Reference Model Supporting Documentation for CABIN Analytical Tools

MODEL NAME: Fraser Basin 2014

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1. STUDY DESIGN AND SITE SELECTION

1.1 Model Purpose

Fraser Basin model development began in 1994 through the Fraser River Action Plan. The goal was to develop new methods, indicators and tools to assess the health of the Fraser River Basin which is affected by point source effluents from pulp and paper mills, mining and wastewater treatment plants and non-point source pollution from logging and urban and agricultural runoff. Since that time, the Fraser Basin model developed through several stages under the direction of Environment Canada scientists. Stage 1 was based on data collected from 1994-1996 by EC and was reported in (Rosenberg et al. 1999). Stage 2 was designed to expand that model to include the Georgia Basin with data collected from 1998-2002 (Sylvestre et al. 2005) by EC. Stage 3 (Reynoldson et al. 2012) was designed to include data from reference sites that were re-sampled annually or on a rotating basis between 2003 and 2010 by EC as well as to include new reference sites from BC Ministry of Environment (BC MOE). This most recent update was designed to refine the model developed by Reynoldson et al. 2012 to provide more reliable assessments specific to the Fraser River Basin and exclude the Georgia Basin.

1.2 Spatial and Temporal Scope

Table 1.Distribution of reference sites among ecoregions and stream orders.

Ecoregion	Order 1	Order 2	Order 3	Order 4	Order 5	Order 6	Order 7	Order 8
Pacific Ranges	2	24	21	9	9			
Lower Mainland	2	8	3	0	4			
Omineca Mountains	1	1	2	2	0	4		
Central Canadian Rockies	3	3	2	7	4	1		
Fraser Plateau	2	4	11	26	17	11	5	4
Fraser Basin	0	0	0	0	0	1	0	9
Chilcotin Ranges	1	0	5	5	2			
Columbia Mtn Highlands	1	3	13	10	4	1	5	
Western Continental Range	0	3	3	6	0	3		
Interior Transition Ranges	3	6	3	3	5			
Thompson-Okanagan Plateau	2	8	10	1	12	0	1	
Southern Rocky Mtns	0	0	0	0	0	1	9	

Table 2.Temporal scope of reference sites within each ecoregion.

Ecoregion	Temporal range	Total sites	Revisited sites	# Years represented by revisited reference sites
Pacific Ranges	1994-2010	65	5	11
Lower Mainland	1995-2010	17	2	2
Omineca Mountains	1994	10	0	0
Central Canadian Rockies	1995-1996	20	0	0
Fraser Plateau	1995-2008	80	13	7
Fraser Basin	1994-2008	10	2	4
Chilcotin Ranges	1996	13	0	0
Columbia Mtn Highlands	1994-2010	37	4	7
Western Continental Range	1995-2008	15	1	3
Interior Transition Ranges	1995-2008	20	1	4
Thompson-Okanagan Plateau	1995-2010	34	2	9
Southern Rocky Mtns	1995-2008	10	2	4

1.3 Site Selection

Early reference sites (1994-2008) were selected based on expert local knowledge of the different watersheds (Rosenberg et al. 1999). Impacts such as logging, pulp mills, agriculture, ranching, recreation and urbanization as well as the degree of impact (i.e. low, moderate and high) were discussed about various subcatchments with BC MOE staff. Final confirmation about reference site status was made during site reconnaissance based on best professional judgment. In the meantime, BC MOE developed a GIS based site selection tool which defined stream and watershed criteria based on natural and stressor information to assist staff in locating potential reference sites. The criteria varied among provincial regions due to the activity in the region (i.e. dominance of logging activity on Vancouver Island). Final decision on site selection was made after site reconnaissance recognizing that the GIS based information is not always current. A small number of recent reference sites selected by BC MOE (<5% after 2009) made use of the GIS-based site selection tool (Norris 2012). Erosional/riffle habitats were targeted. Where riffles were not present, runs were sampled. A site was deemed to be 6x bankfull width. Replicates or QA/QC samples were taken at a subset of sites to assess within site variability at reference sites and also to investigate assessment variability at test sites.

In Stage 1 of the model development, the Fraser River Basin was stratified by ecoregion (12 ecoregions) and stream order (up to 8 stream orders based on 1:50,000 scale) to capture as much variation as possible. At least 3 sites with riffle habitat were randomly selected and sampled on each strata ending up with a total of 219 sampling locations. In addition, 14 sites were sampled over a 2-3 year period to evaluate temporal variability. In stage 2, streams within the Lower Mainland ecoregion were sampled in an effort was made to capture slow moving streams with small substrates as these were the expected test sites in this area. In Stage 3, a subset of reference sites were chosen to be re-sampled to evaluate the change that may occur to the reference model over time. A few sites that were easily accessible sites from two different stream orders in 2 different ecoregions were chosen to be resampled every year. Additional sites from a variety of stream orders and ecoregions were chosen to be re-sampled approximately every 3 years or some combination of years as funding allowed. The results of Reynoldson et al. 2012 proved to be a difficult model after the Stage 3 reference site updates. In this most recent update, all data from Easter Vancouver Island Ecoregion (i.e. Georgia Basin) were removed in an attempt to improve model performance. The final dataset consisted of 331 sites, with some combination of 32 sites revisited in 11 out of the 16 years represented by this model. Refer to Section 1.2 for the distribution of reference sites among stream orders, ecoregions and years. The geographical distribution of the reference sites in the Fraser River Basin is presented in Figure 1.

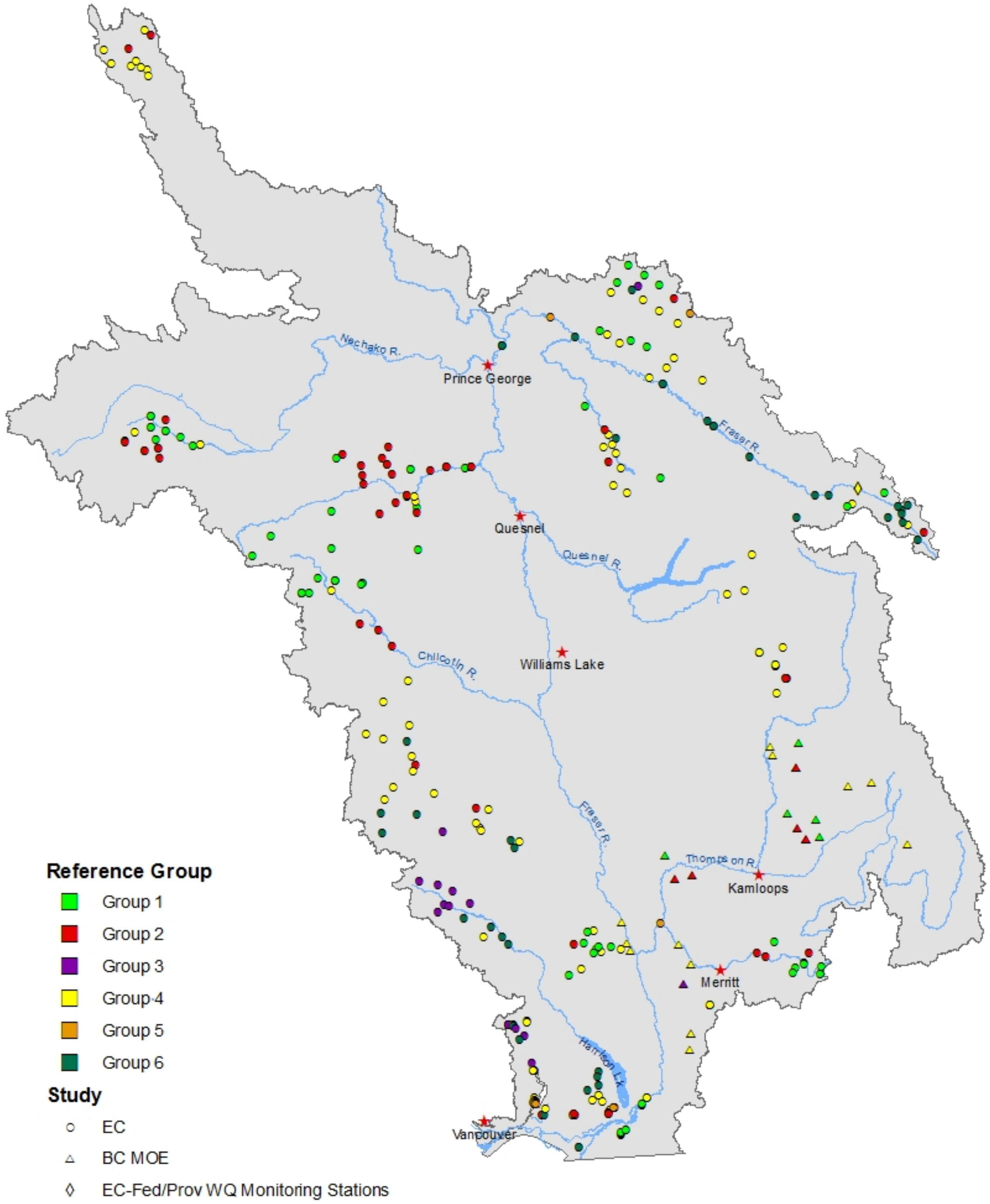

Figure 1. Reference sites from three different CABIN studies sampled in the Fraser River Basin in 1994-2010.

2. REFERENCE DATA AND FINAL MODEL

2.1 Biological description

Outliers were determined through preliminary investigations of the benthic data. CHH10 (1998), CHI04 (1994), CHI08 (1994), CHI09 (1994) were very unique having extremely large abundances of organisms with an average of >55,000 organisms in 1 sample and overage consisting of 87% Chironomidae. An *a priori* decision was made to use raw data. These samples skewed the distribution of abundances and were therefore removed prior to the classification analysis. Classification of the biological data was done using an agglomerative hierarchical fusion using unweighted pair group method using averages (UPGMA) on a Bray-Curtis association matrix (Figure 2).

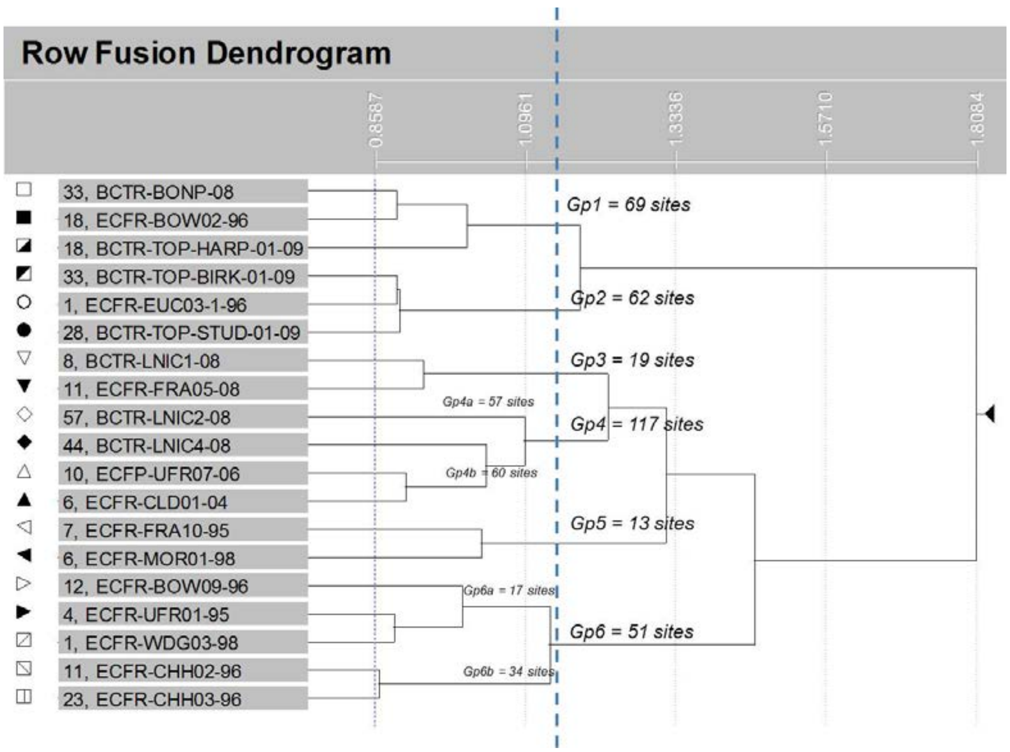

Figure 2. Classification dendrogram of 331 reference sites from the Fraser River Basin. Numbers to the left end of each branch indicate the number of sites on each branch. Grouping structures considered and number of sites within each are group are labeled on the right of each branch. After several iterative models developed with various grouping combinations, the final classification is indicated by labels Gp1, Gp,2, Gp3, Gp4, Gp5, Gp6.

A final grouping structure consisting of 6 groups (Table 3) was decided after various attempts to achieve the best predictive model with various combinations of the different grouping structures from Figure 2. The geographical distribution of reference sites in these groups in the Fraser River Basin are illustrated in Figure 1. The biological communities of the different groups were plotted in ordination space (Figure 3) and the composition and abundance was further described in figures 4, 5, and 6.

Table 3.Number of reference sites classified to each reference group.

GROUP Number	1	2	3	4	5	6
# of Reference Sites	69	62	19	117	13	51

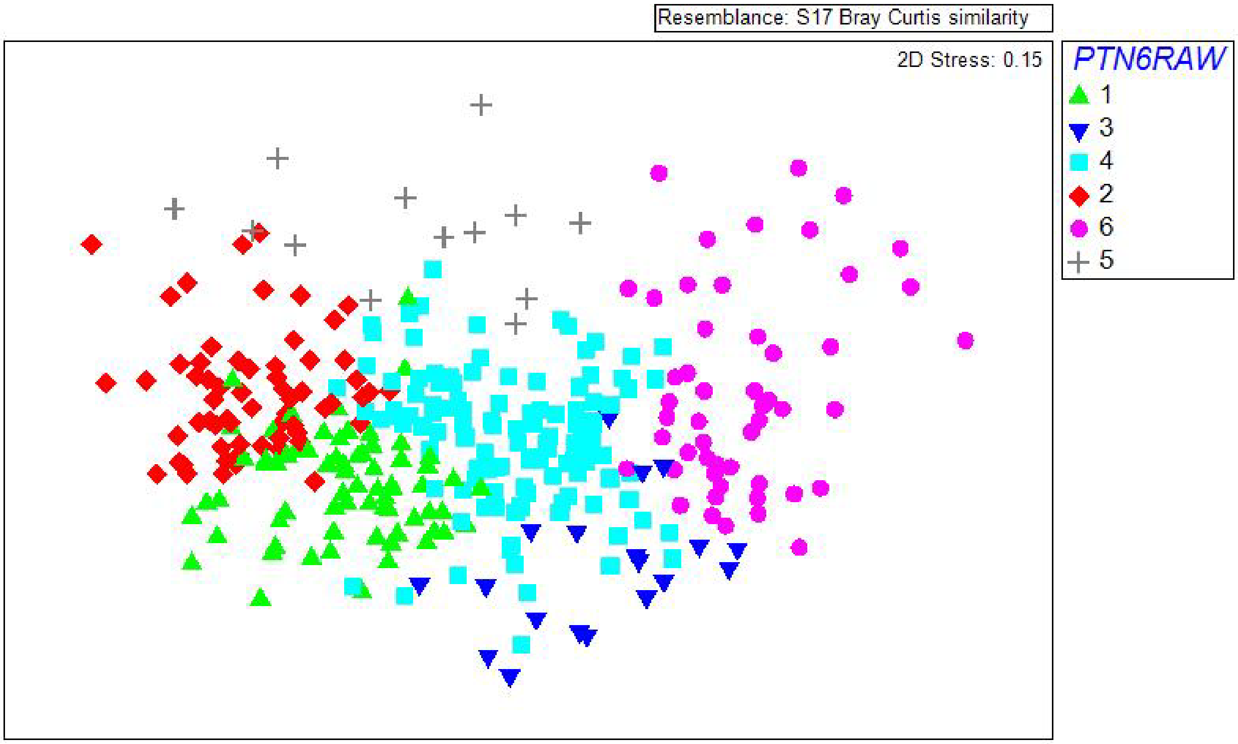

Figure 3. Ordination of 331 reference sites based on Bray-Curtis association of family level raw abundance data. The plot of reference sites represents a gradient of abundance with high abundance on the left and low abundance on the right. A gradient of pollution tolerant organism such as worms and Chironomidae from the top of the plot to pollution sensitive organisms such as EPT on the bottom of the plot.

Groups 1, 2 and 3 had the highest within group similarity ranging from 41 to 46%. Groups 4, 5 and 6 had the lowest within group similarity ranging from 36 to 29%.

Group 1: The similarity within Group 1 was driven by Baetidae, Heptageniidae, Chironomidae and Nemouridae. This group is dominated by EPT organisms particularly Ephemeroptera.

Group 2: The similarity within Group 2 was driven by Chironomidae, Baetidae and Heptageniidae. This group tended to have the most abundant samples ranging from 3,000 to 39,000 organisms. The abundance of Chironomidae tended to be similar to the abundance of EPT.

Group 3: The similarity within Group 3 was driven by Taeniopterygidae, Baetidae and Heptageniidae. This group has the highest proportion of EPT organisms, particularly stoneflies, and the fewest Chironomidae and other taxa.

Group 4: The similarity within Group 4 was driven by Heptageniidae, Chironomidae, Baetidae, Ephemerellidae, and Chloroperlidae. This group tended to have the most species rich samples. This group also had a large proportion of EPT and a larger proportion of Trichoptera than other groups.

Group 5: The similarity within Group 5 was driven by Chironomidae and Naididae. The community is dominated by Diptera and non-insects with few EPT organisms.

Group 6: The similarity within Group 6 was driven by Heptageniidae, Chironomidae, Baetidae, Taeniopterygidae, Ephemerellidae, and Capniidae. This group had the fewest abundance of organisms ranging from 165 to 730 organisms, primarily from the EPT orders. This group tended to have the most diverse samples

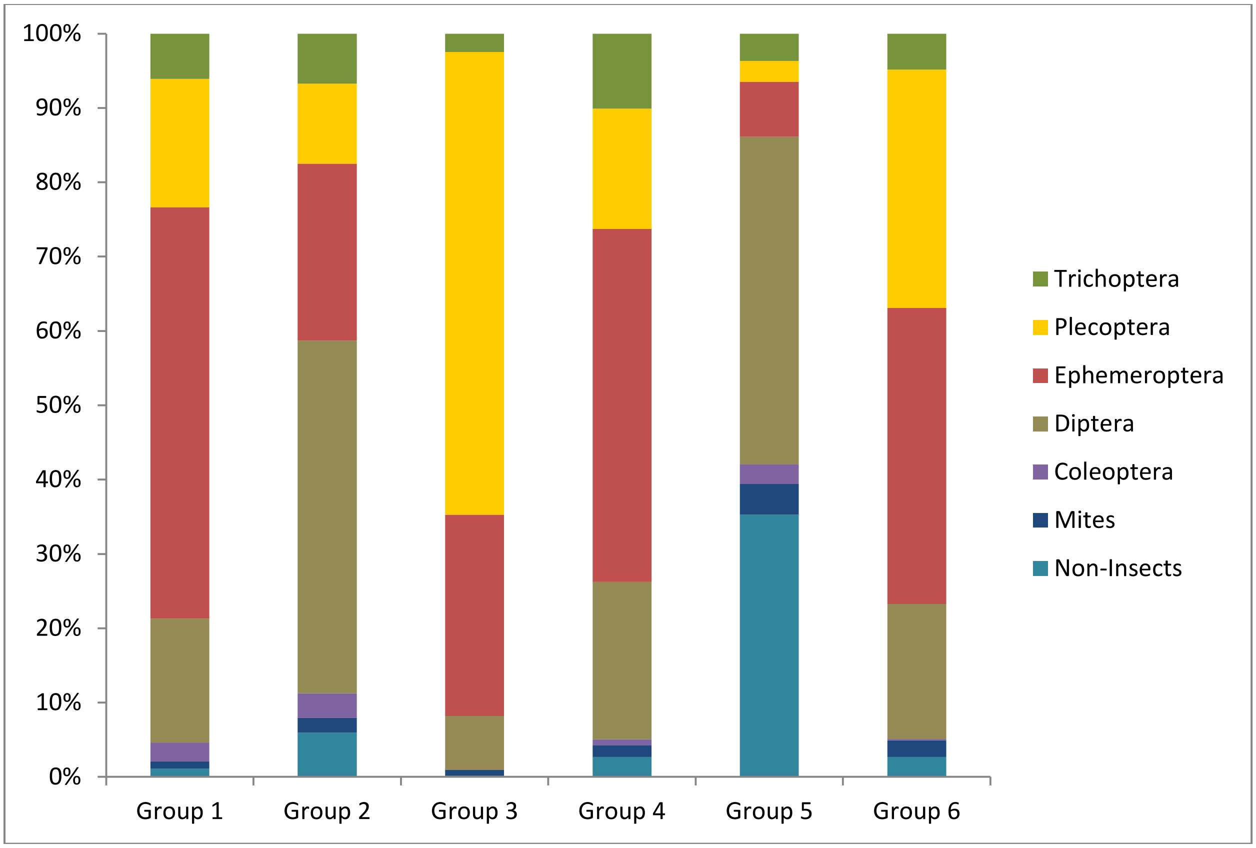

Figure 4. Proportion of major taxa groups within each reference group

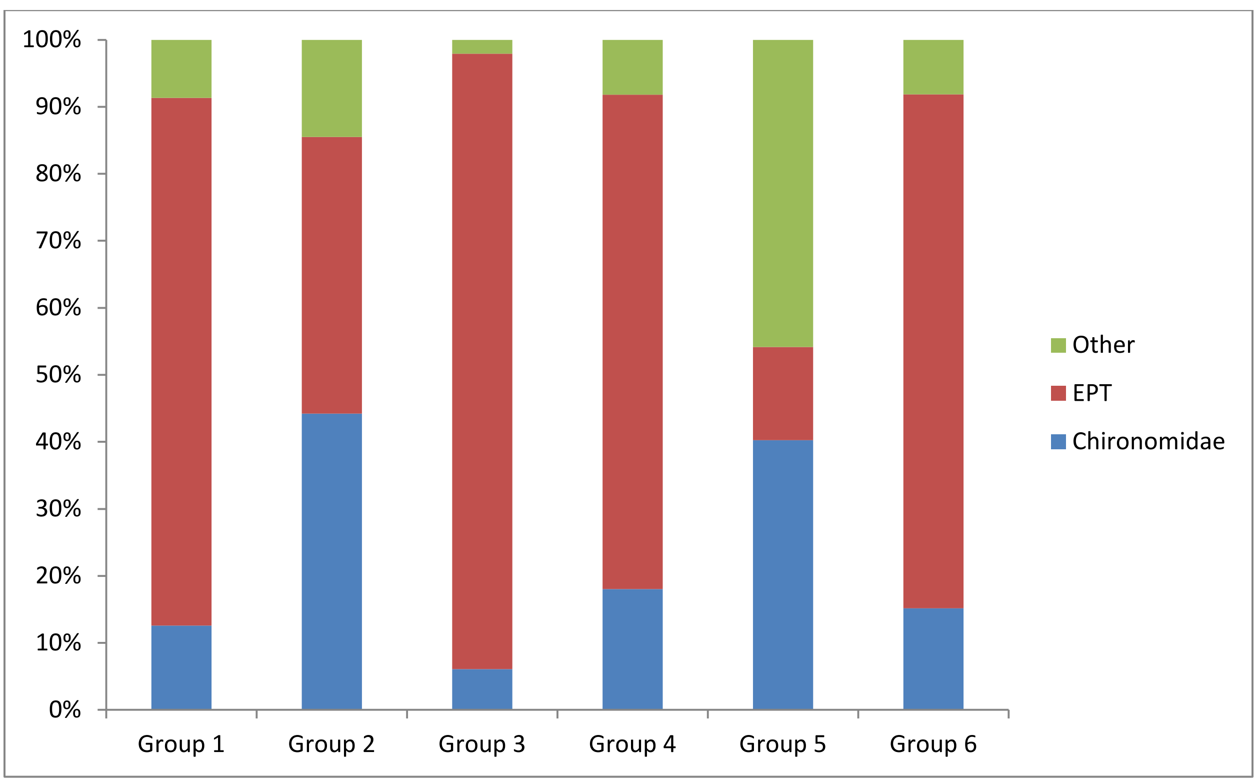

Figure 5. Proportion of key taxonomic composition metrics in each reference group

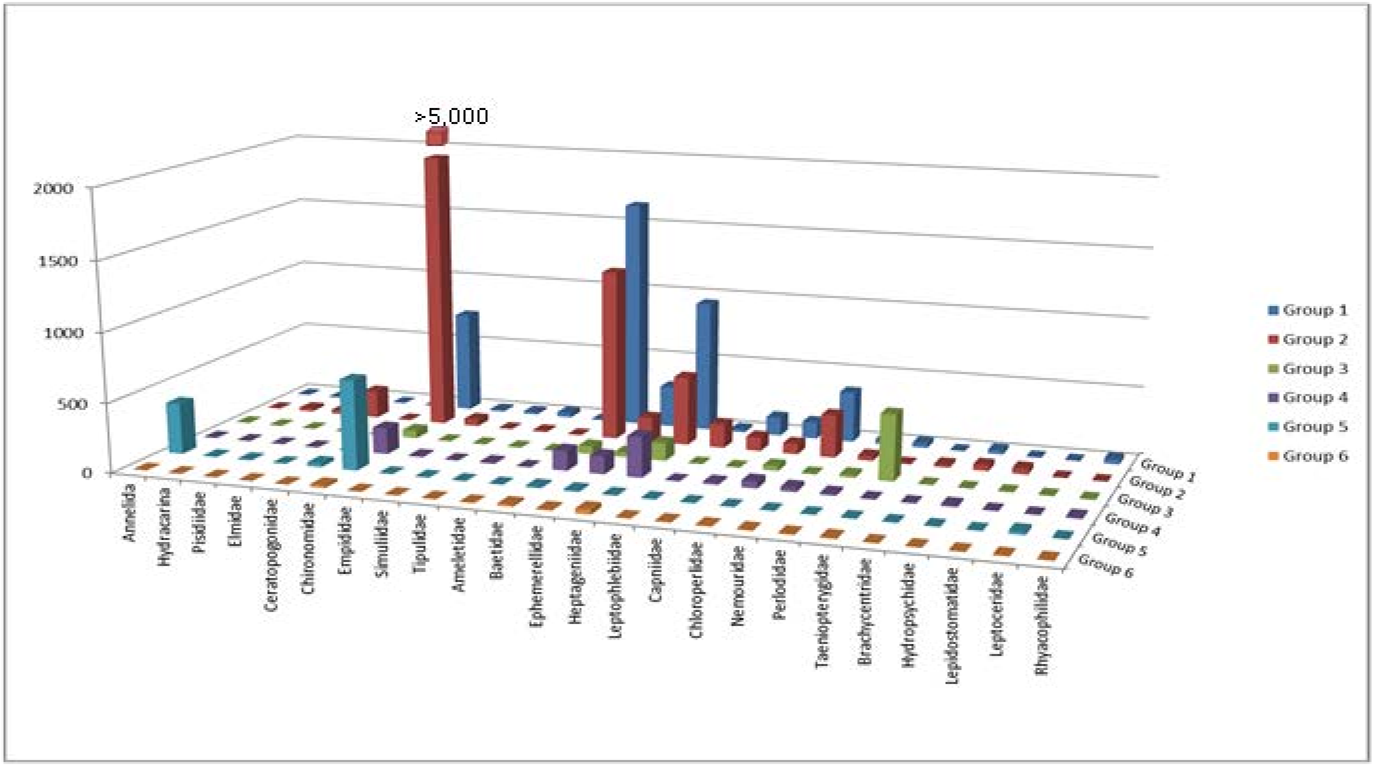

Figure 6. Median abundance of family level taxa in each reference group.

2.2 Habitat Description

Table 4. Summary of selected habitat characteristics of the classified biological groups. Variables in bold were predictors in the revised 2014 model.

Habitat Variable	**Units**	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5**	**Group 6**
Ecoregion (mode)		Fraser Plateau	Fraser Plateau	Pacific Ranges	Columbia Mountains and Highlands	Pacific Ranges	Pacific Ranges
Latitude (median)	decimal degrees	52.6	53.03	50.56	51.32	49.36	51.19
Longitude (median)	decimal degrees	-122.04	-123.47	-122.84	-121.66	-122.63	-122.03
Altitude (median)	fasl	3480	3205	2160	2700	133	1975
Drainage area (median)	km^2	72	104	84	96	59	509
Stream Order (median)	**ordinal**	**4**	**4**	**3**	**4**	**3**	**4**
Channel Measurements							
Slope of riffle (median)	**m/m**	**0.01**	**0.0085**	**0.0193**	**0.014**	**0.0048**	**0.0049**
Width-bankfull (median)	**m**	**9.3**	**13.75**	**83.2**	**25**	**47.3**	**46.4**
Width-wetted (median)	m	5.6	5.85	15	11.4	30	23
Depth-average (median)	cm	18.5	18.5	24.4	27	36	31.6
Depth-maximum (median)	cm	27	25	42	38	48	46
Velocity-average (median)	m/s	0.4	0.35	0.5	0.41	0.16	0.44
Velocity-maximum (median)	m/s	0.6	0.545	0.64	0.68	0.2	0.68

Habitat Variable	Units	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Frequency of riffles	**%**	**85.5**	**67.7**	**89.5**	**80.3**	**23**	**47.1**
Frequency of riparian grasses	%	52.2	80.6	26.3	47	84.6	23.5
Frequency of riparian conifers	%	88.4	72.6	73.7	88.9	46.2	92.2
Dominant Substrate category (median)	**ordinal**	**6**	**6**	**8**	**7**	**4**	**7**
Substrate Embeddedness category (median)	ordinal	4	4	4	4	4	3
Surrounding material substrate category (median)	ordinal	3	3	4	3	2	2
Topography							
Average Elevation in the upstream watershed	m	1463.74	1313.11	1701.61	1481.13	870.24	1544.92
Average slope in the upstream watershed	**%**	**14.1**	**9.1**	**41.9**	**32.0**	**25.0**	**40.7**
Average proportion of the watershed with slopes 30-50%	%	8.0	1.9	31.3	27.7	16.1	30.5
Average proportion of the watershed with slopes <30%	%	89.6	97.7	33.8	53.8	63.4	36.5
Landcover							
Average proportion of the watershed with Water	**%**	**1.38**	**2.47**	**1.00**	**1.55**	**1.80**	**1.01**
Average proportion of the watershed with Snow/Ice	**%**	**0.55**	**0.43**	**30.72**	**4.63**	**3.62**	**10.64**
Average proportion of the watershed with Rock/Rubble	%	1.48	0.97	0.77	1.83	2.36	6.21
Average proportion of the watershed with Wetland-Herb	**%**	**0.46**	**0.97**	**0.03**	**0.18**	**0.68**	**0.12**
Bedrock Geology							
Average proportion of the watershed with intrusive bedrock	%	17.42	17.26	67.78	32.39	47.45	39.67
Average proportion of the watershed with sedimentary bedrock	**%**	**25.96**	**13.8**	**18.33**	**27.76**	**15.9**	**49.84**
Average proportion of the watershed with volcanic bedrock	%	39.38	48.28	6.07	22.85	28.38	6.14
Climate							
30 yr Average Degree Days for upstream watershed	days	139.3	132.8	143.4	132.9	100.4	135.6
30 yr Average February Precipitation for upstream watershed	**mm**	**60.0**	**67.0**	**127.5**	**95.0**	**171.5**	**117.7**
30 yr Average Total Precipitation for upstream watershed	mm	755.3	834.3	1286.6	1071.7	1751.3	1254.7
30 yr Average July Maximum Temperature for upstream watershed	**deg C**	**17.6**	**18.5**	**16.5**	**17.5**	**20.3**	**16.7**
30 yr Average Annual Temperature for upstream watershed	deg C	1.37	2.02	2.16	1.89	5.56	1.77

Group 1 and Group 2 tend to be high altitude locations with their upstream drainage areas having low gradients. These sites are also dominated by volcanic bedrock. Group 1 tended to be smaller and steeper than Group 2 sites. The Group 2 sites tend to have a lot more water (i.e. rivers, lakes) in the upstream watershed on areal basis.

Group 3 was the smallest group of reference sites. These tended to have steep riffles, large substrates with a relatively large proportion of snow/ice landcover and intrusive bedrock. They have a fair amount of precipitation but the lower maximum summer temperatures.

Group 4 was the largest group of reference sites with habitat characteristics that did not show extremes. Similar to the MDS plot of the biological data, these sites tended to have characteristics within the range of all the other groups.

Group 5 and Group 6 sites tended to be the low altitude sites, with low slopes, large widths and depths and slow velocities. Group 5 sites tended to have the smallest and most embedded substrates. These watersheds also received the most precipitation and the highest temperatures. Group 6 sites are distinguished from Group 5 sites by the larger substrates and the proportion of sedimentary bedrock. This group of sites tended to contain the Fraser River mainstem sites and other large rivers.

2.3 Model Results and Performance

Nearly 100 variables were identified as potential predictor variables, many of which were generated using GIS and nationally available data layers. The channel variables included descriptors of habitat, substrate, flow and the riparian zone and were measured on site. The habitat variables reflect a range of variable types including continuous, ordinal and categorical values.

Several approaches were used to select the final habitat predictors:

1. Forward and Backward Stepwise DFA and then optimization by variable removal and entry based on individual F scores or tolerance values.
2. Variable selection based on similarity matrix matching using BVSTEP in PRIMER with raw and normalized habitat data.
3. Optimal model from the above approaches and adding variables that best predicted individual reference groups in DFA.

Selection of a final model was based on a number of factors:

1. Wilk's lambda (λ) statistic- lower value indicates greater difference among the means values for the predictor variables
2. F-score – higher score indicates greater among group to within group variation in the predictor variables
3. Overall Accuracy rate – greatest % of reference sites correctly predicted using the jackknifed cross validation method
4. Group Accuracy rate - % of reference sites correctly predicted to each group must be greater than a random assignment. A model where the group with the lowest accuracy rate was maximized may be chosen even though the accuracy rate for another group was decreased but still relatively high.
5. Number of predictor variables – fewer predictors are preferred as these models are more robust
6. Non-correlated variables – correlation among predictor variables was avoided as much as possible to avoid potential over-fitting of the model.

Summary of final model predictors:

1. **Dominant substrate** category (1-9 refer to CABIN field manual)
2. **Stream order** (1:50,000 scale stream network)
3. **Slope** of the riffle (m/m refer to CABIN field manual)
4. **Riffle** presence/absence within the sampling reach (0/1)
5. **Bankfull width** (m)
6. **%Water** landcover - % upstream watershed with water including lakes, reservoirs, rivers (Land Cover geobase.ca)
7. **%Snow/Ice** landcover - % upstream watershed with snow or glaciers (Land Cover geobase.ca)
8. **%Wetland-Herb** landcover - % upstream watershed having wetland with shrub vegetation (Land cover geobase.ca)
9. **%Sedimentary** bedrock - % upstream watershed with sedimentary bedrock (BC Geology Maps)
10. **Precipitation in February** – 30 yr monthly precipitation averages from 1971-2001 summarised for the upstream watershed from rasterised grids (Natural Resources Canada)
11. **Temperature July Maximum** – 30 yr average of maximum July temperatures from 1971-2001 summarised for the upstream watershed from rasterised grids (Natural Resources Canada)
12. **Average %slope** of the upstream watershed – gradients generated for each grid cell in the upstream watershed based on 20 m DEMs using ArcGIS slope function.

Table 5. Discriminant Function Analysis classification and jackknifed cross-validation tables of reference site predictions to reference groups as determined by the cluster analysis (Figure 2).

Classification Matrix

	1	2	3	4	5	6	%correct	% error
1	**36**	17	0	13	0	3	52	48
2	14	**36**	0	4	7	1	58	43
3	1	0	**14**	2	0	2	74	26
4	20	11	4	**64**	5	13	55	45
5	0	2	1	0	**8**	2	62	38
6	0	2	10	11	5	**23**	45	55
Total	71	68	29	94	25	44	**55**	**45**

Jackknifed classification matrix

	1	2	3	4	5	6	%correct	% error
1	**36**	17	0	13	0	3	52	52
2	17	**33**	0	4	7	1	53	47
3	1	0	**12**	2	0	4	63	37
4	20	10	5	**60**	5	17	51	49
5	0	2	2	0	**8**	1	62	38
6	0	2	10	13	6	**20**	39	61
Total	74	64	29	90	25	48	**51**	**49**

Comparison with 2005 Fraser River/Georgia Basin model

The previous 2005 Fraser River/Georgia Basin Model was based solely on field measured variables. The revised model now includes GIS derived variables. In addition to adding new and more recent reference data to the revised model, reference sites from Vancouver Island were removed restricting the baseline to the Fraser Basin only. Consequently, differences in assessments were expected and were re-analysed. Assessments of 67 test sites were reported in Sylvestre et al. 2005, Reynoldson et al. 1999 and Rosenberg et al. 1999 and were previously assessed using the field-based 2005 model. These sites were re-assessed using the revised Fraser Basin 2014 model to examine potential discrepancies in assessments as a result of new predictors, new reference sites and the removal of Vancouver Island reference sites. Assessments that differed by more than one assessment category were considered significant. Re-analysis showed that 43% of test site assessments were unchanged and 42% differed by only 1 band indicating that the assessment results were fairly stable. 15% of assessments differed by more than 1 band and of those 7 site assessments indicated that the model was more sensitive (more different from reference than previous analysis) while only 3 site assessments indicated that the model was less sensitive (more similar to reference than previous analysis).

Table 6. DFA reference group predictions of replicated samples at 30 sites (quality assurance samples #2 and #3) to examine robustness of the model prediction. 88% of sites had the same prediction. Differences occurred where reference groups were overlapping in ordination space and the model demonstrated difficulty in making correct predictions. The probabilities of group membership were similar with overlapping groups.

Site	**QA sample #2**	**QA sample #3**
BOW03	1	1
BRU02	5	5
CHH04	4	4
CHH12	5	5
CHI05	2	2
CKO03	1 (53%), 4(27%)	4 (42%), 1 (37%)
CLA07	2	2
CLB03	5 (31%), 2 (28%), 1(26%)	1 (30%), 2 (29%), 5 (27%)
CLR06	2	1 (53.9%), next highest 2(17.9%)
ELK02	4 (31%), 6 (30%)	6 (40%), 4 (39%)
EUC03	2	2
EUC06	2	2
FRA06	2	3
FRA20	6	6
HRK11	4	4
HUN01	4	4
LIL06	3	3
NIC10	1	1
PIT06	3	3
PIT07	3	3
SAL03	2	2
STN05	1	1
STU02	2	2
TAS04	2	2
TOR01	4	4
TOR02	2	2
TYA08	4	4
UFR06	4	4
WRD12	2	2
WRD16	2	2

3. OTHER RELEVANT LITERATURE

Reynoldson, T.B., J.L. Bailey and A.G. Yates 2012. *The Development of an updated Reference Condition Approach (RCA) Model for the Fraser River Basin*, GHOST Environmental Consulting

Reynoldson, T.B. Rosenberg, D.M., and V.H. Resh. 2001. Design of a regional benthic biomonitoring programme: Development of predictive models of invertebrate community structure using multivariate and multimetric approaches in the Fraser River catchment, British Columbia. *Can . J. Fish. Aqut. Sci.* 58:1395-1410.

Rosenberg, D.M., T.B. Reynoldson and V.H. Resh. 1999. *Establishing reference conditions for benthic invertebrate monitoring in the Fraser River Catchment, British Columbia,* Canada. Fraser River Action Plan, Environment Canada, Vancouver BC DOE FRAP 1998-32.

Sylvestre, S., M. Fluegel, and T. Tuominen 2005. *Benthic Invertebrate Assessment of Streams in the Georgia Basin using the Reference Condition Approach: Expansion of the Fraser River Invertebrate Monitoring Program 1998-2002*. Environment Canada, Vancouver BC. EC/GB/04/81 194 p.

APPENDIX: DATA COLLECTION, ANALYSIS AND QUALITY ASSURANCE

1. Field Collection

CABIN Study Name	**EC-Fraser River**	**EC-Fed/Prov WQ Monitoring**	**BCMOE-Thompson Region**
Agencies involved	Environment Canada	Environment Canada	British Columbia Ministry of Environment
Date range	1994-2012	2006-2012	2007-2012
Sampling season	Sept-Oct	Sept-Oct	Sept-Oct
# reference samples	302	2	27
# QA samples (spatial QA)	30	0	0
# revisited sites (temporal QA)	27	1	4
Certified samplers (Y or N)	Y	Y	Y
400 um kicknet (Y or N)	Y	Y	Y
Preservative used	10% buffered Neutral Formalin	10% buffered Neutral Formalin	Ethanol or Formalin

2. Macroinvertebrate Identification

CABIN Study Name	**EC-Fraser River**	**EC-Fed/Prov WQ Monitoring**	**BCMOE-Thompson Region**
Taxonomist	Environment Canada, (1994-2005) Cordillera Consulting (2006, 2008, 2009) EcoAnalysts (2007, 2010)	Environment Canada, (2001-2005) Cordillera Consulting (2006, 2008, 2009) EcoAnalysts (2007, 2010)	Fraser Environmental Cordillera Consulting (2007-2010)
Marchant Box used (Y or N) or Other Sampling Device (specify)	Y	Y	N, Caton Tray
Subsample count	200 (1994-2001) 300 (2002-2010)	200 (2001) 300 (2002-2010)	300
10% of reference samples sent to National Lab for QA	Y (2006-2010)	Y (2006-2010)	N
Reference Collection maintained	Y	N	N

3. GIS Analyses

All GIS data were generated by Adam Yates (University of Western Ontario). Watersheds were delineated using ArcGIS 10 ArcHdyro 2.0 (ESRI 2010). Delineations were based on 20 m resolution digital elevation models (DEM) and a 1:50,000 scale hydrological network. The DEM was subjected to pre-processing which "burned in" the stream network into the DEM and filled sinks to improve flow modeling. The corrected DEM was used to calculate flow direction and flow accumulation to carry out the terrain procession steps to model catchment areas (AcrHydro 2010). The delineated catchments were described using the GIS layers in the table below collected from publicly available sources.

Descriptor	***Scale/ Resolution***	***Source and method***
Basin Morphometry	*20 m*	*Area and perimeter were calculated from delineated catchments as described above*
Bedrock	*1:100,000*	*BC Ministry of Energy and Mines – BC Digital Geology Maps 2005 - http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/DigitalGeologyMaps/Pages/default.aspx* *Intersected with catchment boundaries using intersect function in ArcGIS (ESRI 2010)*
Climate	*7.5 km*	*Natural Resources Canada (contact: Dan McKenney – dan.mckenney@nrcan-rncan.gc.ca)* *Summarized using rasterized grids describing temperatures normal from 1971-2001 giving long term monthly and annual averages of temperature and precipitations. Grids were used to generate average, minimum and maximum values for each catchment using Geospatial Modelling Environment v. 0.6.0.0 (Beyer 2012). Where catchments were completely contained within one grid cell, catchments were assigned the value of that cell.*
Hydrology	*1:50,000*	*www.geobase.ca – National Hydro Network* *Intersected with catchment boundaries using intersect function in ArcGIS (ESRI 2010)*
Land Use	*1:2,000,000*	*www.geobase.ca – Land Cover* *Intersected with catchment boundaries using intersect function in ArcGIS (ESRI 2010)*
Topography	*20 m*	*www.geobase.ca – Digital Elevation Data* *Described using 20 m DEM and the Geospatial Modeling Environment v. 0.6.0.0 (Beyer 2012) to describe the maximum and minimum elevation in each catchment. Percent slope was generated from the DEM using the slope function in ArcGIS (ESRI 2010) and classified into one of four groups based on the slope value for each grid cell (i.e. <30%, 30-50%, 50-60%, >60%). Areas of each class within each catchment were then calculated.*

4. Laboratory Analyses

Laboratory analyses for nutrients, major ions, chlorophyll-a, periphyton biomass, particle size distribution, and total suspended sediment are stored in CABIN but are not used as predictors in the development of the model. Nutrient and major ion analyses were conducted at Environment Canada's National Laboratory for Environmental Testing (1994-1996) and the Pacific Environment Science Centre (2001-2010). Chlorphyll-a and periphyton biomass were analysed by the Freshwater Institute in Winnipeg (1994-2001). Particle size distribution of interstitial sediment samples were measured by Environment Canada's National Laboratory for Environmental Testing (1994-2001). Total suspended sediments were filtered, dried and weighed by project staff.

5. Statistical Analyses

Several software packages were used in the development of the Fraser model.

1. Excel- data manipulation and storage
2. PATN V.3.12 - classification and ordination of test sites for assessment
3. PRIMER 6 - classification, MDS ordination, ANOSIM, SIMPER
4. SYSTAT 13 - discriminant analysis and plotting BEAST assessments with probability ellipses

The model was reviewed by CABIN Science Team APRIL 2014