RIVER REACH DELINEATIONS AND BEAVER MOVEMENT IN GRAND TETON NATIONAL PARK

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✦ INTRODUCTION

This project had two components, with the first component providing a background for the second component. Water resources in Grand Teton National Park (GTNP) are both unregulated and regulated by human management. The Jackson Lake Dam and the ponds scattered across the park influence the flow of water. In the process of managing the water it is important to have knowledge of the different components of the streams through which the water flows. One component of this project was to examine the different segments of the major rivers in GTNP and identify the river forms that are displayed by the different reaches of the Snake River above and below Jackson Lake, Buffalo Fork and Pacific Creek. The river form can be segregated into three main categories; the single channel, the meandering channel and the braided channel (Knighton 1984). The different river forms are part of the overall structural composition of the river and can be used to delineate the segments or reaches of the river. The river continuum concept presented by Vannote et al. (1980) provides a theoretical background upon which to construct the river reach system. In 2007, Nelson (2007) completed a reach system project while investigating the fluvial geomorphology of the Snake River below Jackson Lake Dam (Figure 1.). His 20 river reaches provided a zonation of the river that incorporated a range of geomorphic features. This same type of system can be used throughout the GTNP so that researchers have a common spatial unit designation when referencing portions of the Snake River and its tributaries. Ackers (1988) in his work on alluvial channel hydraulics identified three dimensions of meanders that should be considered; width, depth and slope. He further agreed with Hey (1978) that there are nine factors that define river geometry and that these should be considered as well: average bank full velocity, hydraulic mean depth, maximum bank full depth, slope, wave length of bed forms, their mean height, bank full wetted perimeter, channel sinuousity and arc length of meanders. Nelson's work (Nelson 2007) added another parameter by including a braiding index into the representation of river reach designations. In a more recent work, the Livers and Wohl (2014) study confirmed Nelson's approach by comparing reach characteristics between glacial and fluvial process domains using similar reach designation characteristics to determine reach differences.

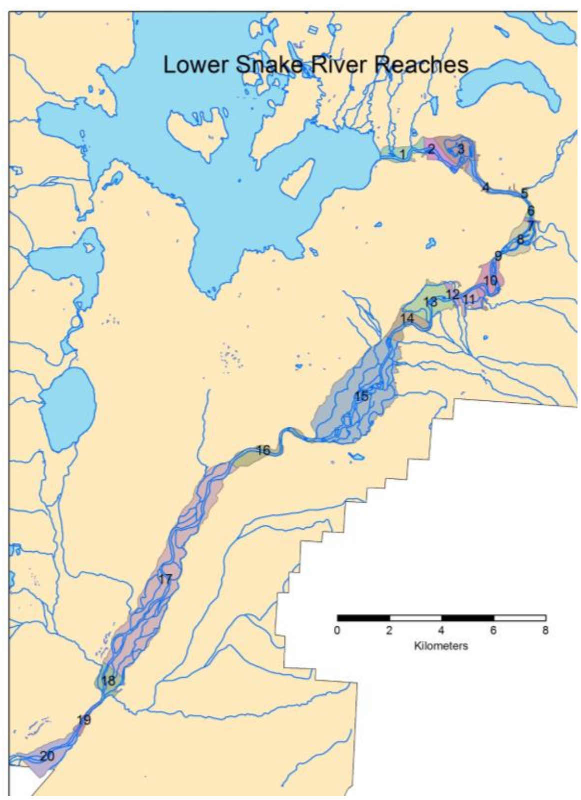

Figure 1. Lower Snake River reaches (Nelson 2007).

Determining reach units for analytic purposes provides an important mechanism by which researchers from a variety of disciplines can address river characteristics in a uniform way. Naiman et al. (1987) examined the longitudinal patterns of ecosystem processes and community structure of the Moisie River, Canada. The significance of this work was that the fluvial geomorphic reaches of the river provided a means by which vegetation ecologists and both micro- and macro-invertebrate specialists could uniformly distinguish differences and similarities along the full length of the river referencing the same reach units. Markovic et al. (2012) utilized the same types of concepts in their study of fish ecology along river studies in New York and Germany incorporating GIS techniques and modeling to analyze fish distributions along reach segments. Again, the utility of forming a reach segment based on physical characteristics of the river provides a solid base upon which other researchers can reference.

The second component of this research project was to continue work on the spatial ecology of beavers in Grand Teton National Park (GTNP). The beaver population of GTNP is divided between beaver colonies located along the major tributaries and those that are aligned with specific ponds. In the 2014 beaver census (Gribb and Harlow 2014), the number of beaver colonies adjacent to a major stream tributary was over 2:1 relative to those found in ponds. Figure 2 illustrates the dispersion of beaver caches identified during the October 2014 aerial census. In an attempt to understand the spatial behavior of beavers, this study attempted to concentrate on river beaver movement. Most beaver movement studies examine beavers adjacent to ponds (McClintic et al. 2014, Bloomquist et al. 2012, McNew and Woolf 2005, and Fryxell and Doucet 1991). Beaver ponds and their smaller streams inhibit the area of foraging. However, as the GTNP data suggests, there are more colonies adjacent to rivers in the GTNP and there is little knowledge of the spatial ecology of these river beavers. In a recent article on beaver movement, McClintic et al. (2014) state that beavers are active in their search for food, to acquire resources, breeding purposes, and to escape predation. Beavers are central place foragers and their trips from the lodge or den generally relate to food gathering; however, the distance traveled is based on their age and maternal status: frequent short trips for provisioning their off-spring with longer trips for self-feeding or sub-adults exploring for new habitats. This component of the project would have focused on beaver movement along the four major rivers: the Snake River above Jackson Lake, the Snake River below Jackson Lake, the Buffalo Fork and Pacific Creek. In the 1975-77 study by Collins (1976), he only examined the territory of each colony and speculated on a density of 1 colony per 1.3km along the Snake River below Jackson Lake Dam. He did not investigate the actual range of movement of beavers along the river. Baker and Hill (2003) found that beavers construct or utilize multiple lodges or bank dens throughout their home range, thus their movements could extend beyond the colony territories as delineated by Collins.

Unfortunately, the University of Wyoming Institutional Animal Care and Use Committee process was not completed until mid-September, 2015. This situation did not provide the researchers with enough time to locate, trap and attach GPS units to beavers to collect sufficient location data to determine beaver movements during the summer months. It was imperative to the research that movement data was collected through the summer, fall and winter months because of the feeding behavior differences during the seasons. While this component of the project was not completed, it is rescheduled into our future efforts.

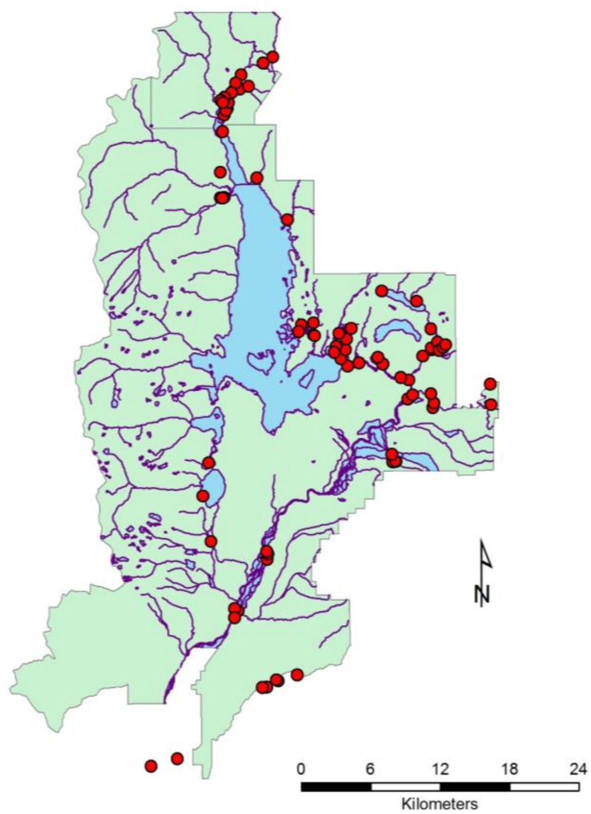

Figure 2. Beaver cache locations, aerial survey, October, 2014.

This ongoing project addresses the problem of determining the concentration of beaver colonies based on river reach characteristics and a geomorphic interpretation of beaver habitat based on river form. It is hypothesized that beaver colonies will have a higher concentration in areas that are braided, offering more opportunity to access water and associated vegetation communities as preferred beaver habitat. The river reach segment system was continued along the three rivers not completed by Nelson (2007): Upper Snake River above Jackson Lake, Buffalo Fork, and Pacific Creek. The river reaches delineation process involved a combination of satellite imagery (LiDAR), hydrology and field measurement. The LiDAR imagery data was obtained in 2014, with an estimated elevation accuracy of 25cm (Hodgson et.al 2005). Studies on hydro-geomorphology demonstrate that LiDAR data is a useful tool to discern river structure (Liermann et al. 2012, Bertoldi et al. 2011, and Hauer et al. 2009).

A total of 157 river field transects were collected to both act as ground truth for LiDAR measurements and to collect measurements of river hydraulic characteristics. Vegetation along the river banks introduces some error in the LiDAR measurements (Hutton and Brazier 2012), but this was not corrected. Stromberg et al. (2007) determined that accurate surface topography and vegetation are required to "…understand the complex interactions between riparian vegetation, water availability and channel morphology" (Hutton and Brazier 2012).

✦ METHODS AND ANALYSES

In verifying the river reaches delineated by Nelson (2007) two approaches have been taken. First, compiling spatial data for GIS analysis using soils (Figures 3-5; SCS 1982) vegetation (Figures 6-8; GTNP 2005), DEM, and river hydrology and comparing each reach for distinct characteristics. The second approach was to collect specific fluvial geomorphic factors at random locations along the Lower Snake River below Jackson Lake Dam (Figure 9). The samples were based on river confluences and braiding characteristics. The factors measured at each location provided a basic understanding of river structure and vegetation characteristics: bankfull elevation, width, bank height, bank vegetation types, vegetation height, and braiding index. A combination of aerial photography and LiDAR data were used to determine critical geometrical structures in the river system including bars, islands, and the overall floodplain (Hauer et al. 2009). These same river

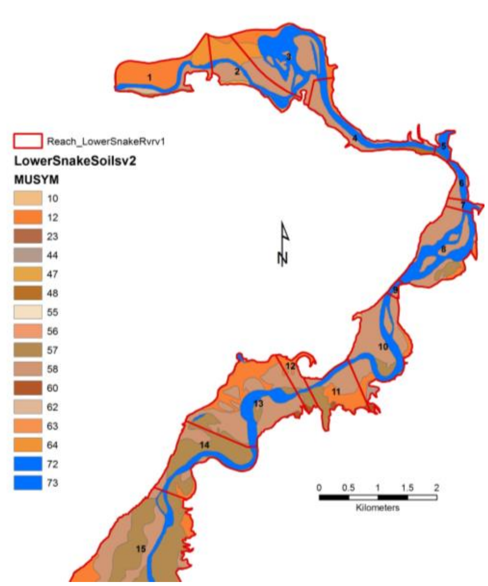

Figure 3. Lower Snake River soils, North Section (SRC 1982). See Appendix A for soil codes in figure.

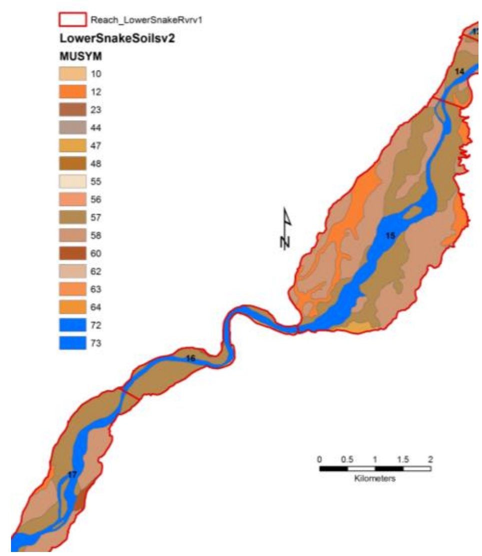

Figure 4. Lower Snake River soils, Middle Section (SRC 1982). See Appendix A for soil codes in figure.

structure and vegetation variables were collected at sample sites along the Upper Snake River, Buffalo Fork, and Pacific Creek. As mentioned previously, 157 transects were completed on the four main rivers in Grand Teton National Park. This portion of the study, however, examined only the characteristics of the Lower Snake River incorporating the 43 transects along the 43km of the Lower Snake River. All of the data was then integrated into ArcGIS (ESRI v.10.2) and preliminary statistical analysis performed in EXCEL (v10. 1).

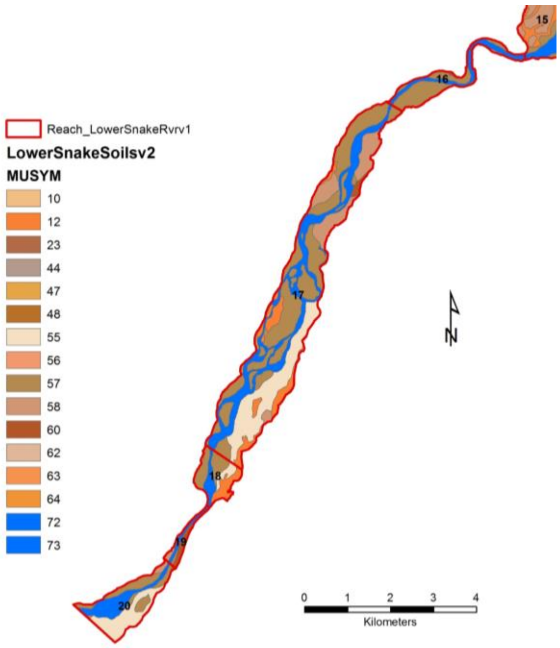

Figure 5. Lower Snake River soils, South Section (SRC 1982). See Appendix A for soil codes in figure.

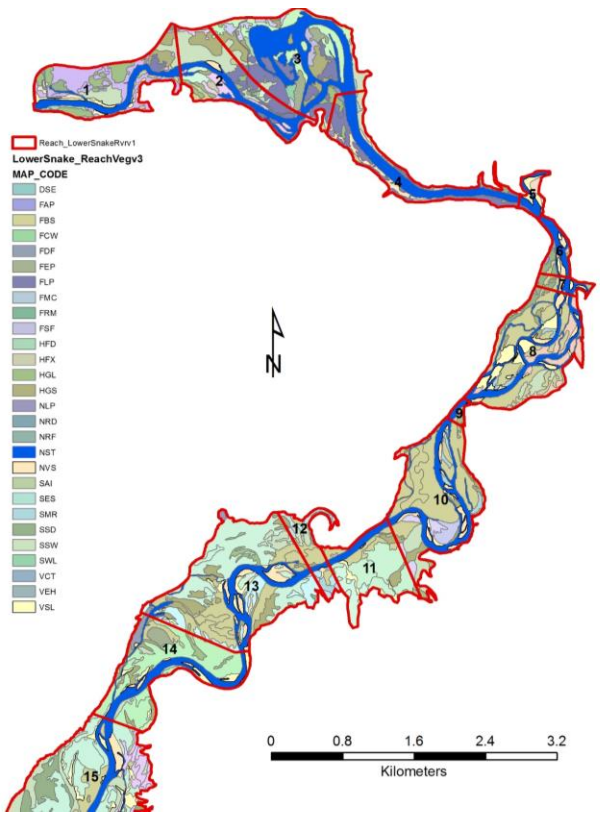

Figure 6. Lower Snake River vegetation, North Section (GTNP 2005).). See Appendix A for vegetation codes in figure.

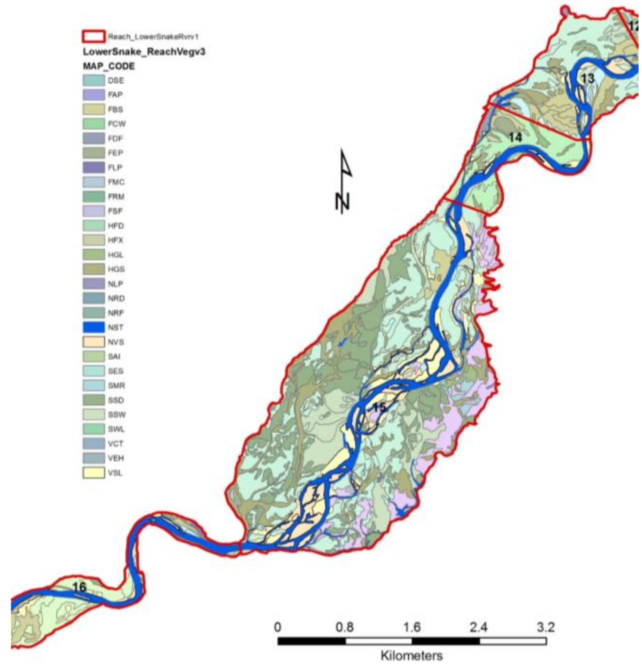

Figure 7. Lower Snake River vegetation, Middle Section (GTNP 2005). See Appendix A for vegetation codes in figure.

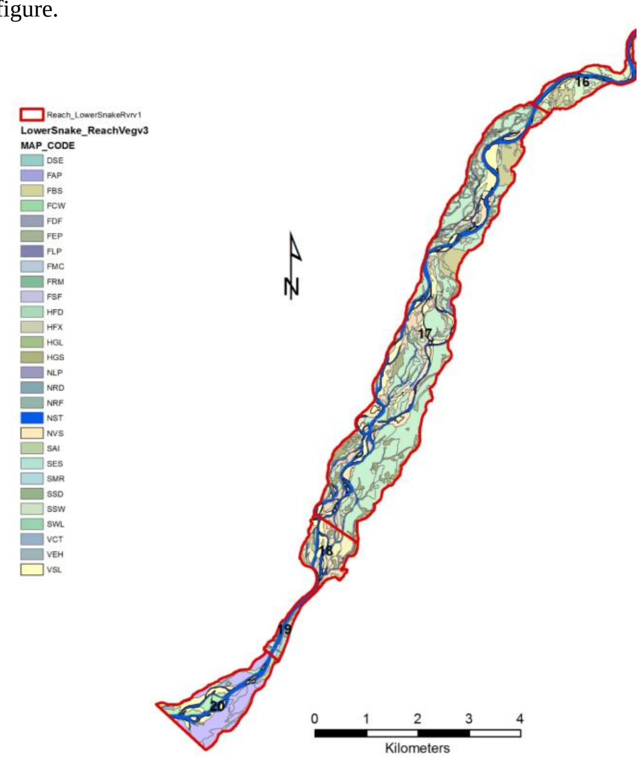

Figure 8. Lower Snake River vegetation, South Section (GTNP 2005). See Appendix A for vegetation codes in figure.

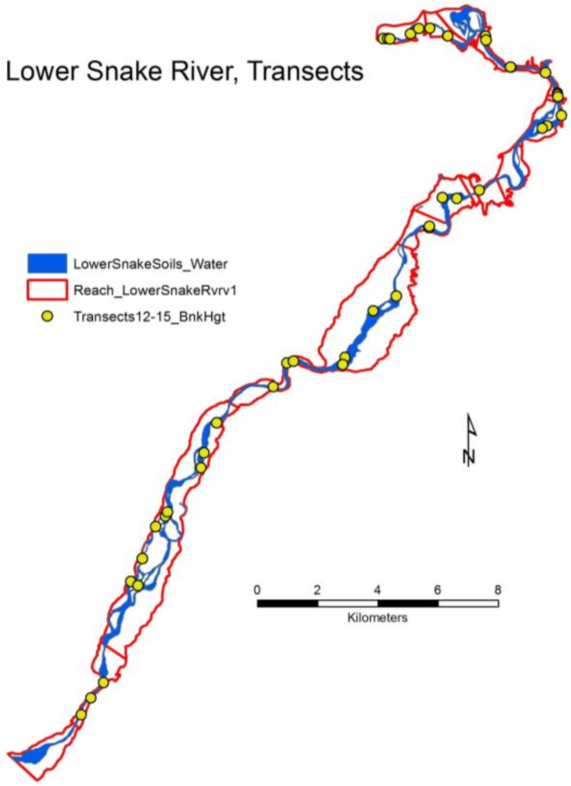

Figure 9. Lower Snake River transects.

Three main characteristics of the Nelson reach delineations were used to verify his reach boundaries: floodplain width, river form, and braiding index. The other major characteristics concerning river depth and width would have been difficult to verify because of the movement and changes in the Snake River since his 2007 study. Using simple overlay techniques superimposing the Nelson reach boundaries to the LiDAR imagery and NAP aerial photography sample points were designated to determine the accuracy of the Nelson boundaries for the Lower Snake River. In the 125 points selected, the Nelson boundary was within 5m in 97% of the locations. It was believed that this falls within the U.S.G.S. mapping standards, and thus his delineations could be used as geomorphic reaches along the Lower Snake River.

A total of 18 variables were used to examine the relationship between river reaches and concentrations of beavers (Figure 10) along the lower Snake River (Appendix B). Table 1 lists the correlations between variables and active beaver lodges with correlations of r=0.5 or above (p=0.05) (Appendix B). Some of the most logical relationships exist between soils and physical features on the ground. For instance, the more sand in the soil, there is more likelihood to find sandbars (0.964); similarly, the higher the braiding index, the higher the number of sandbars along the river (0.632). Sand soils are also strong factors in vegetation, with a positive relationship between sand and *Populus spp.* (0.988), and *Salix spp.* (0.720) was considered strongly correlated as well. The distribution of number of beavers (ReachTot) by reach has a strangely configured distribution: it is mildly strong with *Populus spp.* (0.506) and even stronger with *Salix spp.* (0.752) and somewhat strong with sandbars (0.617) and soils with GT3in cobbles (0.567). Surprisingly, beavers generally try not to build bank dens in sands and cobbles, so in this case, they are building bank lodges. The relationships change when we convert from total number of beavers to beaver density per sq. km. in each reach. Reaches #15 (19) and #17 (10) have the most beavers, however, when you convert to a density value they do not have the highest density of beavers; reaches #5 and #6 at the confluences of Pacific Creek and Buffalo Fork have that distinction with 18.73 and 13.68, respectively. In addition, it was found that there was a negative relationship between the density of beavers per sq. km. and the percent of a reach in *Populus spp.* (-0.579). This can be explained by the fact that though cottonwoods and aspens are a favorite tree, as the tree density increases there is less area for willows (*Salix spp.*), which is a more stable component to their diet.

Table 1. Summary of correlations between stream variables and active beaver lodges with correlations of r=0.5 or above (p=0.05). See Appendix B for variable definitions and Appendix C for the full correlation matrix.

	BraidIndx	Salix	RvrSandBars	Sand	SandPc	ReachTot	BvrDenSqKm
Sandbars	0.519			0.964		0.617	
RvrSandbar	0.632			0.600			
Populus		0.788	0.716	0.988		0.506	
PopulusPC				0.581	0.831		-0.579
Salix				0.720		0.752	
GT3in						0.567	
GT3inPC							0.513
BvrDenSqKm					-0.562		

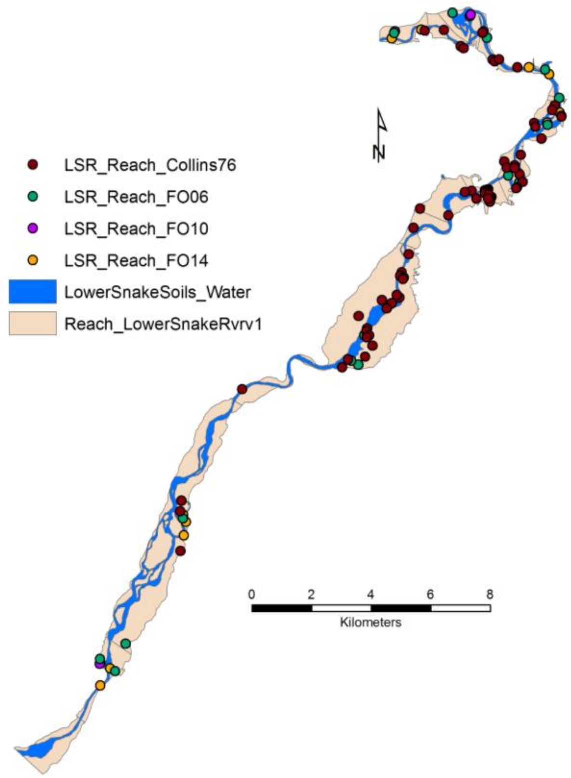

Figure 10. Lower Snake River, Beaver Locations, 1976-2014.

In reviewing the correlation matrix of all variables (Appendix C), there are some relationships that need to be examined. One of our working hypotheses is that there would be a higher concentration of beavers in reaches with a higher braiding index. Indeed, there is a mild correlation between braiding index (BraidIndex) and number of beaver colonies in a reach (ReachTot) (0.365), however, in comparison to beavers per river kilometer (BvrDenKm), there is a weak negative correlation (-0.088) and the same is true for the number of beavers per sq. km. per reach (BvrDenSqKm) (-0.115). These correlations could be a function of the larger reaches having more braids and more beavers in total, but when calculated per river km. or sq.km., it holds that a slightly negative correlation exists because there is less of a probability to build a bank den or lodge. This condition exists because sands are a dominant soil with braids. Another characteristic of importance is that the percent *Populus spp.* (PopulusPC) is negative for both the density of beavers along the river length (BvrDenKm) (-0.382) and beaver's per sq. km (BvrDenSqKm) (-0.579), again this relates back to the fact that beavers have a preference for willows (*Salix spp.*) for food rather than cottonwoods and aspen (*Populus spp.*). Just the opposite occurs in the relationship between beaver density along the river (BvrDenKm) (0.479) and beaver density per square km. (BvrDenSqKm) (0.184) as well as the percent of each reach in *Salix spp.* (SalixPC) which are both positive, however, the latter is much weaker because of the influence of the larger reaches with less density of beavers per sq. km.

In summary, the basic relationships between the main reach physical characteristics provide a strong background for understanding Nelson's reach configurations. Nelson's reaches are premised on river form: single channel, meandering channel and braided channel. The reach soils that are predominately sand have the most sandbars and area in sandbars. Similarly, the amount of area of each reach with *Populus spp.* and *Salix spp.* is mildly related to the length of river segments that have the most sandbars. Also, the braiding index has a strong relationship with the length of river segments that is sandbars. The one variable that represented the river form, sinuosity index (SinIndex), did not display any strong or even mild relationships with any of the other reach physical properties.

Overall, the relationship between beaver totals (ReachTot) and beaver densities (BvrDenKm and BvrDenSqKm) and the physical characteristics of the reaches appear to be weak or, in only a few factors, somewhat mild. There is a weak relationship between beaver totals (ReachTot) within a reach and the braiding index (BraidIndex). Beaver totals per reach also have a mild relationship with *Populus spp.*, *Salix spp.* and sandbars, as well as areas in which *Populus spp.* and *Salix spp.* are found. However, if converting to the number of beavers to a density per sq. km. (BvrDenSqKm), there is a mild negative correlation with the percent of a reach in *Populus spp.* Interestingly, as the beaver density per sq. km. increases, the percent of the reach with soils that have large cobbles (greater than 3") (GT3inPC) also increases. Though beavers do not prefer cobbled river banks for bank dens, they will use the bank for a bank lodge. It appears that active beaver lodge/den areas aligned with areas of *Populus spp.* and *Salix spp.* as long as there is easy access by water.

✦ CONCLUSIONS

There are three main conclusions that can be drawn from this study. First, the Nelson reaches do follow the river form pattern and the physical characteristics of each reach, as they relate soils, vegetation, and braiding. Second, the total number of beavers or their density is only weakly related to the physical form of the river, while the stronger correlations are with the vegetation. Without the appropriate density of *Populus spp.* for building materials and a supplementary source of food, in concert with *Salix spp.* as a main food item, the beavers would not be within that reach. This is evident by the reaches that are single channel or a meandering channel. However, variables that were not included in this summary analysis were the possibility that the reach included a confluence with another major river (Pacific Creek or Buffalo Fork) or a smaller tributary (Cottonwood Creek, Spread Creek or Ditch Creek). These could be sources of additional beavers that are introduced into the Lower Snake River from these waterways into that reach. Further, Nelson et al. (2013) stated that the dynamic characteristics of the Snake River below Jackson Lake dam have a more "…temporal and longitudinal complexity" than previously considered. They later state that river channel changes are greatly influenced by streamflow and flood events. This can be easily illustrated by the change in flow patterns on the Lower Snake River yearly and over time. Finally, this study demonstrates the need for more in-depth analysis of beaver movement between reaches or into back channels. Beavers are very mobile during the spring runoff and during the summer; it is only in the late fall, after the first freeze, that beavers establish their cache for the winter. Thus, more information on the six month period (May-October) would provide a better understanding of their spatial dynamics during the period of most river activity.

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Appendix A. Category labels for maps showing soils (Figures 3-5) and vegetation (Figures 4-6).

Soils

10	Crow Creek silt loam 10-20% slope
12	Cryaquolls-Cryofibrists Complex
23	Leavitt-Youga Complex 0-3% slope
44	Slocum-Silas loams
47	Taglake-Sebud Association
48	Taglake-Sebud Association Steep
55	Tetonville gravelly loam
56	Tetonville Complex
57	Tetonville-Riverwash Complex
58	Tetonville-Wilsonville fine sandy loam
60	Tineman gravelly loam
62	Tineman-Bearmouth gravely loam 0-3% slope
63	Tineman-Bearmouth gravely loam 3-40% slope
64	Tineman Association
72/73	Water

Vegetation

DSE	Artemisia arbuscular Dwarf Shrubland
FAP	Populus tremuloides Forest
FBS	Picea pungens Riparian Forest
FCW	Populus angustifolia-P.balsamifera Riparian Forest
FDF	Pseudotsuga menziesii Forest
FEP	Mixed Evergreen-Populus spp. Forest
FLP	Pinus contorta Forest
FMC	Mixed Conier Forest
FRM	Mixed Conifer-Populus spp. Ribarian Forest
FSF	Abies lasiocarpa-Pinus englemannii Forest
HFD	Montane Mesic Forb Herbaceous Vegetation
HFX	Montane Xeric Forb Herbaceous Vegetation
HGL	Mixed Grassland Herbaceous Vegetation
HGS	Flooded Wet Meadow Herbaceous Vegetation
NLP	Natural and Artificial Lakes and Ponds
NRD	Transportation Communication, and Utilities
NRF	Mixed Urban or Built-up Land
NST	Streams
NVS	Sandy Areas other than Beaches
SAI	Alnus incana Shrubland
SES	Artemisia spp. – Purshia tridentate Mixed Shrubland
SMR	Mixed Tall Deciduous Shrubland
SSD	Artemisia spp. Dry Shrubland
SSW	Artemisia spp./Daisphora floribunda Mesic Shrubland
SWL	Salix spp. Shrubland
VCT	Cliff and Talus Sparse Vegetation
VEH	Exposed Hillside Sparse Vegetation
VSL	Exposed Lake Shoreline-Stream Deposit Sparse Vegetation.

Appendix B. List of variables used in correlation analyses between river reach variables and concentrations of beavers along the lower Snake River. See Appendix C for the full correlation matrix and see Table 1 for a summary of correlations between variables and active beaver lodges with correlations of r=0.5 or above (p=0.05).

BraidIndex	The number of stream braids per km.
Slope	The slope of each river reach measured by river elevation
SinIndex	Sinuosity index
Populus	The number of sq. meters in each reach with Populus spp.
Salix	The number of sq. meters in each reach with Salix spp.
Sandbars	The number of sq. meters in each reach that is a sand bar
PopulusPC	Percentage of each reach in Populus spp.
SalixPC	Percentage of each reach in Salix spp.
SandbarPC	Percentage of each reach in sand bars
RvrSandbar	The sq. meters of sand bar per km. of river length
GT3in	The percent of soil fragments that is greater than 3 inches in diameter, cobble
GT3inPC	The percent of soil sample that is greater than 3 inches in diameter
Sand	The number of sq. meters in each reach with Soils with at least 50% sand
SandPC	The percentage of each reach with soils with at least 50% sand
ReachTot	The total number of active beaver lodges from surveys by Collins 1976, And aerial surveys from 2006, 2010 and 2014
ReachPC	Percentage of beaver lodges in each reach from the total of 98 active lodges
BvrDenKm	Beaver lodges per km of stream distance
BvrDenSqKm	Beaver lodge density per sq.km of reach

Appendix C. Correlation matrix showing relationship between river reach variables and concentrations of beavers along the lower Snake River. See Appendix B for a listing of variable codes. Also see Table 1 for a summary of correlations between variables and active beaver lodges with correlations of r=0.5 or above (*p=0.05*).

	BraidIndex	*Slope*	*SinIndex*	*Populus*	*Salix*	*Sandbars*	*PopulusPC*	*SalixPC*	*SandbarPC*	*RvrSandbar*	*GT3in*	*GT3inPC*	*Sand*	*SandPC*	*ReachTot*	*ReachPC*	*BvrDenKm*	*BvrDenSqKm*
BraidIndex	1.000																	
Slope	0.571	1.000																
SinIndex	-0.196	-0.149	1.000															
Populus	0.441	0.467	-0.094	1.000														
Salix	0.463	0.478	0.034	0.739	1.000													
Sandbars	0.519	0.459	-0.112	0.983	0.788	1.000												
PopulusPC	0.177	0.565	-0.153	0.595	0.266	0.491	1.000											
SalixPC	0.070	0.146	0.055	-0.164	0.416	-0.120	-0.201	1.000										
SandbarPC	0.476	0.247	-0.286	0.272	0.078	0.309	0.224	-0.225	1.000									
RvrSandbar	0.632	0.477	-0.260	0.656	0.562	0.716	0.416	-0.043	0.757	1.000								
GT3in	-0.066	-0.058	-0.135	0.277	0.313	0.328	-0.023	-0.157	-0.115	0.198	1.000							
GT3inPC	-0.301	-0.473	-0.139	-0.193	- 0.271	-0.184	-0.318	-0.276	0.189	-0.079	0.456	1.000						
Sand	0.430	0.462	0.027	0.988	0.720	0.964	0.581	-0.161	0.234	0.600	0.220	-0.205	1.000					
SandPC	0.020	0.467	0.261	0.424	0.123	0.316	0.831	-0.193	-0.027	0.151	- 0.096	-0.308	0.483	1.000				
ReachTot	0.365	0.202	0.118	0.506	0.752	0.617	-0.012	0.305	0.053	0.488	0.567	-0.080	0.486	-0.045	1.000			
ReachPC	0.365	0.202	0.118	0.506	0.752	0.617	-0.012	0.305	0.053	0.488	0.567	-0.080	0.486	-0.045	1.000	1.000		
BvrDenKm	-0.088	-0.357	-0.102	-0.258	- 0.077	-0.189	-0.382	0.479	0.194	0.158	- 0.104	0.125	- 0.279	-0.372	0.169	0.169	1.000	
BvrDenSqKm	-0.115	-0.478	-0.053	-0.417	- 0.308	-0.350	-0.579	0.184	0.404	0.018	- 0.086	0.513	- 0.423	-0.562	0.002	0.002	0.736	1.000