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A geospatial model for characterizing the fish resources of the Similkameen River, British Columbia, Canada

Research Article

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ABSTRACT

A geospatial model was been developed in order to rapidly characterize fluvial geomorphological features associated with the fish resources in a river system. The model uses four easily-quantified geospatial attributes – channel width, plan view sinuosity, longitudinal slope and fractal dimension – for classifying a stream channel into geomorphic response units (GRUs), which are the key working elements of the geospatial model used in this work. Using the geospatial model, a total of five GRUs were defined along the river channel. The model framework was tested using data from a 1983 fish survey conducted along the Canadian portion of the Similkameen River. Five fish species were sampled in that survey: rainbow trout, mountain whitefish, sculpin, longnose dace and bridgelip sucker. A hierarchical clustering analysis was conducted using the fish survey data, with good correlation being observed between the fish data clusters and geospatial model GRUs. It is concluded that, on the basis of the work reported herein, the geospatial modelling approach provides a simple, rapid tool for a priori classification of the fish resources in a stream.

Keywords
geospatial model, geomorphic response unit, Similkameen River

1.0 Introduction

Watershed ecosystems have been experiencing ever-growing pressure due to human activities. Effective management of riverine systems have become a challenging but imperative task. Adequately addressing this challenge requires expertise and a significant amount of data. Multidisciplinary expertise is essential for river management to understand river behaviour, dynamics and change (Charlton, 2007). Moreover, river system assessment generally depends on labour intensive field surveys. However, in many cases, such surveys are not practical. The development of simple, inexpensive, and rapid river classification techniques would support a wide range of river management decisions to overcome these barriers.

Over the last few decades, ongoing efforts have been dedicated to bridging ecosystem processes and geomorphology, due to the wide recognition of the fundamental role physical process plays upon biotic structure and function (Renschler et al., 2007; Zavadil and Stewardson, 2013). The channel geomorphology and the hydrology of a river system constitute the physical habitat for riverine biota. The quality and availability of physical habitat is a key driver in determining the composition of in-stream species (Maddock et al., 2004). Therefore, fluvial geomorphology can be viewed as an important determinant of ecological processes in a stream (Lindenschmidt and Long, 2013). Understanding the geomorphic pattern of a river system can influence effective biodiversity conservation and habitat restoration measures, support prediction and assessment of river health, and facilitate cross-disciplinary research as well as the integration of research and management.

With the understanding that a river network is composed of arrays of hydrogeomorphic zones defined on the basis of their hydrological and geomorphic properties (Thorp et al, 2006), a number of geomorphic classification schemes have been proposed. Rosgen (1994) created a classification system based on channel slope, sinuosity, width/depth ratio, substrate size, and degree of valley confinement, deriving 41 stream types. Frissell et al. (1986) proposed a framework for stream habitat classification that presented the hierarchical organization of a river system downscaling from the stream segment level, to the reach level, to the pool/riffle unit level, and finally to the microhabitat level. However, these early schemes, being pioneers highlighting the profound relationship between geomorphology and ecosystem ecology, are mostly qualitative and subjective. Recent developments in geospatial databases (e.g. digital elevation models and satellite images), coupled with the advancement of sophisticated spatial analysis tools (e.g. GIS) and data-mining techniques have enabled researchers to quantitatively develop methods to link geomorphology with ecology (e.g. Bizzi and Lerner, 2012; Meixler and Bain, 2012; Collins et al, 2013). Notably, Thorp et al. (2006, 2010) have developed a GIS-based model incorporating many morphological and flow variables to classify the functionally and structurally similar hydrogeomorphic patches of a river, termed Functional Process Zones (FPZ). The FPZ framework provides useful tools for characterizing river landscapes.

This study presents a method, created by Lindenschmidt and Long (2013), for rapid classification of riverine habitat by identifying geomorphic response units based on the theoretical framework of the Geomorphologic Instantaneous Unit Hydrograph (GIUH), initially proposed by Rodriguez-Iturbe and Valdes (1979). This method derives typologies from the main geomorphic characteristics of the fluvial system: longitudinal gradient or slope, width, plan view sinuosity, and fractal dimension. The longitudinal slope of a channel is one of the main driving forces of river geomorphic processes. Channel width reflects the confinement of a stream to fluvial forces. Finally, both sinuosity and fractal dimension represent erosion/deposition processes in response to fluvial forces, but on a different scale, with the latter being on a larger or macro scale. The longitudinal length of the river is divided into segments for characterization of geomorphic features. To remove redundancy resulting from the correlation amongst geomorphic features, factor analysis (i.e. principal component analysis) is applied to derive typologies, which captures distinct combinations of geomorphic features. Patterns of typology clustering are assessed using spatial statistics. These clusters are termed geomorphic response units (GRUs).

The collection of precise hydrological and ecological data usually necessitates the conduction of expensive and time-consuming surveys. With the GRU method, all of the geomorphic features are readily extractable from the geospatial raster or vector files of a river, which makes the GRU method a simplified and rapid tool to reductively classify the functional processes of a riverine network. Furthermore, the GRU method also eliminates the subjectivity of river classification. Detachment for empirical classification improves the transferability and generalization of the model to other stream systems.

This study reports on the classification of the Similkameen River, which is a gravel-bed river in British Columbia, Canada. The GRU method has been used to rapidly characterize fluvial geomorphological features associated with the fish resources in the river system. The distribution of fish assemblage is influenced by the longitudinal changes of river attributes (Walters et al., 2003; D'Ambrosio et al., 2009). Hence, the resultant GRUs were related to fish composition data from a 1983 fish survey conducted at 26 sites along the river, in an attempt to link geomorphology to biota. This study has two objectives: i) to identify different habitat units in the Similkameen River by developing a GRU model; and ii) to verify the representativeness of the GRUs using historical fish habitat survey data.

2.0 Study Site

The Similkameen River, located in southern British Columbia (BC), Canada, is being used as a case study. Originating in the Cascade Mountains, the Similkameen River flows northeasterly from its source, through Manning Park to the Town of Princeton, and then southeasterly to its confluence with the Okanagan River near the City of Oroville in the United States (U.S.A.) (Talayco, 2011). Its total length is 198 kilometers. Soil conditions in the watershed have restricted agricultural activity to the valley bottom. The timber industry is a mainstay of the economy in this region, while ranching and commercial orchard have been historically important (Talayco, 2011). Mining of copper, gold silver, lead, zinc and low-sulphur thermal coal used to take place in the Princeton and Tulameen areas, but most has been closed (Hamilton, 2011). Urbanization in the valley is comparatively less significant (Talayco, 2011).

The Similkameen River watershed includes three of the four rare and significant biogeoclimatic zones in BC (GMA, 2010a). The tributaries and main stem of the Similkameen River provide an approximately 500 kilometers length of fish habitats (GMA, 2010b). Many fish species are endemic to this area (Rosenfeld, 1996). The Canadian part of the river has one natural fish barrier, which is the Similkameen Falls, in the Copper Mountain area immediately downstream of the confluence with the Pasayten River (Rae, 2005). The productivity of aquatic life in the stream, however, is significantly restricted by low nutrient content and cool water temperatures (Rae, 2005). Human effects have increased with the rapid growth of population in this area. Fish production has been significantly impacted in the past 150 years and quality fish habitat is at risk of being damaged or lost (Rae, 2005). Seventeen fish species are known to exist in the river, four of these species are under threat. Umatilla dace (Rhinichthys umatilla) is on the provincial red list, which designates species that are, or are soon to become, threatened or endangered. Chiselmouth (Acrocheilus alutaceus), Columbia sculpin (Cottus hubbsi) and mountain sucker (Catostomus platyrhynchus) are blue-listed for their vulnerability to human or natural impacts (Rae, 2005).

3.0 Methods

3.1 River geomorphic variables

The geomorphic variables of the Similkameen River were derived using data from the 1:50,000 scale CanVec database and 1:50,000 Canadian digital elevation model (CDEM) data. CanVec data are digital carto-

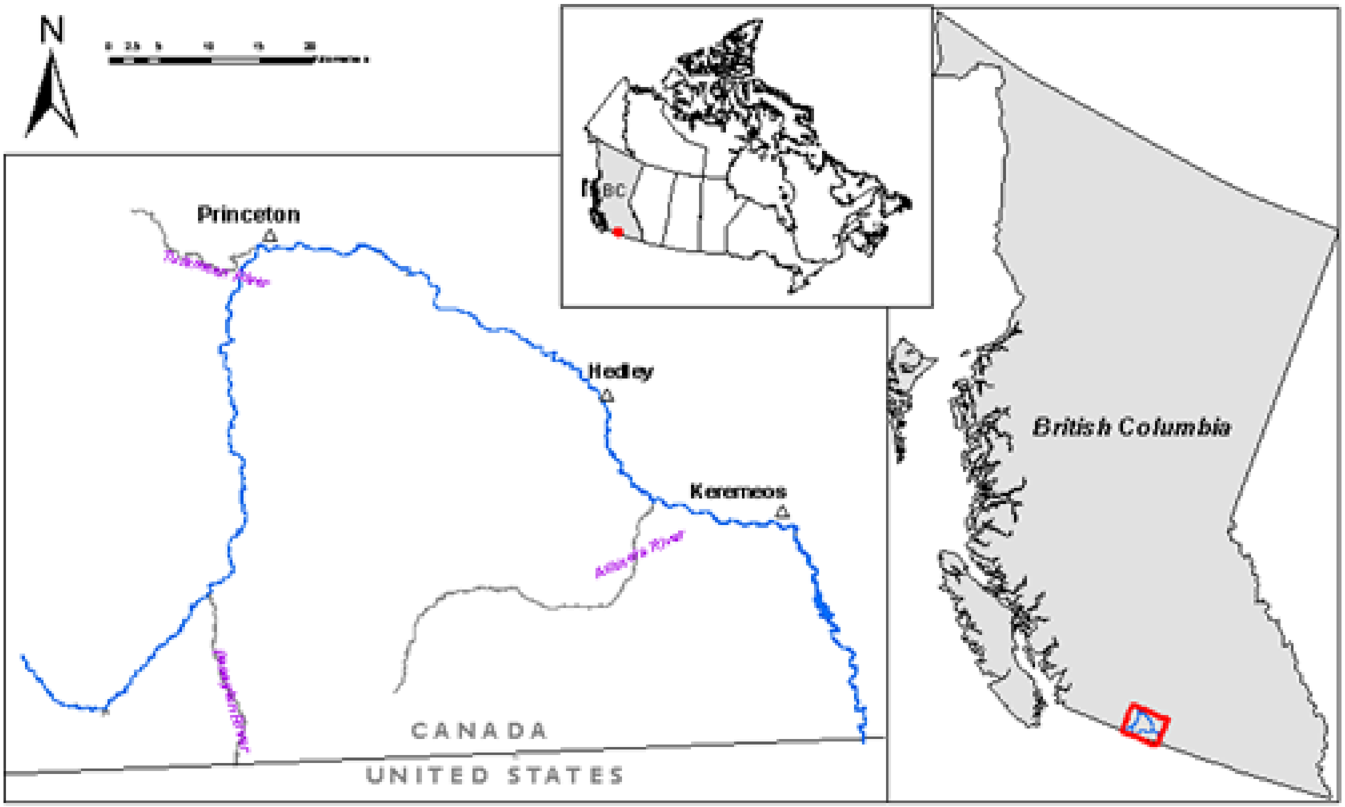

Figure 1. Schematic map of the Similkameen River.

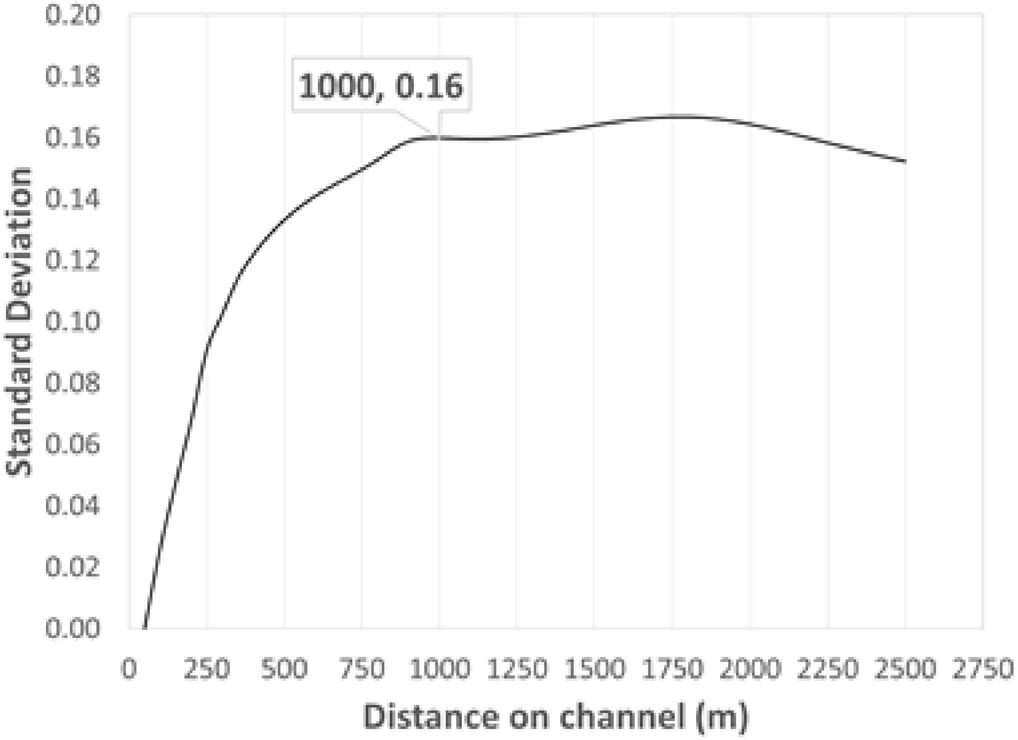

Figure 3. Stream delineation in GIS.

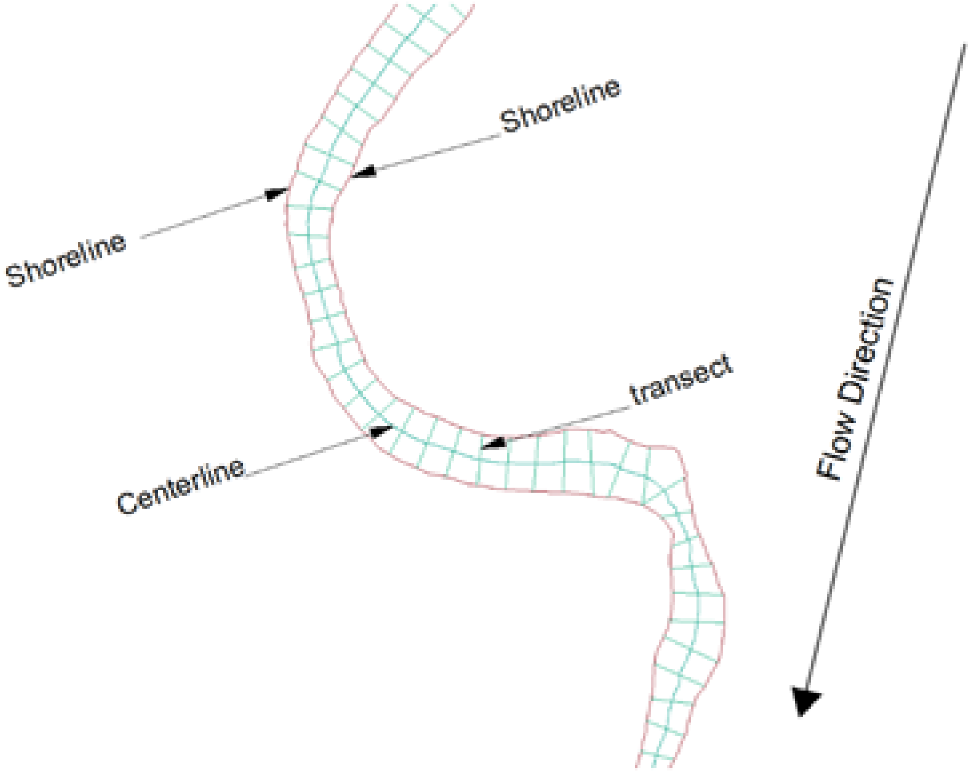

Figure 2. Stream delineation in GIS.

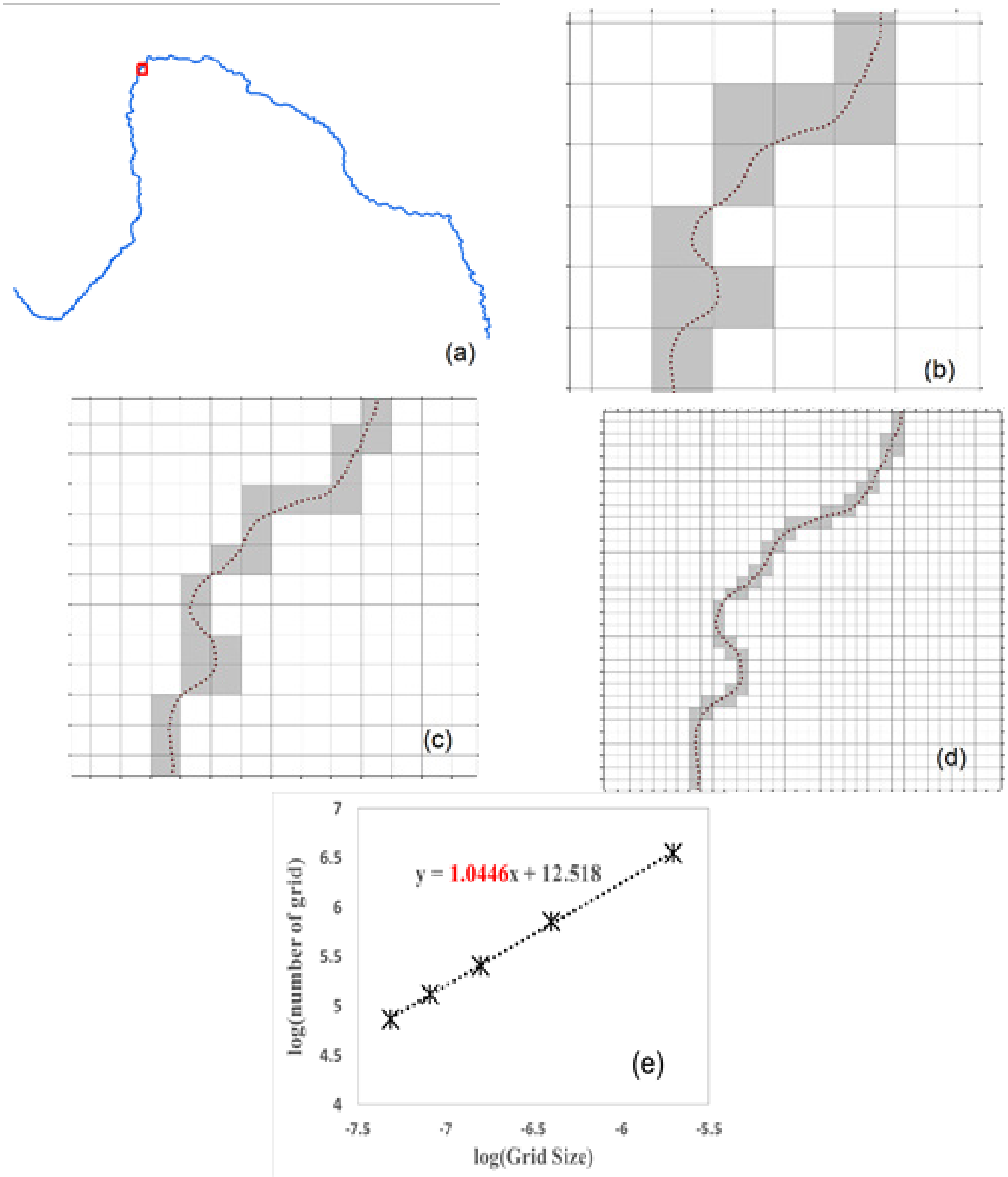

Figure 4. Calculation of a fractal dimension calculation using the box-counting method: (a) Moving window over the stream channel; (b), (c) & (d) Box counting for different grid sizes; (e) An example of the trendline plot showing a fractal dimension of 1.0446.

graphic reference maps produced by Natural Resources Canada (downloadable from http://www.geogratis.ca/) from best available topological data, which have been updated using satellite imagery. The hydrograph theme of the CanVec dataset was used to delineate the river shapefile in ArcGIS (ESRI, 2013). CDEM data are also produced by Natural Resources Canada and were downloaded from the GeoGratis database.

A centerline was added to the river shapefile, on which stations were created at 50 metre intervals. A transect

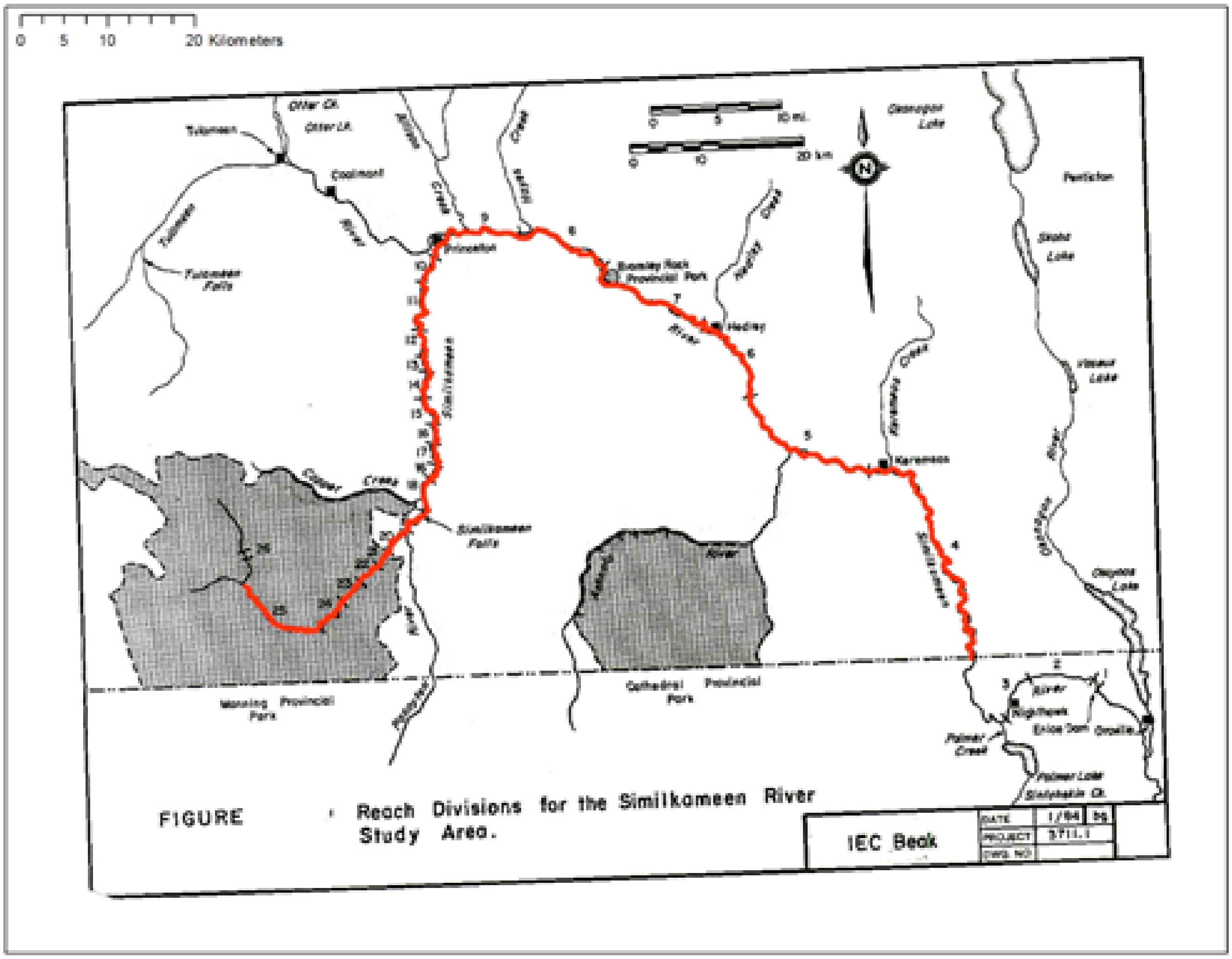

Figure 5. Geo-referenced map of the fish survey from the IEC Beak (DoE, 1984) report. The red line indicates the location of the river channel.

2013). Since a thalweg profile is not available for the Similkameen River, the plan view sinuosity was used in this study. It denotes the degree of meandering of a stream and was derived from the ratio of the actual channel length to the shortest distance between the starting and ending points of a river reach (Lindenschmidt and Long, 2013). It is a dimensionless variable. Sinuosity has a value greater than unity (i.e., larger values of sinuosity correspond to a greater degree of stream meandering). The length of each reach was chosen as the length when standard deviation stabilized (Figure 3). For sinuosity, this corresponded to a reach consisting of 20 consecutive segments (channel distance of 20 × 50 m = 1 km) upstream of each centerline station.

Longitudinal slope was derived by capturing the elevation of the land surface nearest to the centerline stations from the DEM data. It was calculated by subtracting the elevation of a downstream point by the elevation of its upstream neighbor, and then dividing it by the distance between them. It is a dimensionless variable.

Fractal dimension is used to depict the meso-scale morphological feature of a stream in terms of the complexity of its shape. In essence, it describes the tortuosity of the river on a larger surficial geological scale than is otherwise given by sinuosity. It is a dimensionless variable. There are various algorithms for calculating fractal dimension (Dubuc et al., 1989); the box-counting method was applied in this study (Kenkel and Walker, 1996). As shown in Figure 4, the box-counting method was applied by covering an area with a box (or grids) of various sizes as a ‘moving window’ along the river reach, after which the number of boxes containing at least one centerline station was counted. The logarithm values of the count within each box were then plotted against the logarithmic values of the grid size corresponding to each count. An estimation of the fractal dimension is given by the slope of the trend-

reach number	rainbow trout	whitefish	sculpin	dace	sucker
4	0.7	161.0	2.2	1.2	108.0
5	0	0	5.4	0.6	0
6	1.2	41.2	4.5	1.6	75.0
7	2.7	25.9	0.6	0	22.9
8	0	324.0	0.1	0	2059.4
9	27.1	2227.5	1.2	0.1	579.2
10	3.0	661.5	1.9	0.4	0
11	1.4	330.8	1.2	0.2	0
12	57.8	117.6	9.5	1.3	0
13	3.6	51.8	2.9	0	4.1
14	6.3	33.6	2.9	0	0
15	0	0	1.7	0	0
16	0.9	19.3	1.7	0	0
17	0.9	19.3	3.4	0	0
18	0.6	0	2.3	0.1	0
19	0.7	0	3.2	0	0
20	1.0	0	0	4.7	0
21	3.1	0	0	1.2	0
22	6.8	0	0	0.7	0
23	2.2	0	0	0.9	0
24	0.9	0	0	0	0
25	7.8	0	0	0.8	0

Table 1. Fish composition data of the Similkameen River Fish in kg/ha derived from Table 4-9 of the IEC Beak report (DoE, 1984).

line of this plot. In this study, the size of the moving window was determined to have a size of 8 km × 8 km to maximize the range of fractal dimension values.

3.2 Geomorphic typologies

The geomorphic variables at each centerline station were grouped into geomorphic typologies using the Principal Component Analysis (PCA) method. PCA reorganizes information from a set of variables by linearly transforming it into uncorrelated factors, each of which represent the maximal portion of total variance of the variables (Wackernagel, 2003). The factors, termed principal components (PCs), are the linearly transformed eigenvectors of the dataset that are orthogonal to each other. The first component (PC1) represents the most variation and each ensuing component depicts a decreasing portion of the remaining variance. The geomorphic variables were centered and scaled in this analysis. Centering was done by subtracting the means of the variables from their original values; scaling was done by dividing the centered values by their standard deviations. A value called the component score was produced for each component for each cen-

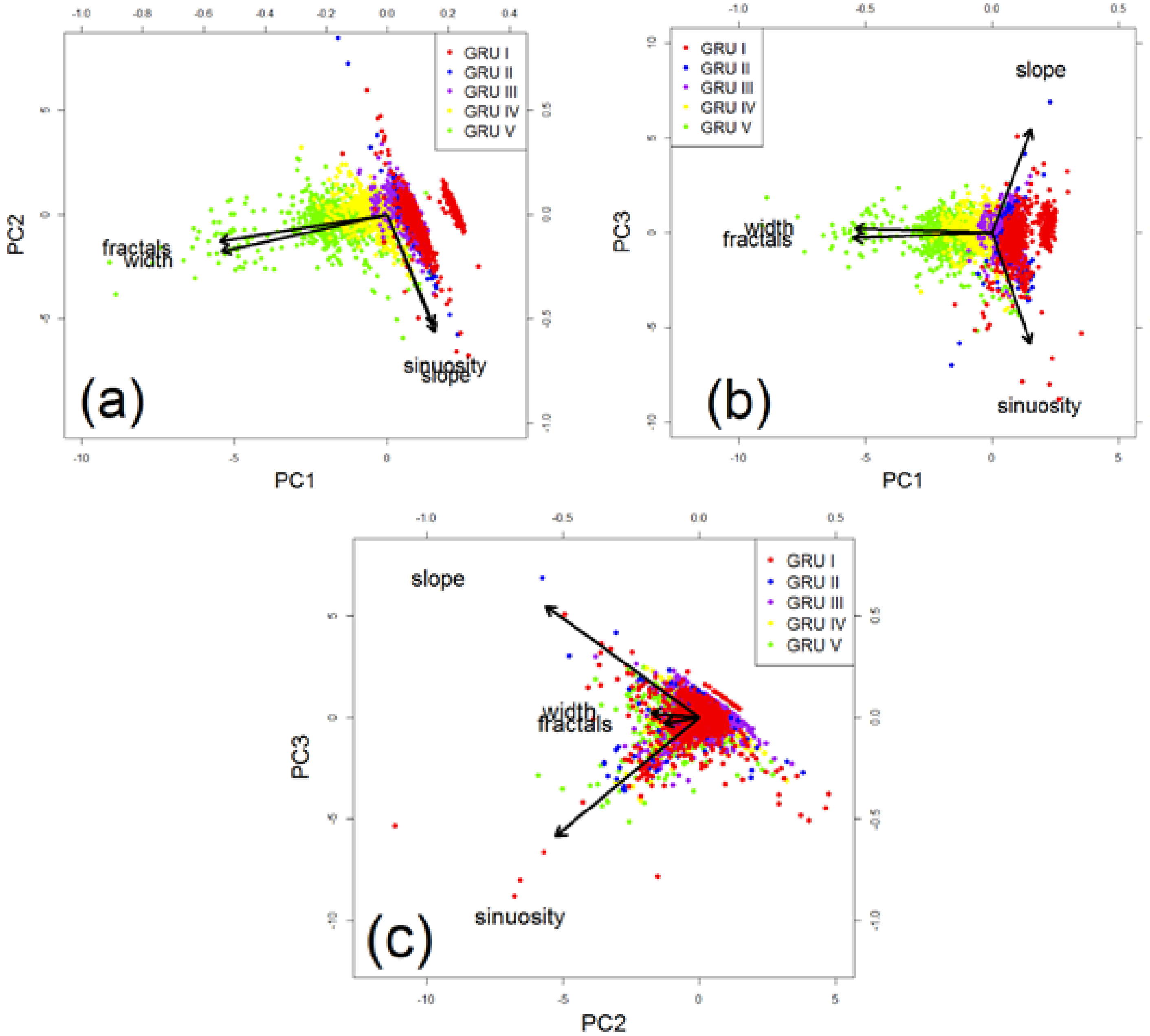

Figure 6. PCA biplots with three variables displayed over x-axis vs. y-axis of: (a) PC1 vs. PC2; (b) PC1 vs. PC3; and (c) PC2 vs. PC3. Data of the five GRUs are displayed in different colors.

	sinuosity	slope	fractal dimension	width
PC1	0.189	0.193	**-0.685**	**-0.677**
PC2	**-0.657**	**-0.702**	-0.161	-0.221
PC3	**-0.729**	**0.682**	-0.035	0.027

Table 2. Correlation coefficients between variables and principal components.

terline station. Component scores denote the variability for each location explained by a single component.

3.3 Geomorphic response units

The Autocorrelation Moran's I test in the Spatial Statistics tools of ArcGIS 10.2 was applied to assess the clustering tendency of the geomorphic typologies. The result, namely Moran's Index = 0.99, z = 60.89, p = 0.0000, indicates a less than 1% likelihood that the clustering pattern could be the result of random chance. A k-means map grouping analysis was then applied to the component scores of the first three principal components to identify the channel areas exhibiting similar geomorphological features. The number of GRU groups was determined by comparison of the values for pseudo-F statistics at different group numbers.

3.4 Fish data

Although fish and fish habitat survey data are rare for the Similkameen River, a study conducted by IEC Beak Consultants in 1983 (DoE, 1984) provides records of the standing crop that were used in this study as an indication of the river's fish resources. This survey followed the British Columbia Fish and Wildlife Branch methodology (de Leeuw, 1981) to sample rainbow trout (Oncorhynchus mykiss), mountain whitefish (Prosopium williamsoni), sculpins (Cottus sp.), longnose dace (Rhinichthys cataractae), and bridgelip suckers (Catostomus columbianus). Based on stream slope, the survey divided the main stem of the Similkameen into 26 reaches, of which reaches No. 4 to No. 25 correspond to the area studied in this paper (Figure 5). One of the two sampling techniques was applied at a representative site depending on prominent hydraulic features: electrofishing was employed in shallow reaches of the stream while snorkeling was conducted in deeper areas. The standing crop values for all fish species caught were calculated by dividing the total weight of the fish species by the total sampled area. Fish biomass in kilograms per hectare was derived from the number of caught/counted fish and the survey area, which is summarized in Table 1. An average was taken for reaches with multiple sample sites.

The fish data were geo-referenced in ArcGIS for subsequent analysis in the geo-spatial model. A hierarchical cluster analysis, based on the Bray-Curtis similarity coefficient, was conducted on the data using R-language (Team, 2013). Based on the cluster dendrogram, reaches of the same cluster were plotted in ArcGIS onto the river channel.

4.0 Results and Discussion

4.1 Principal component analysis (PCA)

The principal components derived from the PCA on the dataset containing all four variables (width, sinuosity, slope and fractal dimension) explained 41.4%, 24.6%, 24.2%, and 9.8% of the variance, respectively. As shown in Figure 6, fractal dimension and channel width appear to be correlated, which indicates that the distribution of the vector space could be well explained by three rather than four principal components. Therefore, consideration is given to the first three principal components (i.e. PC1, PC2, and PC3) in the subsequent analysis; together they explain 90% of the variance.

Geomorphic Response Units (GRUs) were identified based on the clustering patterns of the first three principal components over the entire river reach. This was conducted using the Group Analysis in the Spatial Statistics tools of ArcGIS 10.2. Pseudo F-statistics spiked at two and five (Figure 7). The group number of five was selected to better illustrate the variability between reaches.

The PCA scores of the channel centerline points in Figure 6 are color-coded according to the GRU group to which they belong. Figure 6a present the data with PC1 as the x-axis and PC2 as the y-axis. As PC1 increases with decreasing width and fractals, the GRUs display a pattern of clustering as the river goes downstream. GRU-I has the lowest width and fractals, followed sequentially by GRU-II, III, IV, and V, where the latter has the highest values. The GRU clusters on Figure 6b (PC1 as the x-axis and PC3 as the y-axis) and Figure 6c (PC2 as the x-axis and PC3 as the y-axis) exhibit less clear patterns. As PC3 is positively related to slope and negatively to sinuosity, features of the GRUs can be investigated by combining these two biplots. PCA scores above the line perpendicular to the vector of slope correspond to steeper sections of the channel (steep zone, Figure 8), and vice versa. Those above the line perpendicular to the vector of sinuosity correspond to straighter sections (straight zone, Figure 8), and vice versa. Figure 8 demonstrates an example for the biplot from Figure 6b. A large proportion of scores from GRU-I appears to fall in the steep zone, but it also contains several flat portions. Most scores from GRU-V fall in the flat zone. GRU-II, III, and IV display varying slopes. As for sinuosity, the majority of scores from GRU-I lies in the sin-

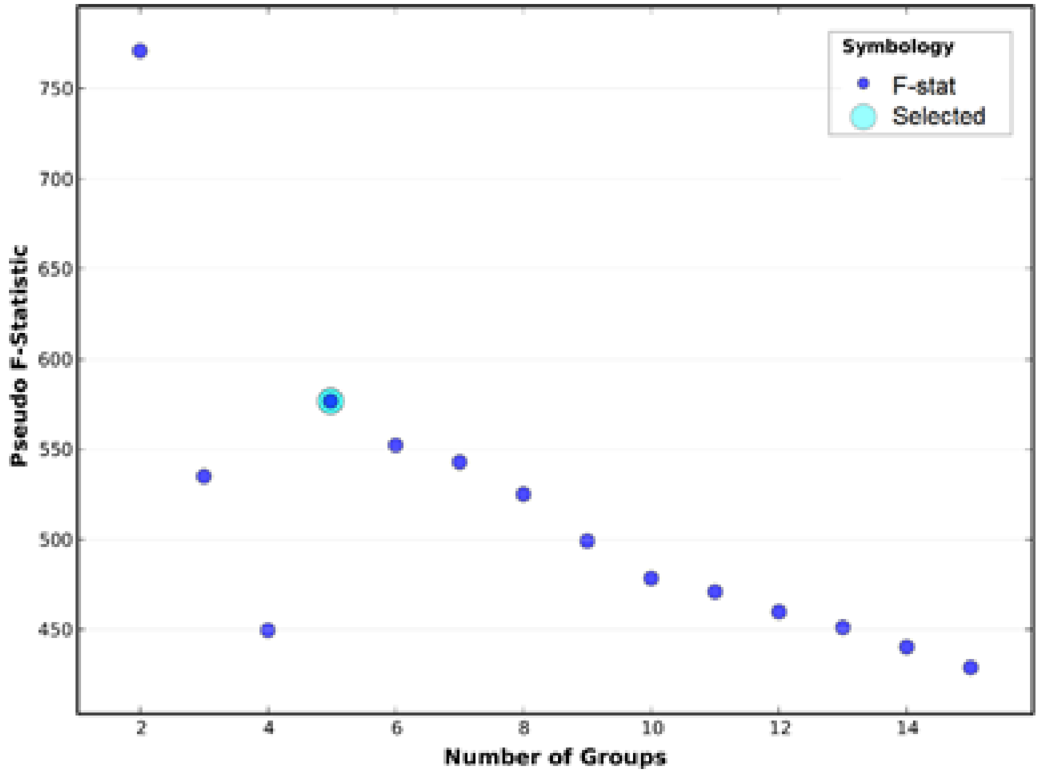

Figure 7. Pseudo F-statistics for different group numbers in the cluster analysis.

uous zone, while GRU-III, IV, and V have more points in the straight zone. GRU-II again displays a mixture.

As shown in Figure 9, GRU-I is found in the upper headwaters of the river where the stream is narrow, steep, and has low fractal dimension and low sinuosity (Figure 10a). GRU-II is located immediately downstream of the confluence of one of its major tributaries, the Pasayten River. This portion of the river is narrow but has varying level of gradient and meandering (Figure 10b). GRU-III consists of a relatively long portion of the river, where the river becomes wider and flatter than the upper stream and has a mix-

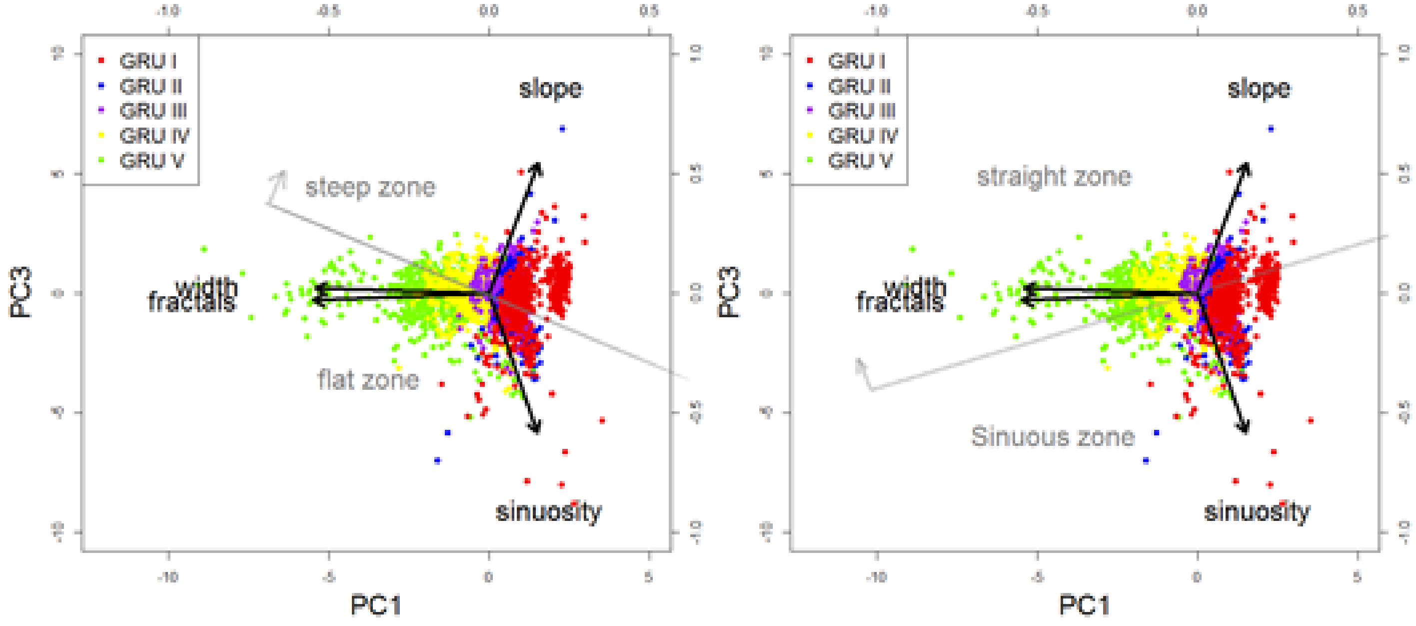

Figure 8. Biplot of PCA scores as shown in Figure 6b and Figure 6c with perpendicular lines to variable vectors indicated.

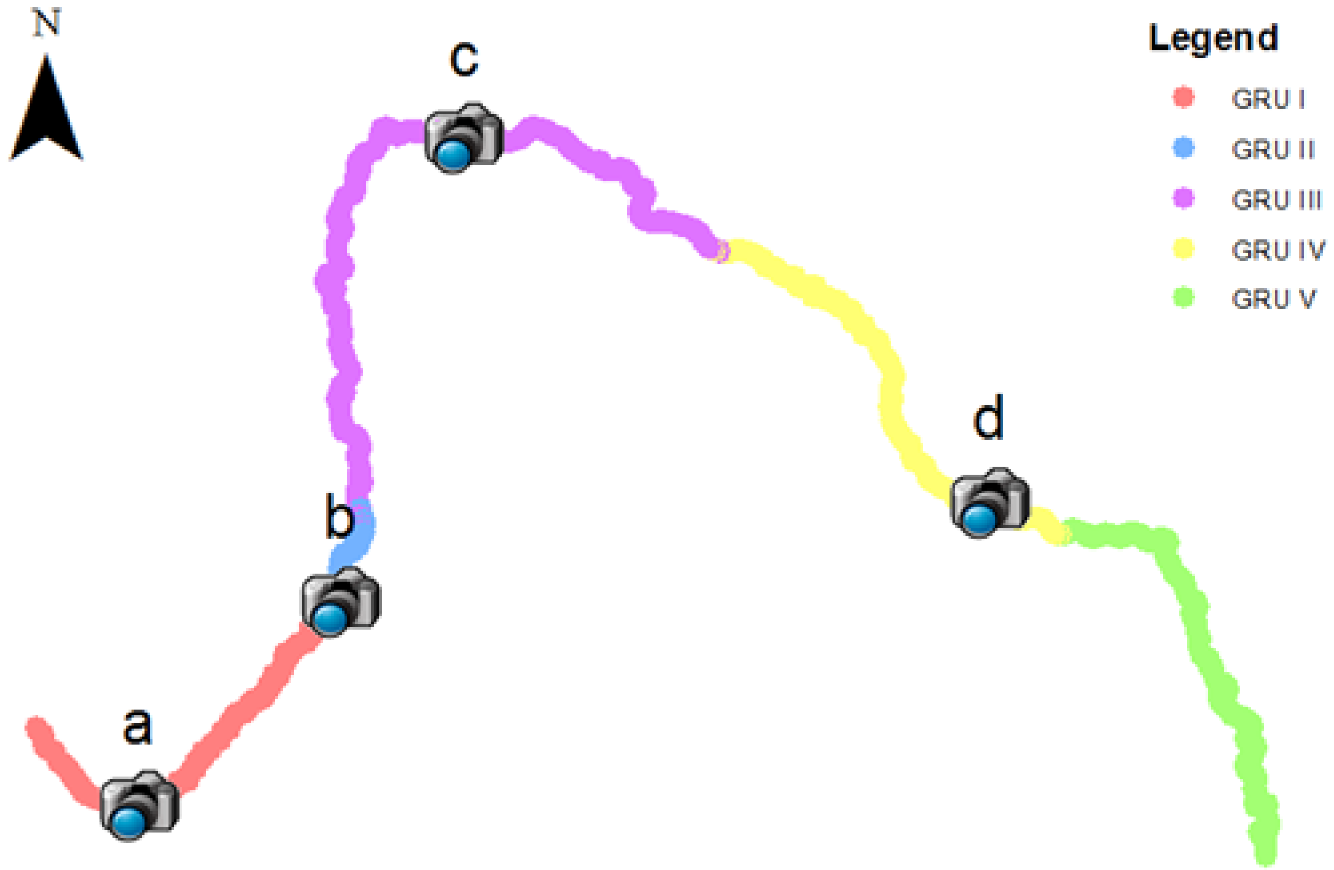

Figure 9. Geomorphic Response Units (GRUs) along the Similkameen River. The camera symbols indicate locations of the photos in Figure 10.

ture of flat and steep sections (Figure 10c). The river channel in GRU-IV is wide and relatively straight but with varying slope (Figure 10d). The geomorphology of GRU-V is wide, straight and flat, interspersed with high slope and sinuous sections. This is the most downstream section of the river within Canada.

4.2 Fish resources data

A hierarchical cluster analysis of fish composition within the different reaches sampled was conducted (Figure 12). The cutting-point in the dendrogram was chosen to be 0.83, which renders five clusters (Figure 12, blue boxes). similarity coefficient. The purple line shows the division of the fish composition clusters.

The fish data clusters were plotted on the river channel and juxtaposed with the GRU plot (Figure 13). The comparison shows that the GRUs correlate quite well with the middle clusters (corresponding to IEC Beak reach numbers 8, 9, 10, 11), lower downstream area clusters (IEC Beak reach number 4) and headwater clusters (IEC Beak reach numbers 17 to 25). However, the GRU analysis has missed some of the variability in the upper middle reaches of the stream (IEC Beak reach numbers 12 to 16). These reaches have the highest biomass of fish along the surveyed section of the river and are likely influenced by habitat features not represented by the geomorphic features evaluated. Important features within this reach, not evaluated in the GRU model, include Similkameen Falls and the confluence with the Tulameen River (Figure 5). Moreover, the geographical scales of the biomass observations and the derivation of the geomorphic features of the stream are quite different. There may therefore be mesohabitat features (e.g., pool-riffle sequences) that influence fish species composition and biomass at a finer resolution than that evaluated using the selected geomorphic features. Nevertheless, the overlap in the classification results of the GRU model and fish biomass data is fairly good.

The distribution and biomass of the fish sampled by IEC Beak align with the pattern one would predict based on the habitat characteristics of the GRU units and general habitat preferences (McPhail and McPhail, 2007) of the dominant fish species in the Similkameen River (mountain whitefish, Prosopium williamsoni,

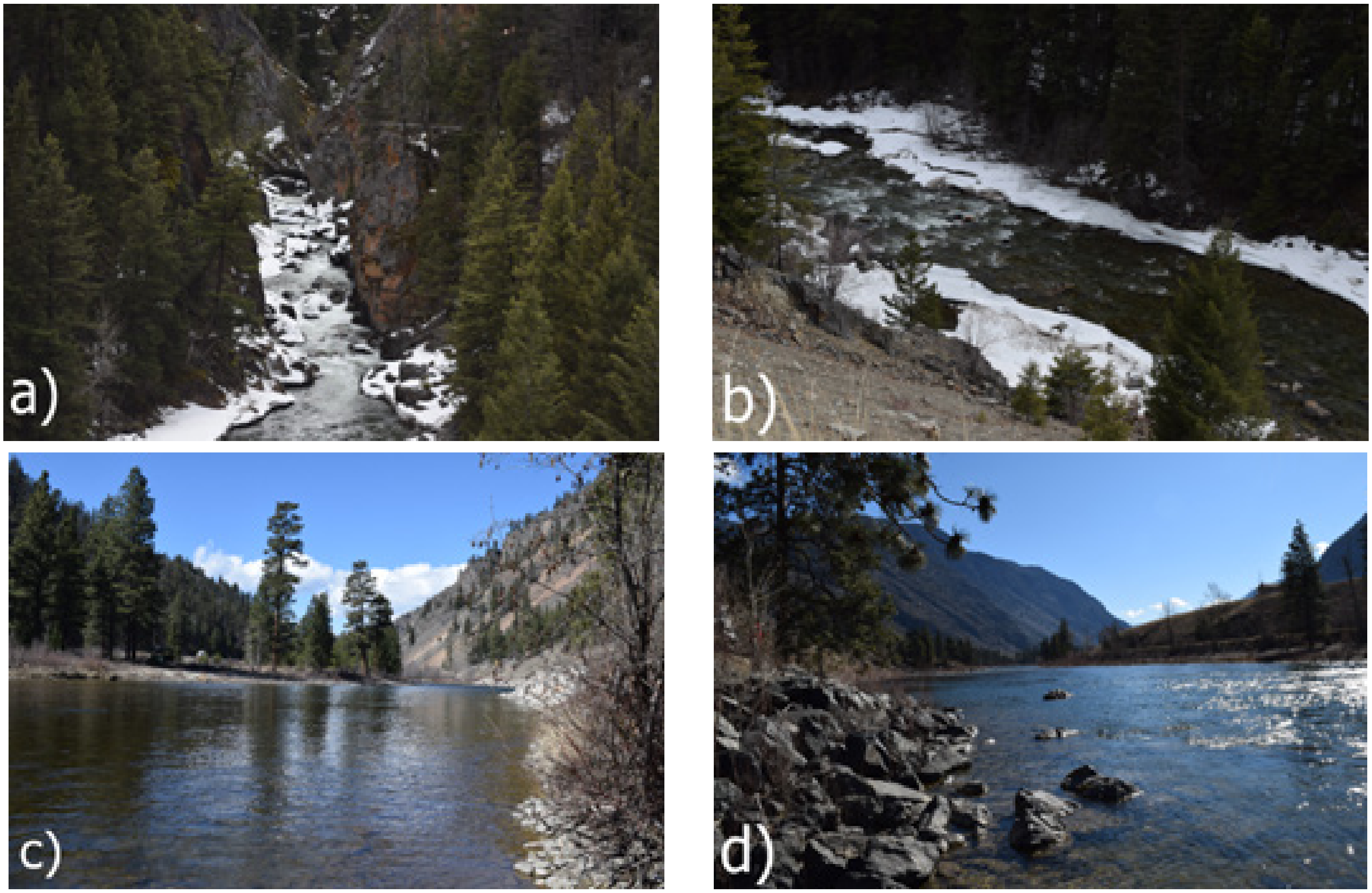

Figure 10. Photographs at various locations within selected GRUs.

bridgelip sucker, Catostomus columbianus, rainbow trout and longnose dace, Rhinichthys cataractae) (Rae, 2005). For example, rainbow trout and longnose dace dominate the steep headwaters section of the river (GRU I) where shallow, riffle habitat with high water velocities is expected to predominate based on the gradient and drainage area. Further downstream, in the steep but narrower GRU III, mountain whitefish dominate, as one would expect based on their preference for deeper water than both rainbow trout and longnose dace. Further downstream, below the confluence with the Tulameen River, there is a preponderance of bridgelip sucker that prefer the low gradient habitat that characterizes the lower reaches of the river.

4.3 Performance of the GRU classification method

The Similkameen River remains relatively intact in terms of channel modification (Moore el al., 2004), therefore natural flow and erosion effects remain the main mechanisms determining river morphology (Hamilton, 2011). The hydrologic regime of the watershed is mainly determined by snowmelt, which is illustrated by the spring freshet between May and July, contrasting to the low flows in summer when little precipitation coincides with less snowmelt (GMA, 2010a). Low flows and warm water temperatures during summer are limiting factors for fish growth and productivity. The BC Ministry of Environment uses the flow corresponding to 20% of the mean annual discharge as the criterion for evaluating instream-flow sensitivity (Hamilton, 2011). They found that most tributary streams of the Similkameen River are flow-sensitive for fish during the July-October period (Hamilton, 2011). Therefore, fish productivity in the Similkameen River has been relatively low, especially in the summer period when irrigation demands and fish spawning peak coincidently (Rae, 2005). As one of the biodiversity hotspots in Canada, the Similkameen River is known to be rich in wildlife diversity. Understanding the characteristics of fish distributions is critical for effective management and conservation of the riverine ecosystem. The GRU model can facilitate resource management by identifying meaningful spatial

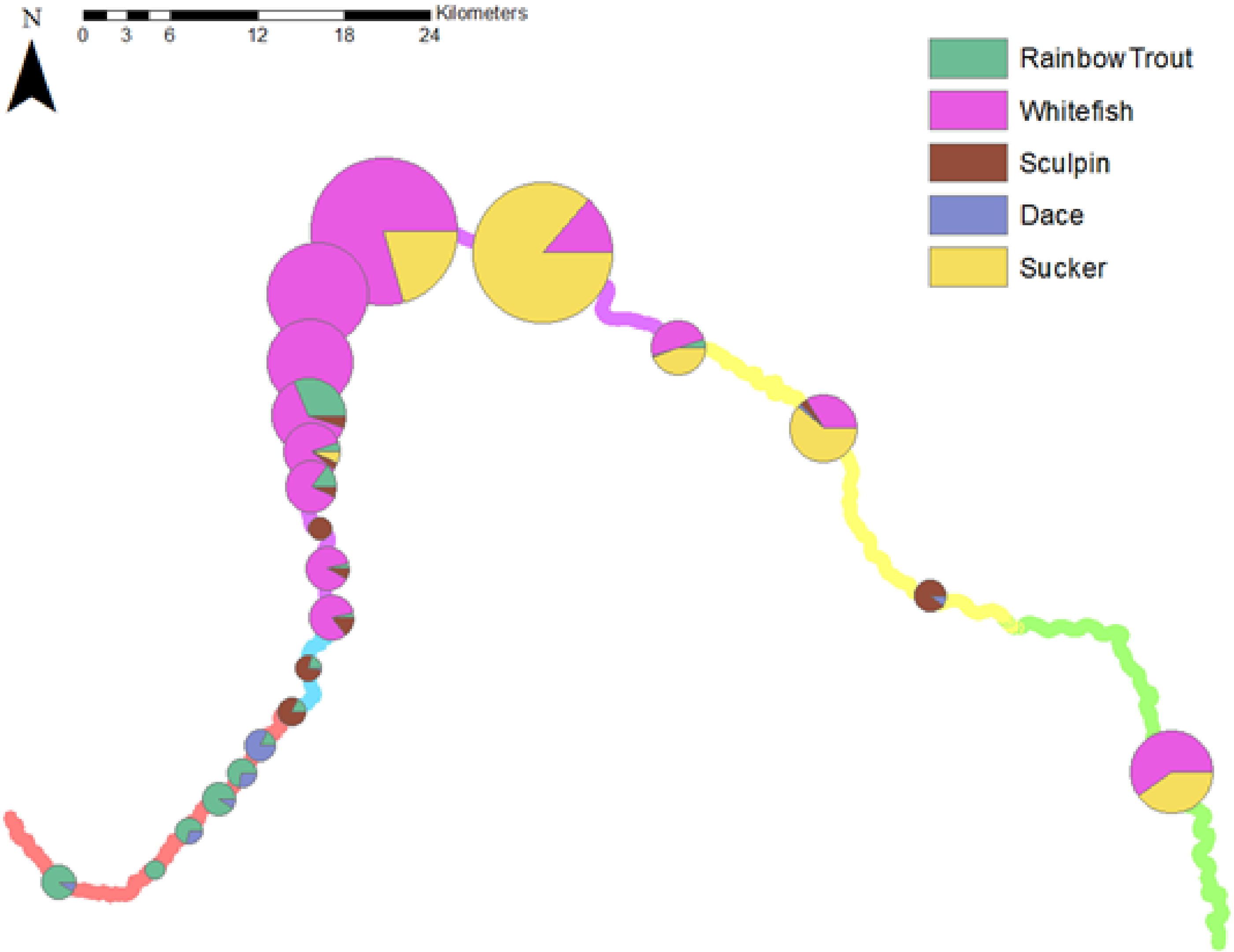

Figure 11. Pie charts of fish composition and biomass in the Similkameen River as given by the IEC Beak survey (DoE, 1984). The size of the pie charts has been defined using the square root of the total fish density.

units along the river network for effective sampling, land use planning and environmental assessment.

The GRU method uses easily accessible and simply extractable data from open-source geospatial databases, which are available for most rivers and streams in North America and several other places around the globe. As such, the method provides considerable potential for cross-stream transference at very low cost. This method therefore offers a planning tool that can be used to evaluate fish habitat at the macrohabitat level and assist in developing sampling protocols that align with the goals of a particular study. For instance, the GRU method could be used to determine the locations and intensity of sampling for a basin-wide evaluation of fish community composition and abundance so as to avoid sampling too intensely in similar habitats. It could also be used to assist in the identification of areas where a specific fish species is most likely to occur based on the distribution of macrohabitat types and the fish species' habitat preferences. This latter technique may be particularly useful in identifying locations where sampling efforts should be focused in attempts to detect rare species. The GRU method can also be used as a management tool to assist in the mapping and maintaining of habitat diversity at the macrohabitat level within watersheds.

Other factors such as water flow, bank texture and sediment transport can also interact with the existing variables and create subtle differences within a GRU. Due to the restriction of data availability, these factors were not considered in this study. Further, in the case of heavily-regulated rivers an index for geomorphic con-

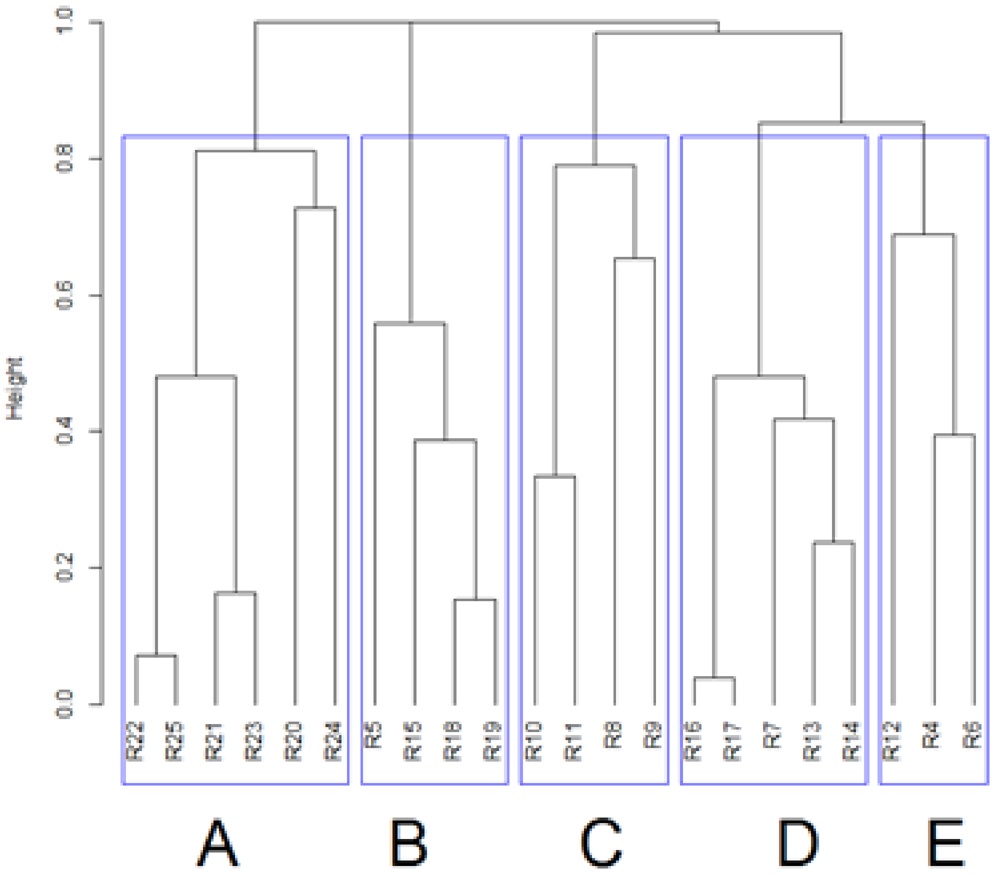

Figure 12. Cluster dendrogram of the fish composition data by reach based on the Bray-Curtis

nectivity can be important for classification. This was not applicable to the current study. However, the GRU method is flexible in incorporating additional variables, with the associated factor analysis eliminating the risk of data redundancy. Built upon the preliminary classification scheme adopted in this study, a systematic classification of river habitat could be developed. In our future work, second tier variables such as valley confinement, fish barriers, braiding, confluence of tributaries, water temperature and river bed substrates, which require intensive observation and measurement efforts, will be incorporated into the GRU analysis in order to accurately capture detailed habitat information.

5.0 Conclusions

This study proposed a framework based on geospatial analysis method and geomorphic data to rapidly characterize a river. Despite limitations due to data availability, the GRU method applied in this study has achieved relatively good correlation with fish community clusters and supported the assumption that geomorphological structures can be an indicator for varying abiotic and biotic regimes of a river system. Using the methodology described herein, the Similkameen River can be classified into GRUs. It has been demonstrated that, the GRUs can be indicators distinguishing different fish resources. In addition, differences in fish abundance and types can be expected to be found in different GRUs. This classification method may serve as a tool in the design of conservation and monitoring activities. Management practitioners may use GRU modelling to make targeted plans that better cater to fish species with different habitat preferences.

A major benefit of this modelling approach is that it provides a means for rapid, inexpensive and objective assessment for landscape-scale river ecosystem classification. Further, it provides a means for bridging geomorphology with ecology, which is an important research field in river science. Applications based on the emerging data-mining techniques of GIS and geo-statistics are promising and essential to coupling these two disciplines. The findings presented in this work indicate the considerable potential of the GRU

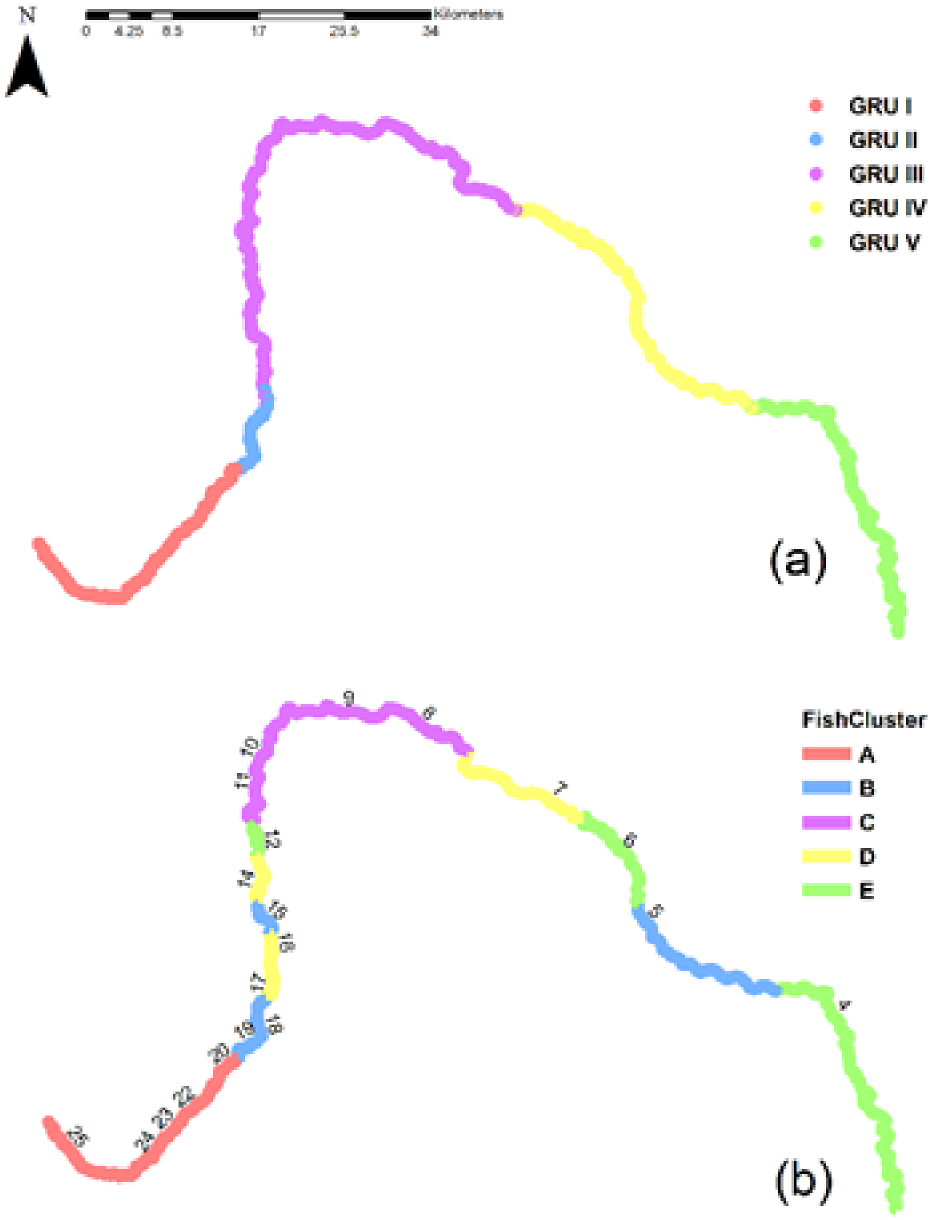

Figure 13. River channel plotted to indicate: (a) GRUs; (b) Fish data clusters; the numbers indicate sampling reaches of the fish data survey conducted by IEC Beak (DoE, 1984).

method to identify geomorphological patterns to better inform fish resource management decisions.

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Software and Data Availablility

- ESRI. Arcgis desktop, Release 10.2.; Environmental Systems Research Institute.: Redlands, CA, 2013.
- R: A language and environment for statistical computing R Foundation for Statistical Computing: Vienna, Austria, 2013.
- ET GeoWizards Version 11.1 for ArcGIS 10.2.; ET SpatialTechniques, South Africa, 2014.

- CanVec data by Natural Resources Canada http://ftp.geogratis.gc.ca/pub/nrcan_rncan/vector/index/html/geospatial_product_index_en.html

- CDEM data by Natural Resources Canada http://ftp.geogratis.gc.ca/pub/nrcan_rncan/vector/index/html/geospatial_product_index_en.html
- Fish survey from the IEC Beak (1983) report https://pisces.bpa.gov/release/documents/documentviewer.aspx?doc=247

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