simpson, NWT.

Reference sites within these basins were sampled at low flow in late August and early September between 2010 and 2017. Initial sampling by ENV focused on the Fort Nelson/Petitot basins in 2010 and 2011 (3 sites). ECCC continued sampling in 2012 (12 sites), 2013 (13 sites), and 2014 (22 sites). A consulting firm (Environmental Dynamics Inc), funded through Geoscience BC, also sampled 2 reference sites in 2011 and 2013. Subsequent sampling filled gaps in the Fort Nelson/Petitot Basin and expanded coverage in the Liard Basin. ECCC sampled 25 sites in 2016 and ENV and ECCC worked collaboratively in 2017 to sample 43 reference sites.

A goal to revisit approximately 10% of reference sites in two or more years was pursued to capture annual fluctuations in hydrology. However, given resource development continued during the period of study, some sites that were initially identified as reference no longer met reference criteria in subsequent years. Therefore, the number of repeated reference sites was less than the anticipated 10% (n=4). PET08 was resampled in 2013 and 2016 (also sampled by ENV in 2011 using code UPET002). BBEA02 and TSO02 were resampled in 2016 and 2017, respectively. STAND02 was sampled by EC in 2012 and revisited (Stanolind Ck) by EDI in 2013.

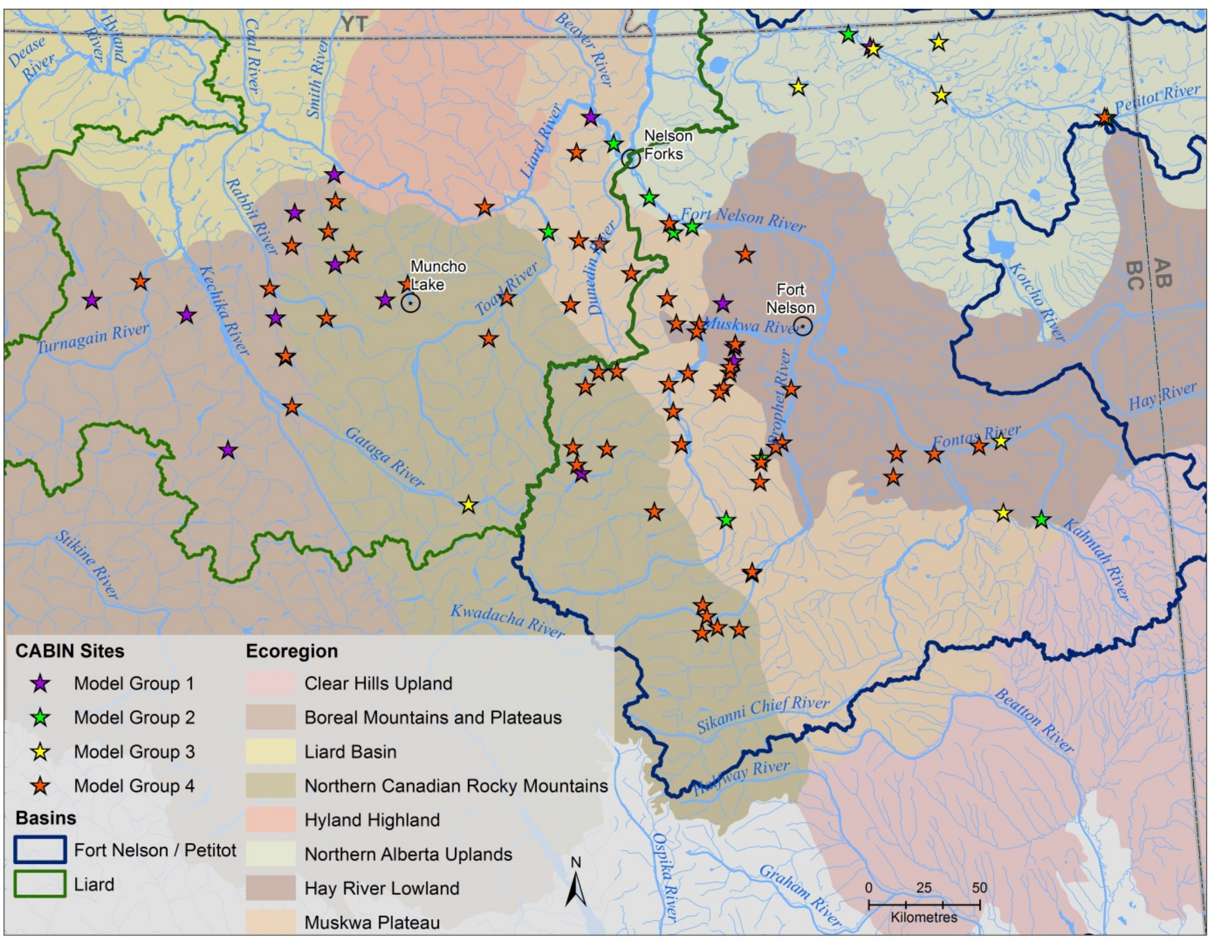

Figure 1. Map of CABIN reference sites within the eight ecoregions found within the Fort Nelson/Petitot and Liard Basins. CABIN reference sites are identified by stars that show the four different biological groups identified in the NEBC 2018 model.

1.3 Reference Site Selection

Potential reference locations were selected by applying the Human Activity Gradient approach (Yates and Bailey, 2010). This method stratifies microbasins in the study area based on natural features and stream order and relies on a stressor gradient to define reference site criteria. To begin, the model study area was subdivided into 3rd order and higher microbasins using the 1:50K B.C. Freshwater Atlas delineations from ENV's DataBC (Appendix C). A total of 2270 microbasins with less than 0.05 % settlement cover (e.g., cities, towns, and remote communities) were considered in the initial stages of the exercise. Stratification of microbasins was done separately for the Liard Basin and the Fort Nelson/Petitot Basin. A step-by-step description of the potential reference microbasin selection process is outlined below.

<u>Step 1: Determining Natural Stratification</u>

1. Identify microbasins within the study area using the B.C. Freshwater Atlas.
2. Quantify the natural features of all microbasins (i.e., physiographic characteristics, bedrock geology, surficial geology, landcover, topography, and climate).
3. Perform Principle Component Analysis (PCA) on each natural feature variable type to reduce natural variables to a set of first component scores.
4. Combine the 1st component scores from each PCA into a single dataset to investigate natural groupings using K means clustering options for 2 to 8 groups.
5. Evaluate each clustering option (2-8 groups) to maximize the among group variation and minimize within group variation using two techniques:
    a. Elbow test of the Kmeans results for each clustering option (i.e., Between SS/Total SS).
    b. Discriminant Function Analysis (DFA) of each clustering option as a factor to describe the natural features to find the largest differences among the group means (i.e., lowest Wilk's Lambda).
6. Distribute sampling sites among groups that meet the defined reference criteria as described below in Step 2 and Step 3.

<u>Step 2: Establishing Stressor Gradient for Northeast B.C.</u>

1. Quantify the major human stressors (i.e., oil and gas activity, transportation and pipelines, forestry, mining, agriculture, and waste discharges) within the identified microbasins using publicly available geospatial data from ENV (https://catalogue.data.gov.bc.ca/dataset) or B.C. Oil and Gas commission (https://data-bcogc.opendata.arcgis.com).
2. Perform PCA on each stressor type to reduce stressor variables of each type to a set of first component scores.
3. Combine 1st component scores from each PCA into a 2nd PCA to calculate the final stressor score for each microbasin. This creates a single first component to describe human stressors in each microbasin.
4. Establish criteria for 2 tiers of reference sites:
    a. First tier of reference sites (best available) have a 0 score on the first component of the combined PCA scores and represent sites where minimal stressors exists.
    b. Second tier of reference sites (next best with minimal exposure) have a low score on the first component from the combined PCA, but have a zero score on at least 1 of the first components from the individual stressor type PCAs.
    c. Any microbasin where a relatively large forest fire was identified since 2010 was eliminated from the list of potential reference sites.

Step 3. Defining Reference Criteria and Selecting Sites

1. Define the maximum value of each stressor variable within tier 1 and tier 2 options (Table 1).
2. Identify the location and number of possible reference microbasins. A total of 1,155 potential reference microbasins were identified (Table 1, Figure 2, and Figure 3).
3. Further stratify possible reference microbasins by stream orders. Within each natural group, 7 stream orders were present. Since stream order 1 is generally impossible to sample or access in this region, 3 sites per stream order 2 – 7 were targeted within each of the defined natural groupings. This resulted in a total of 144 potential reference sites, assuming every stream order was present within each natural grouping.
4. Randomly select 75% more sites than required for sampling to account for inaccessible sites or inappropriate sampling habitats.
5. Verify reference site status using helicopter reconnaissance prior to sampling.

Table 1. Reference site criteria expressed as variable units/microbasin (MB) drainage area based on maximum allowable values from Tier 1 and Tier 2 options of the HAG. Note that pipelines were not included in Table 1 as values were 0% for all HAG groups, with the exception of F5 (< 0.00023%). Major resource and cropland values were 0% for all HAG groups, so were also excluded.

Basin	Total # all MBs	Total # Potential Reference	Roads (km)	Wells (count)	OG Facilities (count)	Water Use (count)	Cutblock/Harvest Tenure (km^2)	Mineral Claim (km^2)	Annual Cropland (km^2)
Fort Nelson/Petitot[a]	**1087**	**377**							
HAG group									
F1	260	124	0	0	0	0	0.19	0	0
F2	328	63	0.02	0.02	0	0.08	0.27	0	0
F3	135	20	0.11	0.07	0.02	0.01	0.007	0	0
F4	160	140	0.35	0.10	0.09	0	0.05	0.036	0
F5	204	30	0.27	0.35	0.06	0.05	0.22	0	0
Liard[b]	**1183**	**778**							
HAG group									
L1	418	259	0	0	0	0	0	0.08	0
L2	274	195	0	0	0	0	0.004	0.001	0
L3	453	312	0	0	0	0	0	0.05	0
L4[c]	38	12	0	0	0	0	0	0.007	0

[a]*Tier 1&2 microbasins considered in order to capture the best available condition in that natural grouping despite the presence of some human disturbance.*

[b]*Due to the low amount of human disturbance in the Liard, only Tier 1 microbasins were considered to represent best available reference sites.*

[c] *HAG Group L4 was excluded from the model due to its remoteness, small size and limited distribution (Figure 3).*

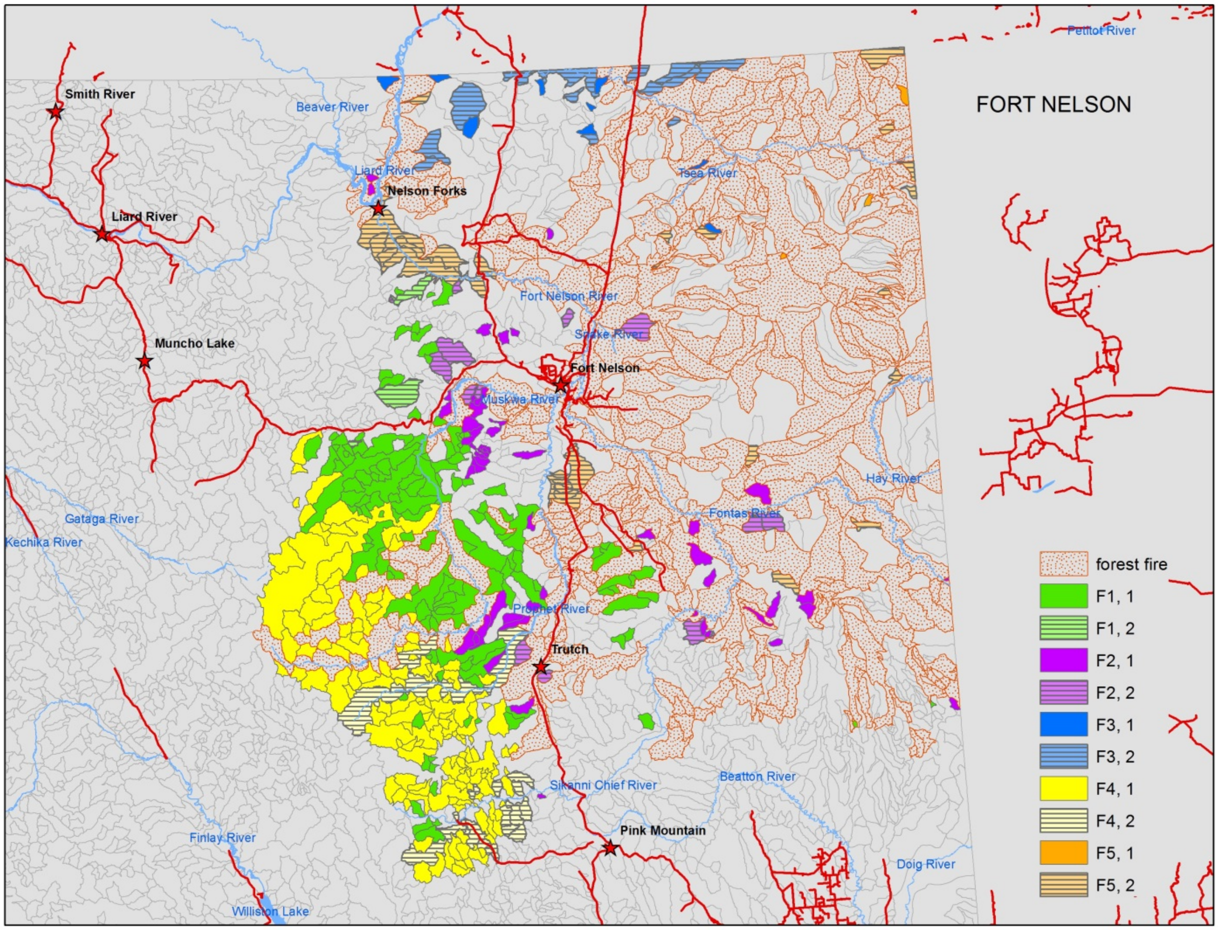

Figure 2. Fort Nelson/Petitot Basin potential reference microbasins identified for each natural group (F1 – F5) and each tier. Tier 1 are shown as solid coloured basins and tier 2 as hatched coloured basins. Microbasins outlined in grey were not considered potential reference based on the stressor gradient. Red dotted microbasins were affected by forest fire to a large extent since 2010. Red stars represent cities, towns, and rural communities.

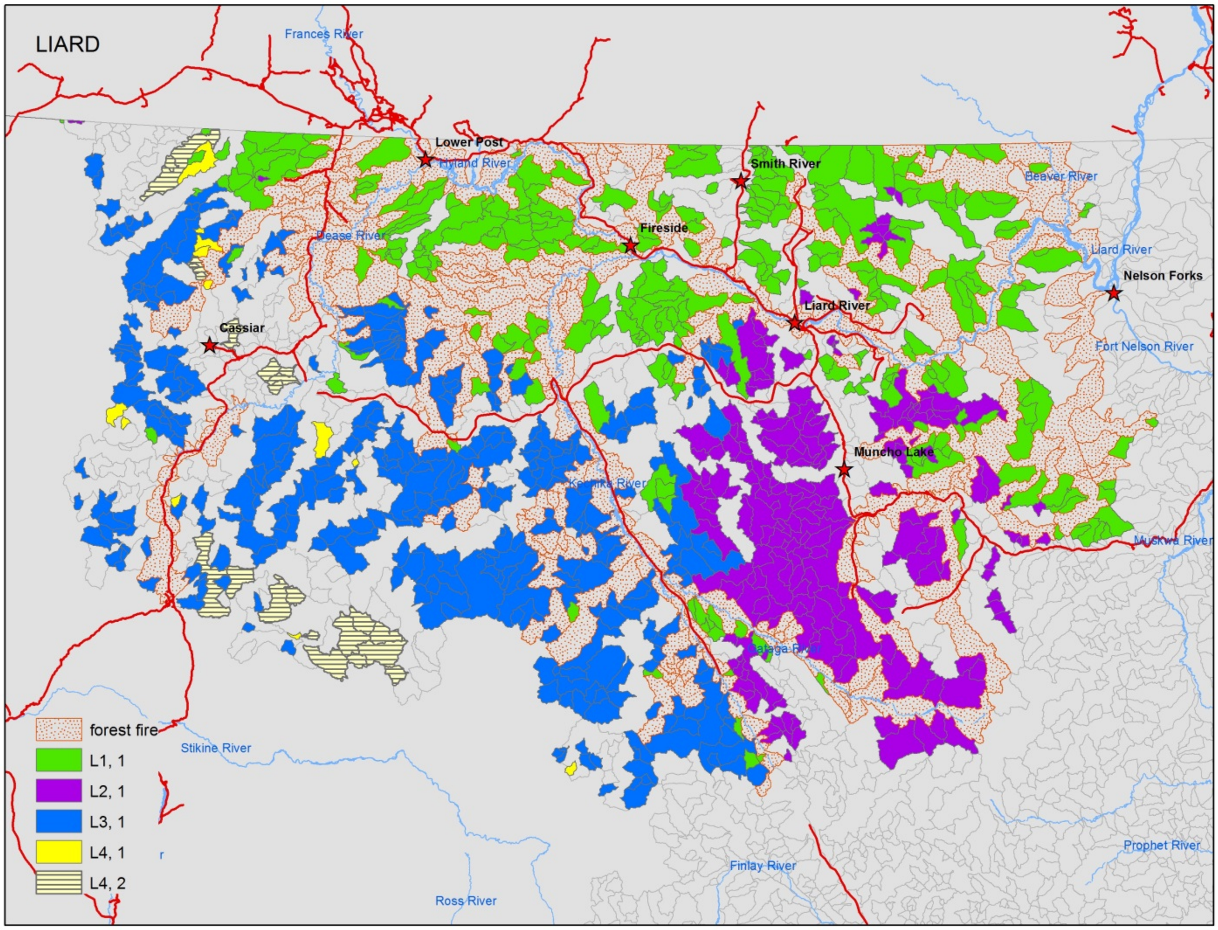

Figure 3. Liard Basin potential reference microbasins identified for each natural group (L1-L4) or each tier. Tier 1 are shown as solid coloured basins and tier 2 as hatched coloured basins. Microbasins outlined in grey were not considered potential reference based on the stressor gradient. Red dotted microbasins were affected by forest fire to a large extent since 2010. Red stars represent cities, towns, and rural communities.

Following these steps, a total of 120 reference sites were sampled between 2010 and 2017 within the Liard (37 sites) and Fort Nelson/Petitot (83 sites) study area and were distributed across the natural groupings (Figure 2 and Figure 3). However, the L4 grouping was excluded from the model due to its remoteness, small size and the limited spatial distribution (Figure 3). There are also gaps in natural grouping F5, likely a result of extensive forest fires in this area, which made it difficult to locate reference sites (Figure 2). As shown in Table 2, there are a few data gaps for very small (i.e., stream order [SO] 2) streams as these are often dry during the summer field season or difficult to access. Gaps also exist for very large (i.e., SO6 and SO7) streams as it is difficult to locate large streams that are minimally impacted by human stressors.

Table 2. Distribution of sites among stream order (SO) and natural grouping.

Stream Order	F1	F2	F3	F4	F5	L1	L2	L3	Total
SO2	2	1	1	0	0	0	1	0	5
SO3	11	3	4	7	6	2	3	3	39
SO4	16*	3	5	5*	9	2	9	2	51
SO5	5	1	0	2	3	1	3	3	18
SO6	0	0	0	1	5*	0	0	0	6
SO7	0	1	0	0	0	0	0	0	1
Total	**34**	**9**	**10**	**15**	**23**	**5**	**16**	**8**	**120**

**includes repeated reference samples for STND02 in F1, BBEA02 in F3, PET08 and TSO02 in F5*

2. REFERENCE DATA AND FINAL MODEL

2.1 Biological description

All samples were collected and processed using the standard CABIN protocols. Cluster analyses using a Bray-Curtis association measure and UPGMA hierarchical clustering was performed in PRIMER 6 to investigate structure in the benthic assemblage data. Assemblage data were not transformed prior to the cluster analyses. SIMPROF was used to help identify outliers and define statistical differences between cluster groups. Classification of family-level reference data produced four biological groups (Figure 4). Ordination of the biological data based on the Bray-Curtis similarities showed some minor overlap of the reference sites within the four groups (Figure 5).

Within the reference dataset, 14 biological communities did not fall into one of the four groups. Six of these samples were not similar to others based on linkage of small groups (three or less samples) to the next sample or group of samples of less than 30% similarity. These six samples were also too few to form a distinct group (including TUCH07_2017, PET02_2012, FROG01_2017, MUSK002_2010, BBEA02_2016, SEED01_2016). These six outliers were characterized by a very low (<141 individuals) abundance of invertebrates. For the remaining eight outliers, a significant SIMPROF result suggests that the invertebrate community at each of those sites was different from all other sites (including TEN05_2014, TSE06_2013, TOAD09_2017, PET09_2013, PET89_2016, PET08_2016, PET08_2012, FTNR01_2014). The reasons for those differences were not immediately apparent in most cases, although one site (TEN05) had a very high abundance of invertebrates (n=16,480), which was 57% baetid mayflies. Several of these samples were collected from the Petitot River (PET08, PET09, PET89), which is a large river in comparison to the streams where the majority of reference samples were collected. All 14 samples were considered outliers and removed from further analysis, resulting in a 4-group classification of 106 samples.

After removal of the 14 outliers, 15 samples were randomly selected from the 106 samples to use later as ***validation data*** (roughly 15%). The number of sites randomly selected from each group was dependent on the size of the group (i.e., proportional random sampling). Each sample was assigned a number from 1 to 106, and a random number generator function was used in excel to select these 15 validation samples. Once samples randomly selected from a single group represented 15% of samples in that group, no further samples were selected from that group. The remaining 91 samples became the ***training data*** for model development.

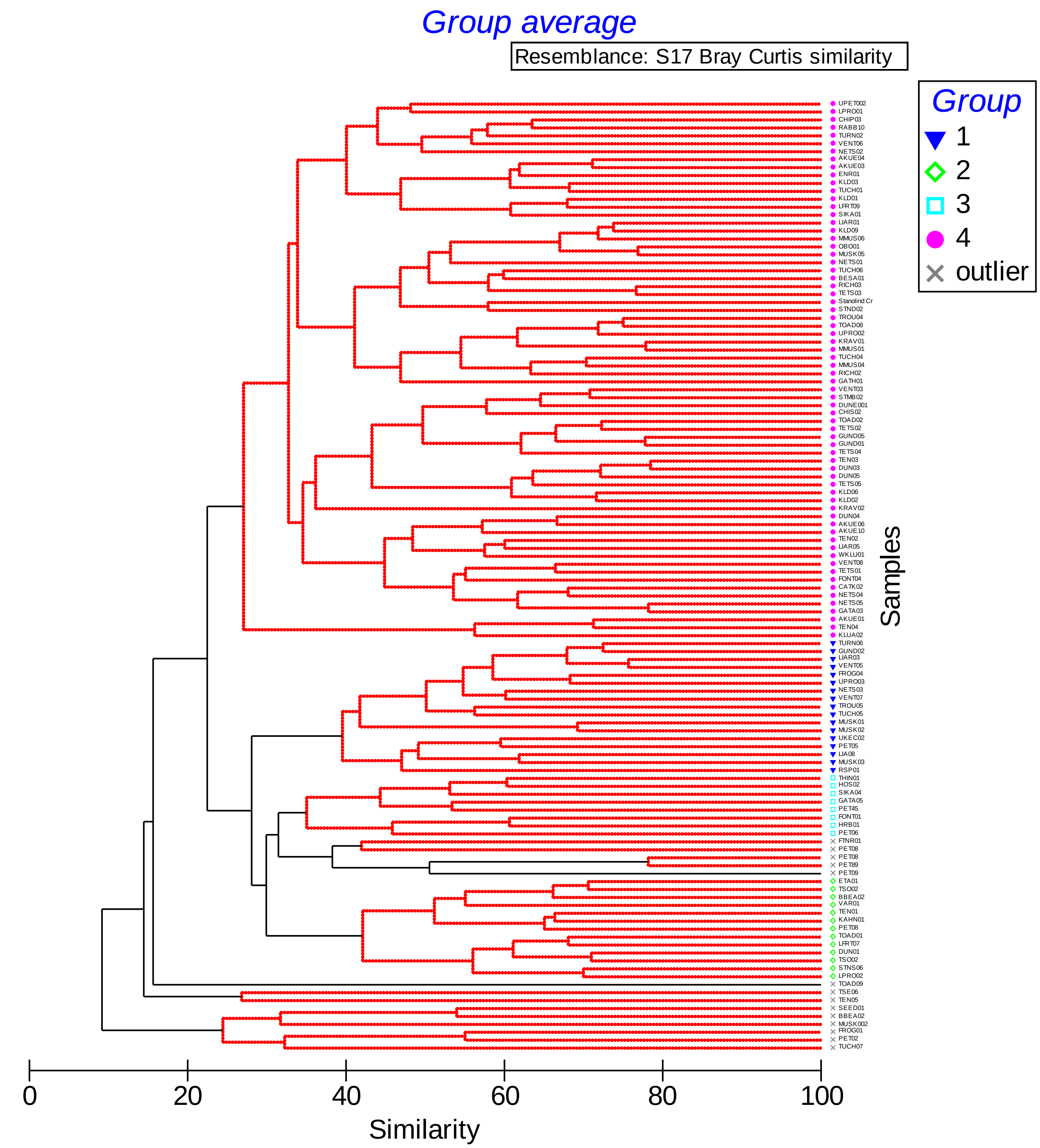

Figure 4. Hierarchical group average cluster analysis of benthic community data from 120 reference sites in PRIMER6 using Bray-Curtis similarity association. SIMPROF permutation tests were performed at every node of the completed dendogram. A non-significant SIMPROF result is shown as samples connected by red lines where a significant SIMPROF result is represented by black lines.

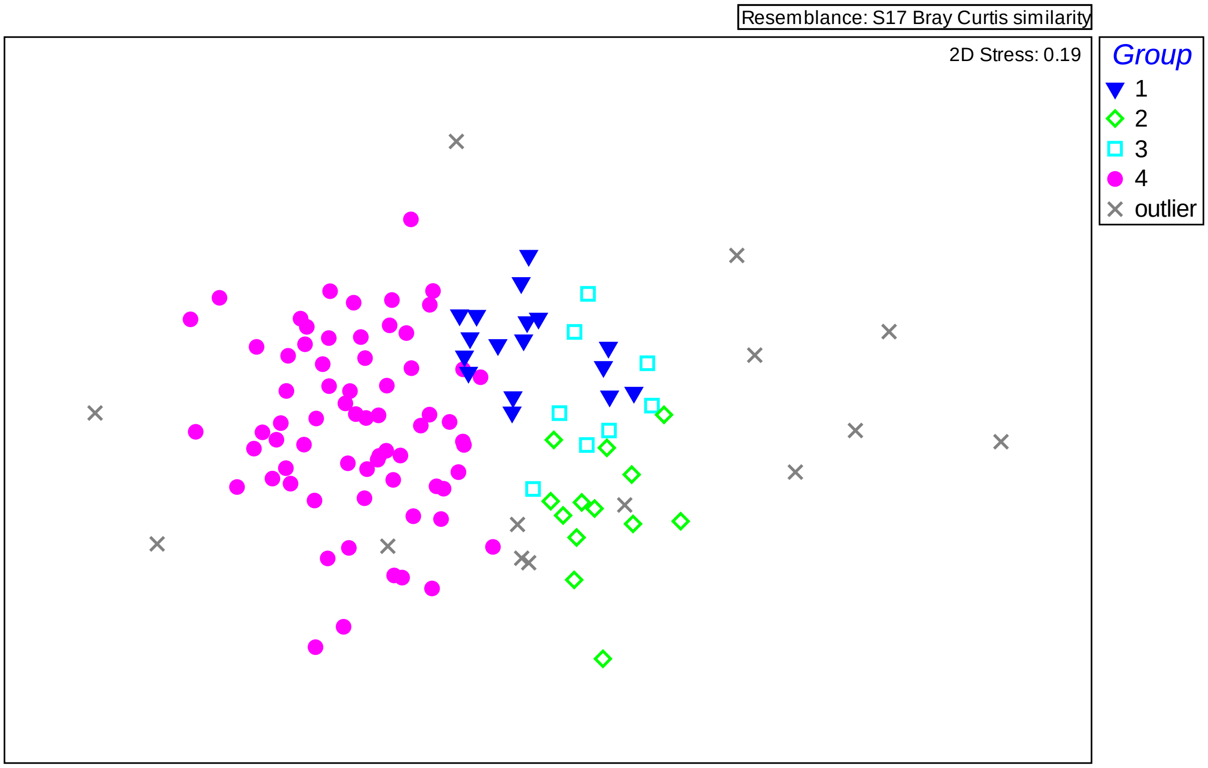

Figure 5. MDS ordination of 120 reference site assemblages in PRIMER6 based on Bray-Curtis similarity of family level taxa coded by cluster group.

The average similarity among sites within each group was lowest in Group 4 (36.1%, Table 4) and greatest in Group 2 (49.4%, Table 4).

Dissimilarities between groups are distinguished by the mayfly families *Heptageniidae*, *Baetidae* and *Ephemerellidae*, the stonefly families *Nemouridae* and *Capniidae* and the caddisfly families *Hydropsychidae* and *Brachycentridae*, and the dipteran families *Chironomidae* and *Simuliidae* (Table 3). In particular, chironomid abundance was an important driver of differences among sites in Group 4, which generally had high abundance of *Chironomidae* and Groups 1, 2 and 3, which had lower *Chironomidae* abundance.

The average number of invertebrates among groups ranged from 383 in Group 2 to 2,631 in Group 4. Among groups, mean family richness was similar, ranging from 16.3 for group 4 to 20.1 for group 3 (Table 4). The orders *Ephemeroptera*, *Plecoptera* and *Trichoptera* (EPT) accounted for 6 to 93% of the community at a given site and ranging from a mean of 61% for Group 3 to 76% for Group 1. Simpson's diversity index ranged from 0.43 to 0.91 among all reference sites.

Table 3. SIMPER results of the top 6 family level taxa and the % contribution to the differences between pairs of reference group communities.

	Group 1		Group 2		Group 3	
Group 2	**Average dissimilarity = 71.4%**					
	Heptageniidae	19.0				
	Baetidae	13.8				
	Nemouridae	12.7				
	Ephemerellidae	8.7				
	Chironomidae	7.6				
	Simuliidae	6.5				
Group 3	**Average dissimilarity = 69.2%**		**Average dissimilarity = 70.8%**			
	Heptageniidae	16.5	Baetidae	15.4		
	Capniidae	11.6	Capniidae	13.6		
	Nemouridae	10.4	Chironomidae	9.7		
	Ephemerellidae	7.5	Hydropsychidae	8.8		
	Hydropsychidae	7.2	Simuliidae	7.5		
	Chironomidae	6.5	Brachycentridae	6.3		
Group 4	**Average dissimilarity = 73.7%**		**Average dissimilarity = 80.8%**		**Average dissimilarity = 80.6%**	
	Chironomidae	19.6	Chironomidae	21.5	Chironomidae	17.6
	Baetidae	16.1	Heptageniidae	17.2	Heptageniidae	15.9
	Heptageniidae	15.0	Baetidae	14.6	Baetidae	15.0
	Nemouridae	9.9	Nemouridae	9.3	Nemouridae	8.4
	Simuliidae	7.0	Simuliidae	7.1	Simuliidae	6.6
	Ephemerellidae	4.6	Ephemerellidae	3.8	Capniidae	6.4

Table 4. Community descriptors summarized by reference group for the training data set.

Community Metric	**Group 1 mean ± SD (range) (n=15)**	**Group 2 mean ± SD (range) (n=11)**	**Group 3 mean ± SD (range) (n=7)**	**Group 4 mean ± SD (range) (n=58)**
Within group similarity	46.5%	49.4%	41.6%	36.1%
Abundance	661 ± 237 (323 – 1050)	383 ± 114 (200 – 524)	632 ± 367 (208 – 1168)	2631 ± 1475 (465 – 8340)
Simpson's diversity	0.83 ± 0.03 (0.77 – 0.88)	0.76 ± 0.11 (0.45 – 0.84)	0.83 ± 0.06 (0.73 – 0.90)	0.73 ± 0.12 (0.43 – 0.91)
Pielou's Evenness	0.74 ± 0.03 (0.68 – 0.78)	0.64 ± 0.08 (0.45 – 0.72)	0.75 ± 0.04 (0.67 – 0.79)	0.65 ± 0.11 (0.40 – 0.89)
Composition Metrics				
%EPT[a]	76 ± 15% (42 – 91%)	64 ± 12% (45 – 86%)	61 ± 13% (42 – 76%)	64 ± 20% (6 – 93%)
% Ephemeroptera (E)	39 ± 15% (15 – 70%)	41 ± 18% (14 – 70%)	12 ± 9% (3 – 25%)	37 ± 20% (2 – 81%)
% Ephemeropterans that are Baetidae	14 ± 11% (0 – 43%)	85 ± 12% (68 – 100%)	53 ± 33% (0 – 100%)	43 ± 32% (0 – 99%)
% Plecoptera	32 ± 17% (6 – 66%)	16 ± 12% (0 – 34%)	28 ± 16% (13 – 57%)	21 ± 16% (3 – 74%)
% Trichoptera (T)	6 ± 4% (0 – 13%)	7 ± 6% (0 – 20%)	21 ± 14% (4 – 43%)	6 ± 7% (0 – 31%)
% Trichopterans that are Hydropsychidae	33 ± 36% (0 – 100%)	58 ± 34% (0 – 91%)	48 ± 30% (0 – 82%)	31 ± 34% (0 – 100%)
% Insects, non-EPT	18 ± 9% (4 – 34%)	33 ± 13% (11 – 53%)	32 ± 14% (15 – 49%)	32 ± 20% (5 – 92%)
% Non-insects	6 ± 8% (0 – 24%)	4 ± 3% (0 – 9%)	6 ± 3% (0 – 11%)	4 ± 5% (0 – 31%)
% Diptera + non-insects	23 ± 15% (6 – 57%)	34 ± 14% (13 – 55%)	34 ± 13% (22 – 58%)	36 ± 20% (7 – 94%)
% Chironomidae	13 ± 7% (3 – 25%)	12 ± 9% (3 – 25%)	20 ± 15% (6 – 44%)	23 ± 18% (1 – 73%)
Richness metrics (number of family level taxa)				
Richness	18.9 ± 5.2 (8 – 29)	18.4 ± 5.3 (6 – 27)	20.1 ± 4.7 (12 – 26)	16.3 ± 3.7 (10 – 28)
EPT Richness	11.6 ± 2.2 (6 – 16)	10.7 ± 2.9 (4 – 15)	11.0 ± 2.2 (9 – 14)	10.2 ± 2.0 (5 – 17)
Ephemeroptera taxa	3.6 ± 0.5 (3 – 4)	3.4 ± 1.5 (1 – 6)	2.4 ± 1.0 (1 – 4)	3.4 ± 0.7 (2 – 5)
Plecoptera taxa	5.1 ± 0.9 (3 – 6)	4.2 ± 1.5 (1 – 6)	4.6 ± 0.5 (4 – 5)	4.5 ± 1.2 (2 – 7)
Trichoptera taxa	2.9 ± 1.8 (0 – 7)	3.2 ± 1.8 (0 – 7)	4.0 ± 1.9 (1 – 7)	2.4 ± 1.4 (0 – 5)
Non-insect taxa	3.0 ± 1.9 (0 – 6)	2.9 ± 1.6 (0 – 6)	4.3 ± 2.2 (0 – 7)	2.5 ± 1.4 (0 – 7)

[a]*EPT = Ephemeroptera* (mayflies), *Plecoptera* (stoneflies) and *Trichoptera* (caddisflies)

2.2 Habitat Description

Habitat data were exported from CABIN and included location descriptors, catchment morphometry, topography, channel/substrate descriptors, surficial geology, land cover, long term climate, and water chemistry. Habitat variables were measured at each site in the field or were calculated using GIS for landscape scale parameters. A total of 225 variables were available as potential predictors.

Variables that had incomplete/inaccurate data or could be affected by disturbance or land use were first removed. As a result, 142 potential predictor variables were removed, which included all GIS-derived variables for land cover. GIS based land cover variables were removed because 15% of all the reference samples (i.e., 18 samples) had a considerable amount of "cloud" and "shadow" (i.e., > 25% watershed coverage) land cover in the upstream watershed, making the remaining data for meaningful land cover variables inaccurate for these sites.

A correlation analyses was run on the remaining 83 habitat variables unaffected by human disturbance to reduce the list of possible predictor variables. The number of possible predictors was reduced to 44 habitat variables that were least correlated with each other. Among these, some groups of variables were selected (e.g., maximum elevation, slope greater than 60%, and slope max) that were highly correlated and each was run separately during the DFA. It was important to have representation from each group of predictors as shown in Table 5 (e.g., location, climate, channel/substrate). Among groups of variables in Table 5, climate variables were the most highly correlated with each other. Variables that had the least number of correlations exceeding 0.75 and the largest range of variation among sites were retained as possible predictors (Table 5). These variables were used in forward and backward stepwise discriminant analyses.

Selected environmental characteristics were summarized for each reference group (Table 6). Sites in reference Group 2 were generally lower altitude, with a large drainage area, and greater average depth and bankfull minus wetted depths (Table 6). On average, 94% of Group 2 catchments had a slope less than 30%. Group 3 reference sites were closer to sites in Groups 2 and 1 than Group 4 on the ordination plot (Figure 5) and dissimilarity scores between pairs of groups were slightly lower (Table 3). However, visual examination of the habitat data suggests that Group 3 sites were narrow and shallow streams with lower velocity and larger substrate size in comparison to Groups 1 and 4. Streams in this group received the lowest annual average precipitation. Similar to Group 2, 89% of the catchment slope was <30%. There was overlap in the standard deviations of mean values of the environmental descriptors among Groups 1 and 4. Sites in these groups were higher altitude, with smaller drainage areas and received higher amounts of precipitation. On average, 18% of the catchments of streams in Groups 1 and 4 had a slope >60%.

Table 5. List of possible predictor variables for DFA.

LOCATION	CLIMATE	CHANNEL/SUBSTRATE
Latitude	Precip JAN*	Depth, bankfull minus wetted
Longitude	Precip MAY	**One of:**
Altitude	Precip JUL	Depth, avg*
StreamOrder	Precip ANNUAL	Depth, max
	Temp, MAR max	Presence of Pools (Binary)
MORPHOMETRY	Temp, OCT max	Presence of Rapids (Binary)
Drainage Area	**One of:**	Presence of Riffles (Binary)
Stream Density	Temp, ANNUAL max	Presence of Straight Run(Binary)
	Temp, ANNUAL mean	Channel slope
TOPOGRAPHY	Temp, ANNUAL min	**One of:**
% Slope <30%		Velocity, avg
% Slope 30-50%	**SURFICIAL GEOLOGY**	Velocity, max
% Slope >60%	% Colluvium	**One of:**
One of:	% Glacial Sediment Blanket	Width, bankfull
Elevation, avg	% Glacial Sediment Hummocky Till	Width, wetted
Elevation, max	% Veneer	**One of:**
Elevation, min	% Glaciolacustrine	Substrate, D50
Slope, avg %	% Organic deposits*	Substrate, Dg
Slope, max % *	% snowpack	

** Predictors in the preliminary NEBC 2016 model. One variable from the preliminary model, "Min temp, MAY" was excluded as a potential predictor for this version because it was more correlated with topography and location variables.*

Table 6. Select environmental characteristics of the four reference groups; predictor variables included in 2018 model are highlighted. Not all of these variables were potential predictor variables, but are summarized for descriptive purposes.

Habitat Variable	Units	Group 1 (n=15)			GROUP 2 (n=11)			GROUP 3 (n=7)			GROUP 4 (n=58)		
		Mean ± SD	**Median**	**Range**	**Mean ± SD**	**Median**	**Range**	**Mean ± SD**	**Median**	**Range**	**Mean ± SD**	**Median**	**Range**
LOCATION/ MORPHOMETRY													
Latitude	dec deg	58.92 ± 0.54	58.89	57.82 to 59.92	59.05 ± 0.66	59.22	57.97 to 59.97	59.10 ± 0.91	59.7	58.01 to 59.92	58.63 ± 0.49	58.65	57.58 to 59.57
Longitude	dec deg	-125.27 ± 1.94	-125.21	-128.25 to -122.07	-123.04 ± 1.36	-123.6	-124.68 to -120.23	-122.23 ± 1.46	-121.5	-125.33 to -121.24	-124.12 ± 1.50	-123.8	-127.88 to -120.25
Altitude	fasl	2208 ± 1017	2382	475 to 3561	1285 ± 454	1164	843 to 2309	1659 ± 841	1528	1063 to 3501	2215 ± 955	1883	1036 to 4970
Drainage Area	km2	165 ± 181	70	13 to 570	1094 ± 2512	102	27 to 8354	403 ± 469	109	46 to 1284	384 ± 1119	99	17 to 8354
Perimeter	km2	79 ± 50	74	18 to 188	207 ± 345	76	43 to 1186	156 ± 117	93	42 to 335	110 ± 160	61	19 to 1186
Stream density	m/km2	2560 ± 1031	2473	1027 to 5534	1649 ± 511	1634	731 to 2428	1256 ± 680	1143	611 to 2494	2423 ± 955	2299	758 to 5340
CHANNEL													
Depth, avg	cm	21.7 ± 10.5	18.4	9.1 to 45.3	27.2 ± 19.9	17.2	4.8 to 72.2	11.9 ± 5.3	12.1	5.6 to 20.6	19.0 ± 8.8	16.8	4.8 to 46.8
Depth, bankfull minus wetted	cm	34.5 ± 17.1	32.2	15 to 84	56.4 ± 16.7	55.6	33 to 90	28.3 ± 14.5	29.7	6 to 48	33.4 ± 19.9	29.8	7.2 to 106.2
Depth, max	cm	30.1 ± 14.1	31.5	12.3 to 60	36.1 ± 27.0	27.0	5.5 to 98	17.8 ± 9.9	15.0	9.4 to 37	27.7 ± 14.0	24.8	6.3 to 78
Channel slope	m/m	0.018 ± 0.016	0.013	0 to 0.057	0.011 ± 0.008	0.01	0.001 to 0.028	0.014 ± 0.007	0.014	0.006 to 0.027	0.014 ± 0.012	0.011	0.001 to 0.067
Velocity, avg	m/s	0.56 ± 0.15	0.545	0.3 to 0.77	0.47 ± 0.20	0.41	0.26 to 0.84	0.38 ± 0.17	0.33	0.23 to 0.71	0.54 ± 0.20	0.53	0.2 to 1.03
Velocity, max	m/s	0.83 ± 0.22	0.79	0.38 to 1.17	0.65 ± 0.24	0.56	0.4 to 1.13	0.52 ± 0.18	0.49	0.37 to 0.9	0.76 ± 0.28	0.78	0.28 to 1.37
Width, bankfull	m	16.3 ± 14.1	11.3	5.7 to 49	22.8 ± 19.1	14.6	4.3 to 60	16.1 ± 15.7	8.9	5.7 to 50	23.6 ± 20.9	13.8	4.1 to 98
Width, wetted	m	11.2 ± 11.2	8.8	2.5 to 46	15.8 ± 15.7	9.0	2.9 to 53	7.8 ± 5.6	4.8	2.5 to 16	13.7 ± 17.1	8.4	1.9 to 98
SUBSTRATE													
Particle diameter, D50	cm	6.7 ± 3.2	6.7	1 to 11.5	8.2 ± 6.1	6.2	1.6 to 23.6	8.0 ± 6.0	4.6	1.9 to 18.6	6.5 ± 2.9	6.6	1.5 to 16
Particle diameter, Dg	cm	5.7 ± 2.7	6.1	0.8 to 10.7	6.0 ± 3.6	4.4	1.6 to 13.1	7.2 ± 5.4	4.5	1.8 to 17.4	6.0 ± 2.8	5.8	0.9 to 15.4
CLIMATE													
Precipitation, Jan	mm	35.0 ± 9.1	37.5	20.5 to 47	24.3 ± 2.1	24.5	21 to 27	24.4 ± 9.3	21.2	18 to 45.3	30.9 ± 7.5	28.7	19 to 43.9
Precipitation, Mar	mm	24.6 ± 4.8	24.8	16 to 35	19.4 ± 2.9	18.6	16 to 25.2	18.9 ± 6.7	17.0	13 to 33.4	24.6 ± 5.0	24.0	14.6 to 36.7
Precipitation, May	mm	50.5 ± 7.5	49.5	40 to 66.2	49.4 ± 8.4	51.0	33.2 to 60	43.2 ± 7.6	40.0	38 to 59.6	55.5 ± 7.9	57.6	33.2 to 67.2
Precipitation, Jul	mm	94.7 ± 14.0	94.9	78 to 127.1	93.2 ± 13.6	96.0	68.5 to 113	83.3 ± 12.8	78.0	72 to 110	103.6 ± 14.5	106.5	68.5 to 129
Precipitation, Annual	mm	567 ± 66	568.0	433 to 741	503 ± 61	513.0	418 to 608	471 ± 102	430.0	392 to 696	583 ± 77	578	399 to 759
Temperature, Mar max	deg C	-2.7 ± 1.6	-3.0	-5.8 to -0.2	-1.6 ± 1.5	-1.2	-5.3 to 0	-3.1 ± 2.0	-3.5	-5.1 to 0	-2.2 ± 1.7	-2.0	-6.5 to 0
Temperature, Annual max	deg C	12.4 ± 6.3	16.0	3 to 18.9	8.8 ± 8.5	4.5	2.2 to 22.5	12.8 ± 9.0	13.9	3 to 21.9	11.6 ± 6.6	15.3	2.2 to 22.7
Temperature, Annual avg	deg C	-2.1 ± 1.4	-2.7	-4.2 to -0.2	-0.7 ± 0.7	-0.7	-2.4 to 0	-1.6 ± 1.3	-1.5	-3.7 to 0	-1.6 ± 1.3	-1.3	-4.6 to 0
Temperature, Annual min	deg C	-17.7 ± 8.4	-22.4	-25 to -6	-11.5 ± 8.7	-6.2	-25.3 to -6	-17.4 ± 10.3	-22.1	-28.1 to -6	-15.7 ± 8.4	-21.2	-25.2 to -6

Table 6 (con't). Select environmental characteristics of the four reference groups; predictor variables included in the 2018 model are highlighted.

Habitat Variable	Units	Group 1 (n=15)			GROUP 2 (n=11)			GROUP 3 (n=7)			GROUP 4 (n=58)		
		Mean ± SD	Median	Range	Mean ± SD	Median	Range	Mean ± SD	Median	Range	Mean ± SD	Median	Range
SURFICIAL GEOLOGY (% upstream catchment area)													
Alluvial	%	0 ± 0	0.0	0	0 ± 0	0.0	0 to 0	0 ± 0	0.0	0.0	0.3 ± 2.1	0.0	0 to 15.5
Bedrock	%	28.2 ± 39.2	1.9	0 to 100	0 ± 0	0.0	0 to 0	14.3 ± 37.8	0.0	0 to 100	15.7 ± 30.4	0.0	0 to 100
Colluvial	%	23.0 ± 31.4	8.3	0 to 89.4	1.7 ± 5.7	0.0	0 to 18.9	10.8 ± 28.6	0.0	0 to 75.6	26.8 ± 38.3	0.0	0 to 100
Glac_Sed_Blanket	%	27.4 ± 40.7	3.3	0 to 100	54.1 ± 33.6	53.5	0 to 100	73.6 ± 42.7	100.0	0 to 100	39.0 ± 44.1	1.9	0 to 100
Glac_Sed_Veneer	%	21.2 ± 32.9	6.5	0 to 99	21.1 ± 33.5	0.0	0 to 100	1.3 ± 3.4	0.0	0 to 9.1	13.0 ± 26.3	0.0	0 to 100
Glaciolacustrine	%	0 ± 0	0.0	0 to 0	3.7 ± 12.3	0.0	0 to 40.9	0 ± 0	0.0	0 to 0	2.7 ± 13.3	0.0	0 to 78.1
Organic deposits	%	0 ± 0.1	0.0	0 to 0.3	18.7 ± 32.5	0.0	0 to 100	0 ± 0	0.0	0 to 0	2.0 ± 7.1	0.0	0 to 46.5
Snow	%	0 ± 0	0.0	0 to 0	0 ± 0	0.0	0 to 0	0 ± 0	0.0	0 to 0	0 ± 0.4	0.0	0 to 2.7
TOPOGRAPHY													
Elevation, avg	m	1143 ± 459	1183	469 to 1959	634 ± 177	617	435 to 991	740 ± 504	520	469 to 1869	1079 ± 434	1081	457 to 2061
Elevation, max	m	1799 ± 619	1980	495 to 2680	941 ± 424	794	487 to 1906	973 ± 758	740	496 to 2656	1647 ± 662	1666	502 to 2940
Elevation, min	m	676 ± 276	693	268 to 1074	383 ± 133	357	256 to 696	501 ± 252	423	337 to 1058	660 ± 285	573	313 to 1508
% catchment with slope <30%	%	58 ± 29	54	16 to 100	94 ± 8	97	75 to 100	89 ± 28	99	25 to 100	64 ± 28	59	17 to 100
% catchment with slope 30-50%	%	18 ± 11	19	0 to 31	4 ± 6	2	0 to 19	4 ± 9	1	0 to 24	16 ± 11	17	0 to 34
% catchment with slope 50-60%	%	4 ± 3	5	0 to 9	1 ± 1	0	0 to 40.9	1 ± 3	0	0 to 7	4 ± 3	4	0 to 12
% catchment with slope >60%	%	19 ± 19	16	0 to 64	1 ± 1	0	0 to 2	6 ± 17	0	0 to 45	16 ± 17	9	0 to 59
Slope, max	%	221 ± 103	197	40 to 416	120 ± 52	141	38 to 195	157 ± 143	103	18 to 431	226 ± 169	169	52 to 802
Slope, min	%	0.1 ± 0.2	0	0 to 0.7	0 ± 0	0	0	0 ± 0	0	0	0 ± 0	0	0 to 0.7
Slope, avg	%	32 ± 18	34	2 to 65	11 ± 6	11	1 to 21	14 ± 19	9	2 to 56	29 ± 18	31	1 to 65

2.3 Final Model and Model Performance

A stepwise DFA using both forward and backward procedures was run to derive a list of the most likely predictor variables. The stepwise models were then iteratively revised adding and removing variables based on tolerance scores and *F* values to achieve the optimal model with a maximum number of variables being no more than the number of sites in the smallest group.

An optimal model has the highest possible overall cross-validation rate with similar individual group error rates and the fewest possible variables. The cross-validation classification rate is based on the model being built from all the data several times with a different reference site being removed from the analysis each time. The resubstitution rate is simply based on reclassifiying each reference site using the model, but without removing it from the model building process. The cross-validation rate is always the lower of the two but is a better test of the model performance. A final set of optimal habitat variables is shown in Table 7 (Wilk's Lambda 0.322, Approximate F-Ratio 6.344, P<0.05). Resubstitution and classification rates are summarized in Table 8.

Table 7. Optimal model variables determined from stepwise and iterative DFA.

Optimal Predictor Variables	Group 1 mean (n=15)	Group 2 mean (n=11)	Group 3 mean (n=7)	Group 4 mean (n=58)	F-to-Remove	Tolerance
Longitude	-125.269	-123.037	-122.229	-124.122	12.424	0.393
Channel – Bankfull minus wetted depth	34.527	56.355	28.347	33.359	7.294	0.832
Climate – Total Annual Precipitation	567.073	503.4	471.029	582.89	11.867	0.536
Climate – Annual Average Temperature	-2.107	-0.727	-1.629	-1.567	10.128	0.322
Hydrology – Drainage Area	165.281	1,094.12	403.153	384.349	5.414	0.451
Surficial Geology – Organic deposits %	0.02	18.672	0	2.016	5.731	0.765

Table 8. DFA classification rates (resubstitution and jackknifed cross validation) for the optimal model.

Resubstitution	Predicted Group 1	Predicted Group 2	Predicted Group 3	Predicted Group 4	%correct	%error
Assigned Group 1	10	0	1	4	67	33
Assigned Group 2	0	8	1	2	73	23
Assigned Group 3	0	0	6	1	86	14
Assigned Group 4	13	3	3	39	67	33
Total	**23**	**11**	**11**	**46**	**69**	**31**
Jackknifed Cross-Validation	**Predicted Group 1**	**Predicted Group 2**	**Predicted Group 3**	**Predicted Group 4**	**%correct**	**%error**
Assigned Group 1	9	0	1	5	60	40
Assigned Group 2	0	8	1	2	73	27
Assigned Group 3	0	0	6	1	86	14
Assigned Group 4	13	4	3	38	66	34
Total	**22**	**12**	**11**	**46**	**67**	**33**

Model performance was assessed using validation data. The small size of some validation groups limits evaluation of model performance. Validation sites were reference sites with known membership to a reference group based on the clustering to define the reference groups in an earlier modelling step. Ideally, the error rates would be similar to or less than those for resubstitution and cross validation. Results in Table 9 show that 50% of sites in Groups 1 and 2 are being misclassified to Group 4 (although this is based on a very low sample size) and 40% of sites in Group 4 are being misclassified to Group 1.

Table 9. DFA classification rates of validation data (reference sites with known reference group membership) for the optimal model.

Validation Data	Predicted Group 1	Predicted Group 2	Predicted Group 3	Predicted Group 4	%correct	%error
Known Group 1	1			1	50	50
Known Group 2		1		1	50	50
Known Group 3			1		100	0
Known Group 4	4			6	60	40
Total	**5**	**1**	**1**	**8**	**60**	**40**

Model performance was assessed using simulated disturbance data based on work by Bailey et. al. (2012) and adapted to resource development in B.C. by Strachan and Pappas (2016). CABIN records from B.C. were used to generate taxa tolerance scores, which were based on expected changes to the stream environment caused by resource development, such as unconventional oil and gas. The score reflects taxa tolerance to potential changes in the stream environment from these development activities, including fining of substrate and increased turbidity caused by increased erosion. For example, invertebrate families that are associated with boulder substrates and low embeddedness are expected to be sensitive to increases in small and sandy/silty substrates and increases in embeddedness (Table 10).

The use of simulated data allows for a calculation of Type 1 (mistakenly determining a reference site is impaired) and Type 2 (not detecting impairment at a site that is affected by disturbance) error rates for a given model for an estimated disturbance. A low Type 1 error rate often means that the Type 2 error rate will be high. A preferred model would have a balance of Type 1 and Type 2 error rates and also a decrease in Type 2 error rates as disturbance intensity increases.

Table 10. Expected response variables representing potential unconventional resource development impacts in the Shale Gas development area of B.C. and the expected correlations with tolerant or sensitive taxa (from Strachan and Pappas, 2016).

Response Variable	Development-sensitive taxa correlation	Development-tolerant taxa correlation	Insensitive taxa correlation
TSS	Negative	Positive	None
Turbidity	Negative	Positive	None
Bedrock %	Positive	Negative	None
Boulder %	Positive	Negative	None
Gravel %	Negative	Positive	None
Sand %	Negative	Positive	None
Silt/Clay %	Negative	Positive	None
Embeddedness[a]	Positive	Negative	None
Dominant Substrate[b]	Positive	Negative	None

[a]Note that the data in CABIN is entered such that a low embeddedness score means high actual embeddedness so the correlations appears opposite.
[b]Note that in CABIN, larger categories indicate larger dominant substrates so the correlation appears opposite.

Approximately 3,500 CABIN records in B.C. were used to generate correlations of 170 benthic macroinvertebrate families with nine CABIN variables related to substrate and disturbance: total suspended solids (TSS), turbidity, dominant substrate type, embeddedness, and proportions of substrate types (bedrock, boulder, gravel, sand, silt/clay). Families were assigned by each habitat variable as being potentially insensitive based on whether the correlation was positive, negative or there was no correlation. The final resource development tolerance score for each family was determined by its position on the Tolerant > Insensitive > Sensitive continuum, scaled from +1 (highly tolerant) to -1 (highly sensitive) based on the number of variables on which it was ranked in each category. Taxa with tolerance scores below -0.65 were designated “sensitive”, taxa with tolerance scores above 0.65 were designated “tolerant”, and all other taxa designated “insensitive” (Table 10). The resource development tolerance score was applied to 15 randomly selected reference samples to generate simulated assemblages at three levels of intensity (S1 or low, S2 or moderate, S3 or high). Figure 6 illustrates the changes of simulated disturbance to abundance and taxa richness due to resource development at three different intensities for the 15 validation sites.

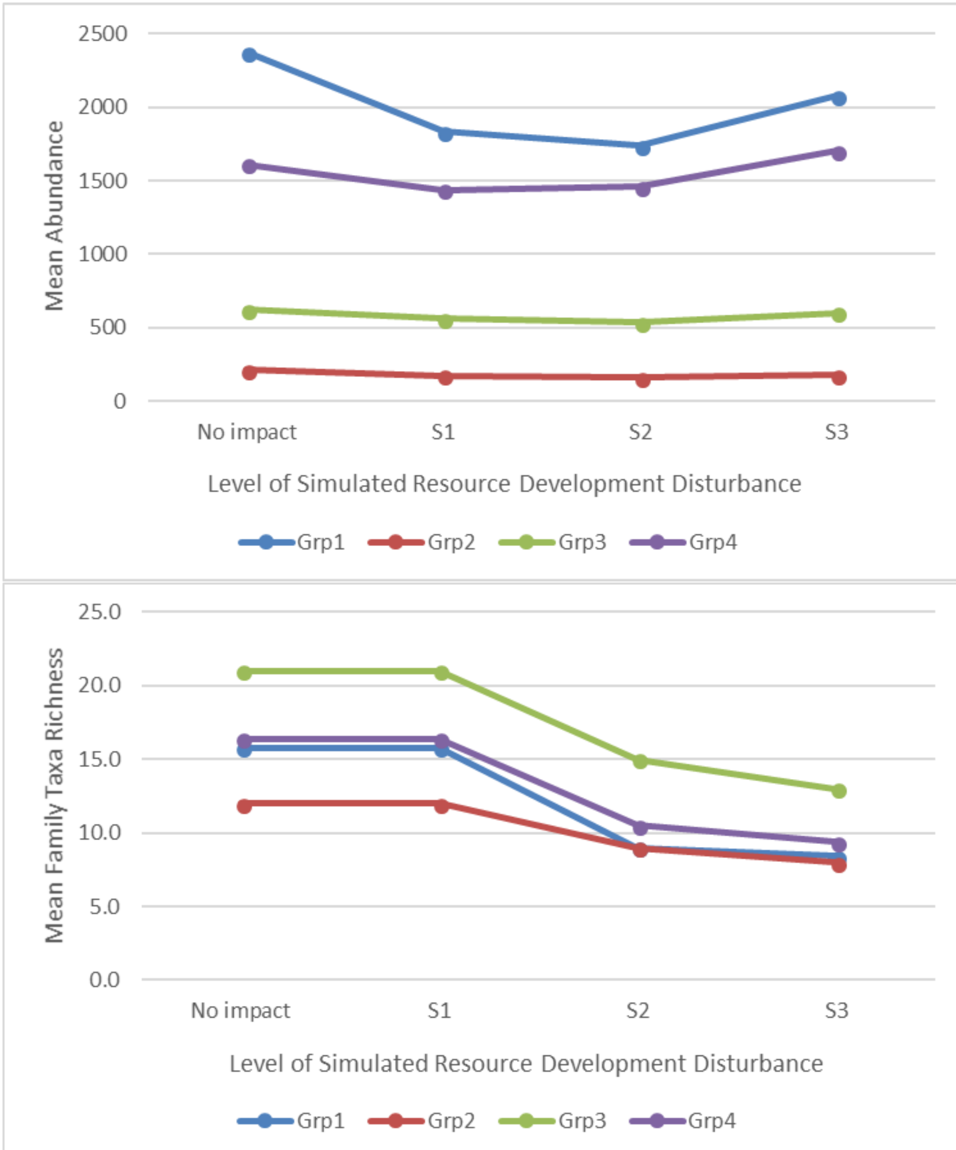

Figure 6. Change in mean abundance of invertebrate animals (top) and mean family taxa richness (bottom) for the four reference condition groups in response to three levels of simulated resource development disturbance (S1, S2, S3) (Group 1, n=1; Group 2, n=2; Group 3, n=1; Group 4, n=11).

The CABIN standard uses a 90% ellipse as the first threshold for detecting divergence from the expected reference condition. At the 90% threshold, the Type 1 error rate is 27% and the Type 2 error rate ranges from 60% for S1, to 53% for S2 and 40% for S3 (Figure 7). Using a modified threshold of 75%, the Type 1 error rate is slightly higher (33%) but the Type 2 error rates ranged from 47% for S1, to 20% for S2 and S3. Overall, the modified ellipses resulted in improved Type 2 errors, and the Type 1 error rate was not that different between the two sets of ellipses. Therefore, we recommend using the modified CABIN ellipses for this model for distinguishing levels of divergence from the expected reference condition.

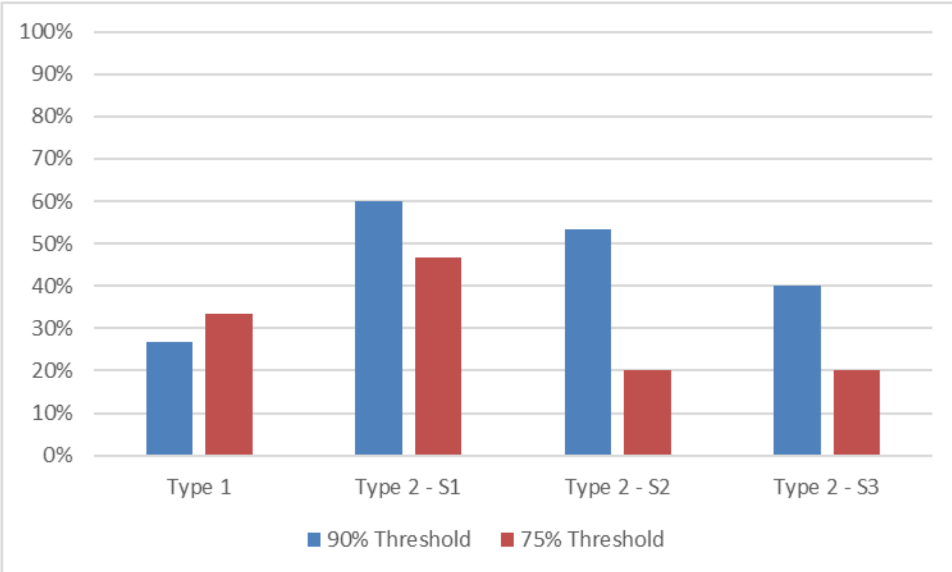

Figure 7. Type 1 and Type 2 error rates based on test site assessment results for 15 validation sites untreated (Type 1) and treated with three levels of simulated intensities (S1, S2 and S3) of resource development using 90% confidence threshold and 75% confidence threshold.

2.4 Model Results and Performance

Sensitivity of the NEBC 2018 model was further assessed by comparing test assessments to assessments results generated using the existing 2016 NEBC preliminary model (Strachan and Pappas, 2016). A total of 30 test sites were assessed as shown in Table 11. Ordinations of the NEBC reference site communities and individual test site communities were plotted with 75, 90 and 95% probability ellipses for the 2016 model (modified ellipses) and both modified probability ellipses (75, 90 and 95%) and standard probability ellipses (90 and 99 and 99.9%) for the 2018 NEBC model. All results are summarized in Table 11. Overall, comparison of the 2016 preliminary and 2018 standard ellipse models showed that for 40% of test sites, there was no difference in assessment results, while for 37% of test sites, the 2018 was less sensitive by one band. For 3% of test sites, the 2018 model was more sensitive by one band (Table 12). Only a small percentage of test sites differed by two (13%) or three bands (3%). A difference of 3 bands may be due to a misclassification of the test site to the wrong reference group. A comparison of the 2016 preliminary and 2018 modified ellipse models showed that for 50% of test sites there was no difference in assessment results, while for 13% of test sites, the 2018 was less sensitive by two or more bands, and more sensitive by one or two bands for 37% of test sites (Table 12). This provides further support for using modified ellipses for the 2018 model.

Test site results ranging from “mildly divergent” to “highly divergent” for a large river site (PET01) sampled five times over 6 years, suggest that the model may not be useful for larger river sites. This is not unexpected, since there was only one reference condition site in a large river (stream order 6) included in the model.

Table 11. Summary of test site assessment results for NEBC area sites using the preliminary 2016 NEBC Model with modified ellipses (Strachan and Pappas, 2016) and the 2018 NEBC Model with both standard and modified ellipses. Possible results include R=reference condition, MD=mildly divergent from reference condition, D=divergent from reference condition, and HD=highly divergent from reference condition.

Site code	CABIN sample ID	Site name	Basin	Year	2016 model modified ellipses	2018 model standard ellipses	2018 model modified ellipses
BC-FNR001-10	18225	Tsimeh Creek	Fort Nelson River	2010	HD	HD	HD
BC-LFRT002-11	18503	Delkpay Creek	Lower Fort Nelson River	2011	HD	R	MD
BC-LFRT003-11	18504	Klenteh Creek	Lower Fort Nelson River	2011	HD	D	HD
BC-LFRT005-11	18505	Kiwigana River	Lower Fort Nelson River	2011	MD	MD	HD
BC-LPET004-11	18507	D'Easum Creek	Lower Petitot River	2011	HD	HD	HD
BC-MUSK001-10	18220	Akue Creek	Muskwa River	2010	HD	HD	HD
EC-CAP02-13	22469	Capot-Blanc Creek tributary	Capot-Blanc	2013	D	R	R
EC-CVR01-12	20668	Lower Courvoisier Creek	Courvoisier Creek	2012	D	MD	HD
EC-DIL01-12	20681	Dilly Creek	Dilly Creek	2012	MD	MD	HD
EC-EML01-12	20674	Lower Emile Creek	Emile Creek	2012	MD	MD	HD
EC-EML01-13	22463	Lower Emile Creek	Emile Creek	2013	R	R	MD
EC-EML01-14	24146	Lower Emile Creek	Emile Creek	2014	HD	D	HD
EC-EML01-17	29943	Lower Emile Creek	Emile Creek	2017	N/A	D	HD
EC-EML02-12	20675	Upper Emile Creek	Emile Creek	2012	D	MD	D
EC-HOS01-13	22477	Hossitl Creek	Petitot River	2013	MD	R	MD
EC-MUSK04-12	20664	Muskwa River tributary near the mouth	Muskwa River	2012	D	MD	HD
EC-PET01-12	20676	Petitot River upstream of Highway No. 77	Petitot River	2012	HD	MD	HD
EC-PET01-13	22464	Petitot River upstream of Highway No. 77	Petitot River	2013	MD	MD	HD
EC-PET01-14	24144	Petitot River upstream of Highway No. 77	Petitot River	2014	MD	MD	D
EC-PET01-16	28543	Petitot River upstream of Highway No. 77	Petitot River	2016	N/A	HD	HD
EC-PET01-17	29939	Petitot River upstream of Highway No. 77	Petitot River	2017	N/A	MD	D
EC-PET03-12	20677	Fortune Creek near the mouth	Petitot River	2012	D	R	R
EC-PET03-13	22461	Fortune Creek near the mouth	Petitot River	2013	HD	HD	HD

Site code	CABIN sample ID	Site name	Basin	Year	2016 model modified ellipses	2018 model standard ellipses	2018 model modified ellipses
EC-PET03-14	24145	Fortune Creek near the mouth	Petitot River	2014	MD	MD	HD
EC-PET04-12	20678	Stanislas Creek	Petitot River	2012	MD	R	MD
EC-PET07-12	20679	Petitot River mainstem ds of Tsea River	Petitot River	2012	D	MD	D
EC-PET07-13	22480	Petitot River mainstem ds of Tsea River	Petitot River	2013	HD	R	R
EC-PET07-14	24143	Petitot River mainstem ds of Tsea River	Petitot River	2014	D	MD	D
EC-PET07-16	28513	Petitot River mainstem ds of Tsea River	Petitot River	2016	N/A	MD	D
EC-STND01-12	20665	Stanolind Creek tributary	Stanolind Creek	2012	D	MD	D
EC-THET01-12	20672	Thetlaandoa Creek	Petitot River	2012	HD	MD	HD
EC-THET01-13	22479	Thetlaandoa Creek	Petitot River	2013	R	MD	HD
EC-TSEA001-12	20673	Tsea River	Tsea River	2012	R	R	MD
EC-TSEA002-12	20658	Trib to Tsea River	Tsea River	2012	D	MD	HD

Table 12. Comparison of assessment results using NEBC 2016 preliminary model based on modified ellipses (Strachan and Pappas, 2016) and 2018 NEBC model using both standard and modified ellipses.

	2018 Standard Ellipses		2018 Modified Ellipses	
Model comparison	# of test site assessments	% of total assessments	# of test site assessments	% of total assessments
Same site assessment using both models	12	40%	15	50%
2018 model less sensitive by 1 band	11	37%	0	0%
2018 model less sensitive by 2 bands	4	13%	3	10%
2018 model less sensitive by 3 band	2	7%	1	3%
2018 model more sensitive by 1 bands	1	3%	5	17%
2018 model more sensitive by 2 or more bands	0	‘-	6	20%

3.0 CONCLUSIONS AND RECOMMENDATIONS

The 2018 NEBC model includes the Liard and Fort Nelson/Petitot Basins within B.C. This is an updated model to evaluate effects of unconventional oil and gas development and will also provide a baseline for bioassessments related to other human disturbances in this area, such as forestry, agriculture, mining, and residential/urban development. The model was built using data from 91 reference sites in these watersheds, which were selected using the Human Activity Gradient approach. There are a few gaps that remain in this model in small (stream order 2) and larger streams (stream order >5), as well as sites located within the L4 and F5 natural habitat groupings. Classification of the reference data produced 4 distinct biological groups. A review of habitat data found a high degree of similarity of habitat variables between Groups 1 and 4, which may contribute to difficulties in successfully predicting sites to the proper reference group. Optimal predictor variables include longitude, bankfull minus wetted depth, total annual precipitation, annual average temperature, drainage area, and % organic deposits.

There were very few large rivers (stream order 5 or greater) included among the reference sites used for modelling. This lack of larger river sites in the reference data base, combined with test site results ranging from “mildly divergent” to “highly divergent” for a large river site (PET01) sampled five times over 6 years, suggest that the model may not be useful for larger river sites. If assessments of larger rivers are a priority, efforts should focus on collecting more samples from larger rivers in reference condition for the next round of modelling in NEBC.

Moving forward, we suggest that the 2018 NEBC model is uploaded to CABIN using modified ellipses. The classification rates for the DFA and validation data are lower than we would like. There was difficulty building a robust model mainly due to a lack of suitable or useful habitat variables that could clearly distinguish between groups of sites (e.g., land cover and climate). Future modelling efforts should identify and incorporate relevant habitat variables that could serve as potential predictor variables. For example, an annual variable for total precipitation that could be linked to samples by year would be a more useful representation of wet and dry years than climate variables that are currently calculated as a 30-year average (1971-2001) as described in Appendix C.

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APPENDICES: DATA COLLECTION, ANALYSIS AND QUALITY ASSURANCE

A. Field Collection

CABIN Study Name	**EC-NEBC Baseline WQ Monitoring**	**BCMOE-Omineca/Peace Region**	**GeoScience BC–Horn River Basin**
Agencies involved	Environment Canada	BC Ministry of Environment	Environmental Dynamics
Date range	2012-2017	2010-2017	2011-2013
Sampling season	Late August	Late August	Early/mid-September
# reference samples	95	24	2
Certified samplers (Y or N)	Y	Y	Y
Certified team leader (Y or N)	Y	Y	Y
400 um kicknet (Y or N)	Y	Y	Y
Preservative used	Formalin	Ethanol/Formalin	Formalin

B. Macroinvertebrate Identification

CABIN Study Name	**EC-NEBC Baseline WQ Monitoring**	**BCMOE-Omineca/Peace Region**	**GeoScience BC–Horn River Basin**
Taxonomist	Cordillera Consulting	Cordillera Consulting	Cordillera Consulting; EcoAnalysts
Marchant Box used (Y or N)	Y	Y	Y
Subsample count	300	300	300
10% of reference samples sent to National Lab for QA	Y	Y	N
Reference Collection maintained	Y	N	N

C. GIS Analyses

Description	Scale/Resolution	Source
Microbasin polygons (HAG)	1:50,000	http://www.env.gov.bc.ca/esd/distdata/ecosystems/bc50kwsa/shapefiles DataBC – BC Ministry of Environment WaterShed Atlas50K Drainage areas (lwsdbcgz). Microbasin polygons intersected with natural landscape features (i.e. geology, landcover) were used in the Human Activity Gradient site selection process to identify potential reference basins.
Basin Morphometry	25 m	https://earthexplorer.usgs.gov/ Upstream basin outlines specific to the sampling locations were obtained using Digital Elevation Model (DEM) data in raster format, corresponding to the 1:50K NTS (25 m cell size) NASA Aster map sheets.
Hydrology	1:50,000	https://open.canada.ca/data/en/dataset/a4b190fe-e090-4e6d-881e-b87956c07977 National Hydro Network data in vector format were obtained from the GeoBase portal. After DEM conditioning to fill small depressions, to ensure correct water flows, individual basins upstream of the sample sites were delineated in ArcGIS (ESRI, Inc) using the ArcHydro extension
Geology	1:5,000,000	https://open.canada.ca/data/en/dataset/dc00e0cf-8893-11e0-ac2d-6cf049291510 https://open.canada.ca/data/en/dataset/dbf2fe21-8893-11e0-a455-6cf049291510 Surficial Geology and Bedrock Geology Using the ArcGIS 10.1 intersect function, all vector layers were intersected with the delineated upstream basins to derive attributes within each catchment.
Climate	7.5 km	Historical Climate data 1971-2001 (raster dataset) Natural Resources Canada contact: Dan McKenney - dan.mckenney@canada.ca Climate information was summarized using rasterized grids with climate normals dating from 1971-2001, basin statistics were summarized using Geospatial Modelling Environment v.0.7.2.1. Basins that were completely contained within one grid were given the value of that cell.
Topography	25 m	https://open.canada.ca/data/en/dataset/7f245e4d-76c2-4caa-951a-45d1d2051333 Elevation data were created from a 25 m DEM using the zonal statistics function in ArcGIS for each delineated basin. To generate slope from the DEM, the slope function was used, a vector file was then generated with four groups based on percent slope value (<30%, 30-50%, 50-60%, >60%). The slope layers were then intersected as described above.
Land Use	1:50,000	https://open.canada.ca/data/en/dataset/97126362-5a85-4fe0-9dc2-915464cfdbb7 Land Cover, circa 2000 Vector. Using the ArcGIS 10.1 intersect function, all vector layers were intersected with the delineated upstream basins to derive attributes within each catchment.
Transportation	Date 2014	http://open.canada.ca/data/en/dataset/14f7810f-a625-4872-a1ba-9b86a6c8a2b4 Road Network File 2014 was merged with BC Oil and Gas development road network layers (see below). Using the ArcGIS 10.1 intersect function, all vector layers were intersected with the delineated upstream basins to derive road density within each catchment.
Oil and Gas information	N/A	https://data-bcogc.opendata.arcgis.com. BC Oil and Gas Commission, updated layers accessed annually 2011-2015 Using the ArcGIS 10.1 intersect function; all vector layers were intersected with the delineated upstream basins to derive attributes within each catchment.

D. Laboratory Analyses – NOT APPLICABLE: Parameters analyzed in water samples collected by each agency differed and were not used in the development of this model.

E. Statistical Analyses

Excel – data management after extraction from CABIN database

Primer 6 v.6.1.12 (© Primer-E Ltd, 2009) – classification, MDS ordination, SIMPER, ordination of test site assessment

SYSTAT® v.13.1 (SYSTAT Software, 2009) – principal component analysis, correlations, discriminant function analyses and plotting BEAST assessment with probability ellipses