How Does Stream Order and Flow Impact Coho Habitat Use in the Umpqua River Basin?

A Case Study at Beaver Creek, North Sister Creek and Panther Creek

CE 513—GIS for Water Resources, Winter 2023

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Introduction

Coho salmon are a currently threatened species on the Oregon Coast (NOAA, accessed March 10, 2023). Coho are important to indigenous communities and their decline since the mid-twentieth century has caused massive economic disruption, with several fishing communities collapsing alongside the plummeting counts of coho (Logerwell et al., 2003). This species has a unique 3-year life cycle, spending a year in headwater streams and the middle two years spent in the ocean. They serve as an indicator species for hydrological shifts in stream temperature and discharge because they rely on specific discharge and temperature cues to spur their life stages. As a species reliant on these specific physical parameters, the alterations that climate change may have on headwaters in Oregon could cause mass disruption to the cycles that coho have formed over thousands of years.

NOAA has designated many basins along the Oregon Coast as critical coho habitat, and the Umpqua Basin is one of them, as shown in the highlighted region of Figure 1 below. In this project, I will examine the stream order pathways and flow rates that are present at Beaver Creek, North Sister Creek, and Panther Creek to better understand why coho choose to spawn at these sites compared with more downstream reaches. Within these three tributaries, I expect to see similar physical parameters that might explain why they are key spawning grounds, and I will compare these results to downstream reaches that only serve as migration corridors, not spawning habitat. I will then expand this examination to a basin-wide analysis of stream order and related flow metrics within each coho habitat type.

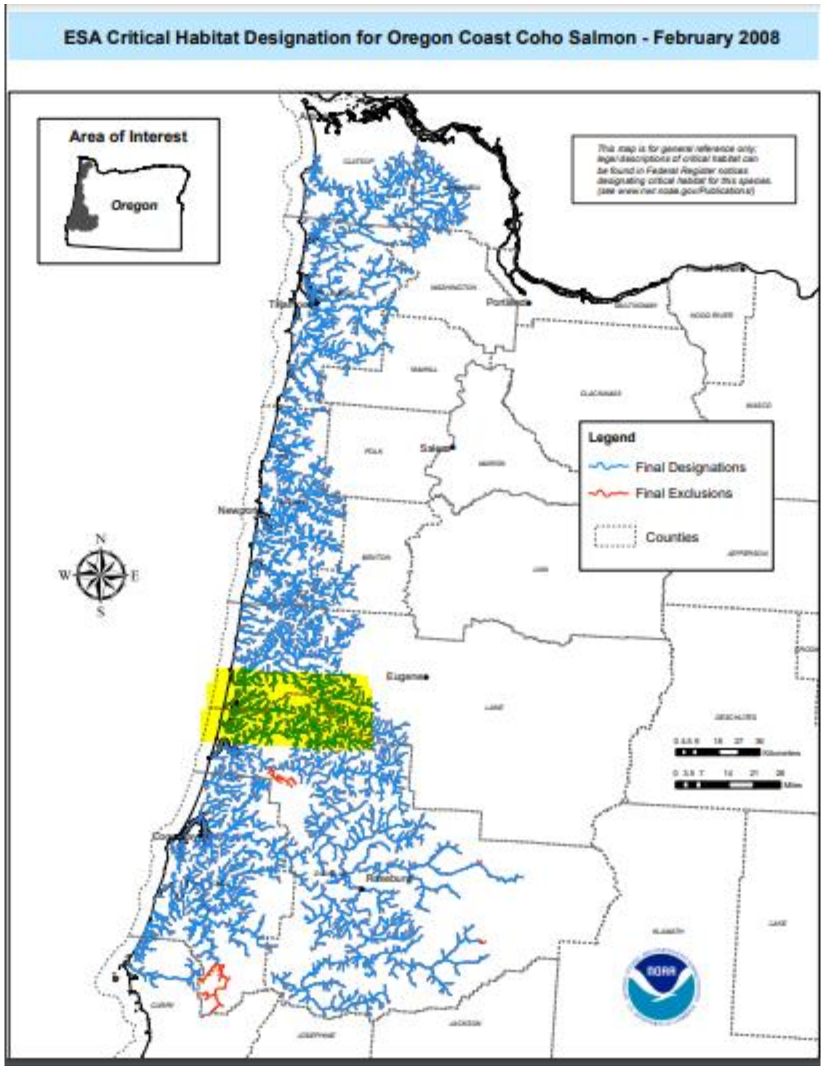
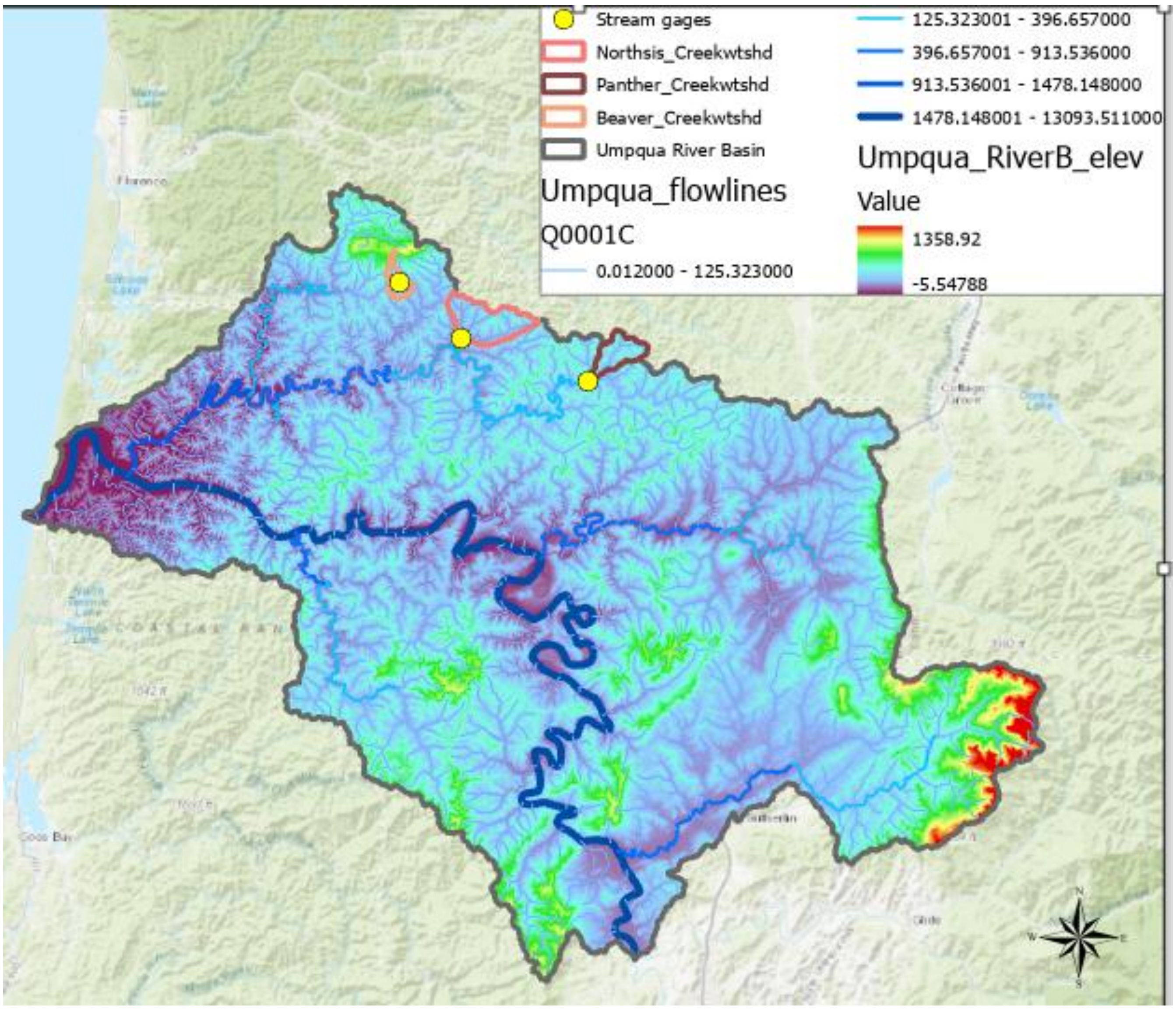


Figure 1. A map of critical coho habitat, produced by NOAA. The Umpqua River Basin is highlighted. Source: NOAA, accessed March 10, 2023

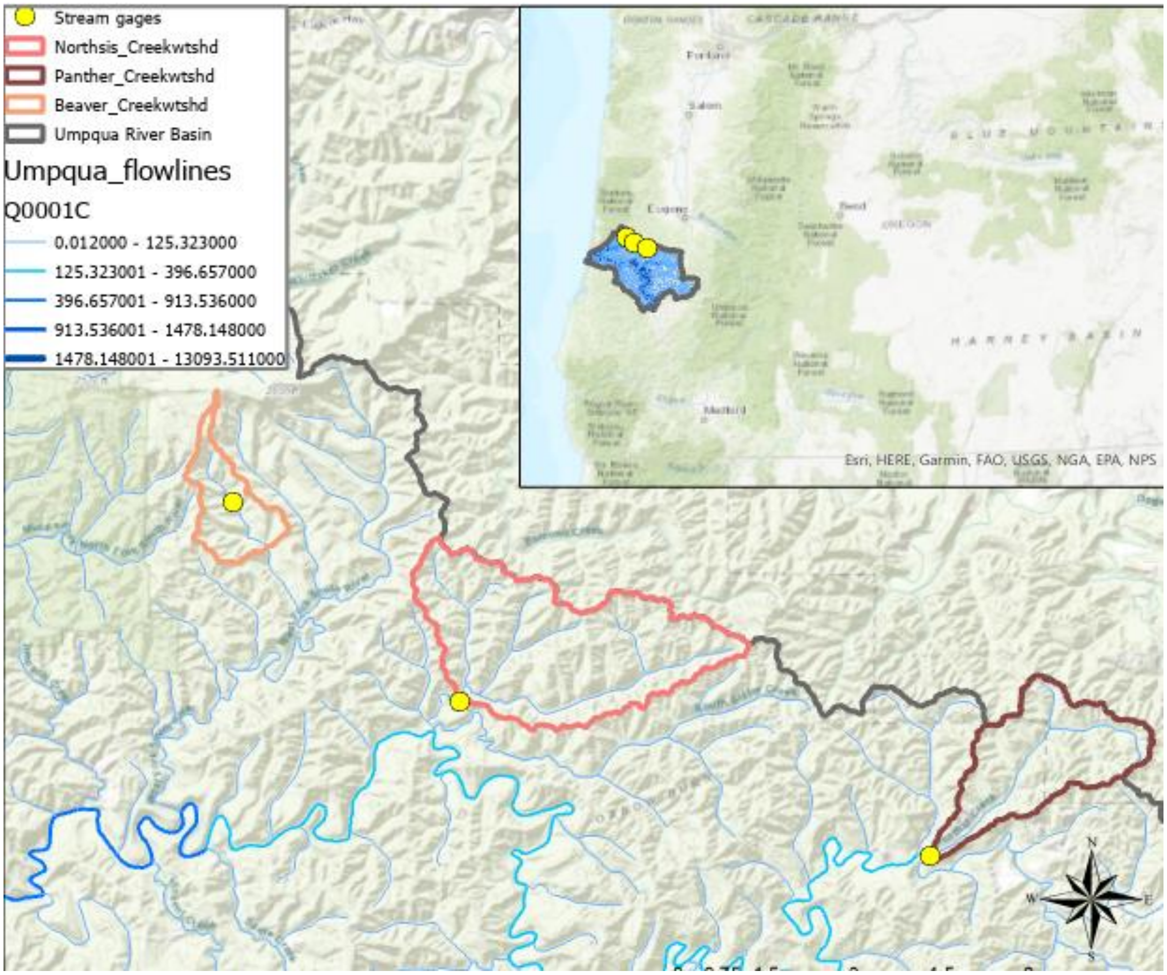
This project will serve as an outline for how similar hydrological and ecological assessments can be conducted in headwater streams using GIS methods. It will also demonstrate the limitations of GIS to delineate headwater streams at the basin-scale using DEMs, showing the need for more fine-scale resolution geospatial products to conduct large-scale assessments of headwater and species health. Water resource managers along the Oregon Coast can also use similar methodologies to analyze how their streams with coho populations are being used by the species, and how stream order and stream flow might influence their future survival with climate change.

Site description

<u>The Umpqua River Basin with Elevation, Flow Lines, and the Three Smith River Watersheds</u>



The Three Smith River Watersheds



Figures 2 and 3: Figure 2 (top) shows the extent of the Umpqua River Basin with its elevation and NHDFlow lines. Figure 3 (bottom) is a zoomed in map of the three tributaries: Beaver Creek (left), North Sister Creek (middle), and Panther Creek (right). These three tributaries are headwater streams that flow into the Smith River.

Umpqua River Basin

The Umpqua River Basin is located southwest of Eugene in the Oregon Coastal Range. The Umpqua River is the main river that flows through this basin, with the Smith River branching off to the North which feeds Beaver Creek, North Sister Creek, and Panther Creek. This basin is a rain-dominated regime with an elevation range of 0m to 1519m and an area of 3917.14km^2. The land cover within the Umpqua River Basin is 72% forest, as shown in Table 1 and Figure 4 below. The soils in the basin are 47% group B, a silt loam or loam, and 41% group C soil, sandy clay loam.

Table 1. A summary table of the major land cover classes in the Umpqua River Basin.

Main Class	Area (km2)	% Area
Barren	5.1966	0.132663
Developed	169.5546	4.328532
Forest	2838.987	72.47605
Herbaceous	204.1173	5.210878
Planted_Cultivated	293.1309	7.483292
Shrubland	292.887	7.477065
Water	42.3756	1.0818
Wetlands	70.8894	1.809724

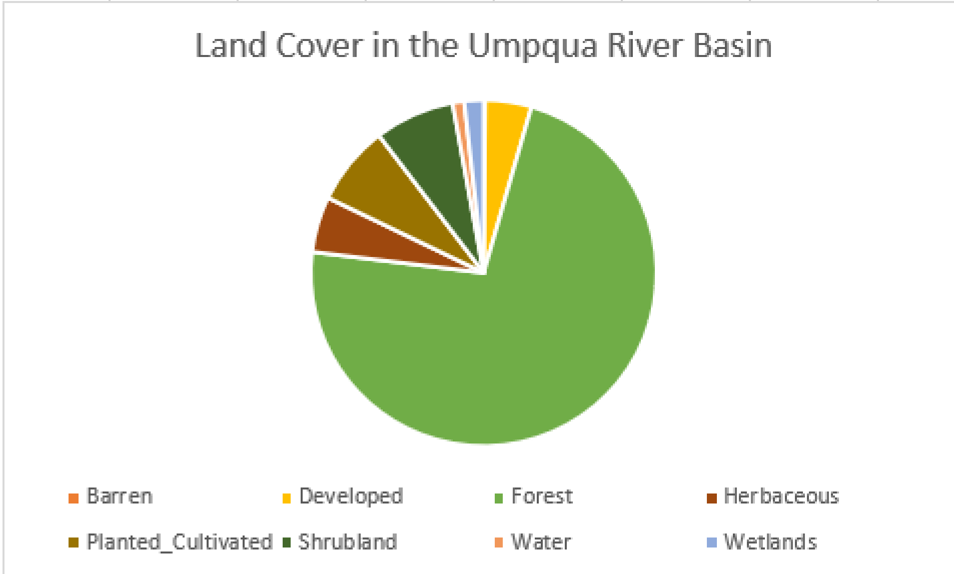


Figure 4. A pie chart showing the land cover in the Umpqua River Basin. The land cover is dominated by forest (70%).

Beaver Creek, Panther Creek, and North Sister Creek

Beaver Creek is 8.04km^2, the smallest of the three tributaries to the Smith River. It has an elevation range of 149.3m – 720.2m. Panther Creek is 13.80km^2 with an elevation range of 188.7m – 494.8m. North Sister Creek is 28.0494km^2, the largest of the three tributaries, and it has an elevation range of 103.7m – 468.1m. The gage stations at these sites are owned by the USDA branch located in Corvallis, OR. They were strategically installed at these locations that also serve as sites for the annual salmon surveys. The gages record 15-minute intervals of stream temperature and pressure, which are collected once every three months to be used in analyses. These sites are shown as the yellow points on the site maps in figures 2 and 3.

The watersheds feeding these three tributary streams are dominated by forests (82%), as shown below in Table 2 and Figure 5. The area around the tributaries is minimally developed with logging operations that use unpaved roads to transport the timber from the Douglas-firdominated stand. While clear cut harvesting activities have been shown to negatively impact aquatic biota in boarding streams, new Best Management Practices (BMPs) require 15m riparian buffer zones and encourage thinning operations rather than clear cut. These restraints have greatly benefitted the aquatic populations, including coho salmon, in these small headwater streams. Many studies have shown negligible impacts from harvesting using BMPs on both stream temperature and turbidity, making analysis of these factors unnecessary in my study (Arismendi et al., 2017; Bladon et al., 2018; Hatten et al., 2018).

Table 2. A table showing the land cover classes in the Smith River tributaries. The three tributaries have been combined for this analysis because they all visually showed similar land cover characteristics.

Land cover class	Area (km2)	% of total basin area
Developed	1.5273	3.290162472
Forest	38.6523	83.26612121
Herbaceous	3.006	6.475629144
Plant_Cultivated	0.0576	0.124083912
Shrubland	3.1374	6.758695568
Wetlands	0.0396	0.085307689
Total	**46.4202**	

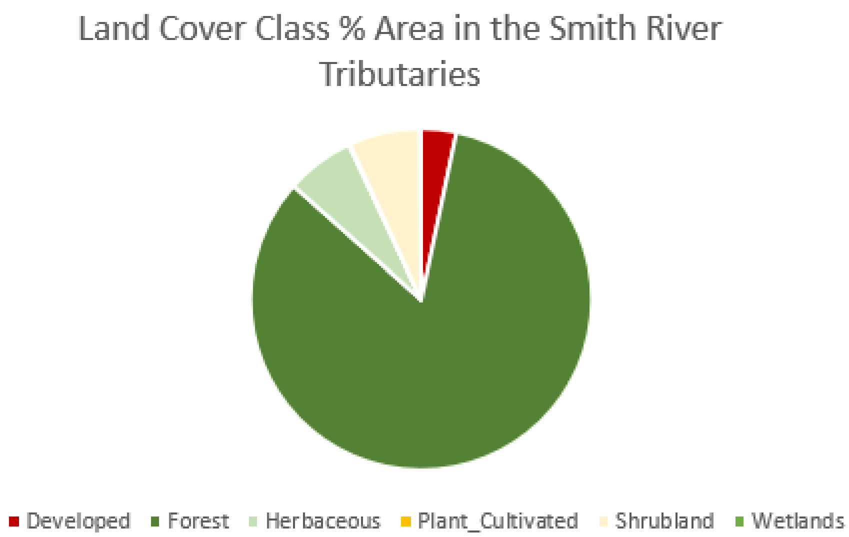


Figure 5. A pie chart showing the percent land cover classes at the Smith River Tributaries. Forest cover makes up the majority of land cover (83%).

Data

For this analysis, I used the NAD83 Lambert-Conformal Conic projected coordinate system, Oregon's state coordinate system. The data used for this analysis is listed below in Table 3. Each dataset listed below had to be reprojected into the NAD83 Lambert-Conformal Conic projected coordinate system, and the raster size for the landcover and soil rasters were changed to 30m-by-30m cells.

Table 3. The data sources used in this analysis.

Title	Data Source	Raster/Vector	Resolution	Link
WBD--National Watershed Boundary Dataset	USGS	Raster	1:24000	https://apps.nationalmap.gov/downloader/#/
NHDPlus--National Hydrography Dataset	USGS	Vector	1:24000	https://apps.nationalmap.gov/downloader/#/
NLCD--National Landcover Database	USGS	Raster	30 meter	https://www.mrlc.gov/data?f%5B0%5D=category%3Aland%20cover&f%5B1%5D=region%3Aconus
Coho Salmon Habitat	ODFW	Vector	1:100000	https://nrimp.dfw.state.or.us/DataClearinghouse/default.aspx?p=202&XMLname=8.xml
The National Map Ground Surface Elevation - 30m	Living Atlas	Raster	30 meter	Living Atlas
Smith River Tributaries Gages and Watersheds	USDA--Corvallis	Point, Vector	Point	Not Online
USA SSURGO - Soil Hydrologic Group	Living Atlas	Raster	30 meter	Living Atlas

GIS Methods

To start my analysis, I entered the location information of my three stream gage sites into Excel as decimal degrees. I then added this data to the map as a table. Once loaded, I right-clicked on the table and selected 'Display XY Data' and the point for my stream gages populated the map. I also added the shapefiles that I got from the USDA Corvallis office for the three watersheds that feed into these stream gages.

I then added the DEM layer from the Living Atlas onto my map. I overlayed the HUC4 raster that I downloaded from USGS WBD overtop of this DEM to outline my basin area and I created a 1km buffer around this basin to avoid edge effects when I clipped the DEM to fit the basin. I used the 'Extract to Mask' feature to clip the DEM to the size of the HUC4 shapefile. The resulting file was the Umpqua River Basin's surface elevation. Using this clipped DEM, I used the Model Builder to execute the steps for stream order delineation, shown below in Figure 6. The steps were as follows:

1. Re-project the downloaded DEM to the Lambert-Conformal Conic projected coordinate system to be aligned with the stream gage and the tributary layers.
2. Use the 'Fill' tool to fill in holes and pits within the DEM.
3. Use the 'Flow Direction' tool to calculate D8 flow direction from the Umpqua Basin DEM.
4. Use the 'Flow Accumulation' tool to calculate the water that will accumulate within each raster cell within the DEM to form a hydrologic network.
5. Use the 'Stream Link' tool to create stream segments combining data from both the flow direction and flow accumulation rasters.

6. Use the ‘Stream Order’ tool to number each cell from 1-5, with 1 being the smallest accumulation, to determine the order of each stream line based on their accumulated flow and flow direction.
7. Use the ‘Stream to Feature’ tool to create a vector layer of the stream segments calculated in step 3.

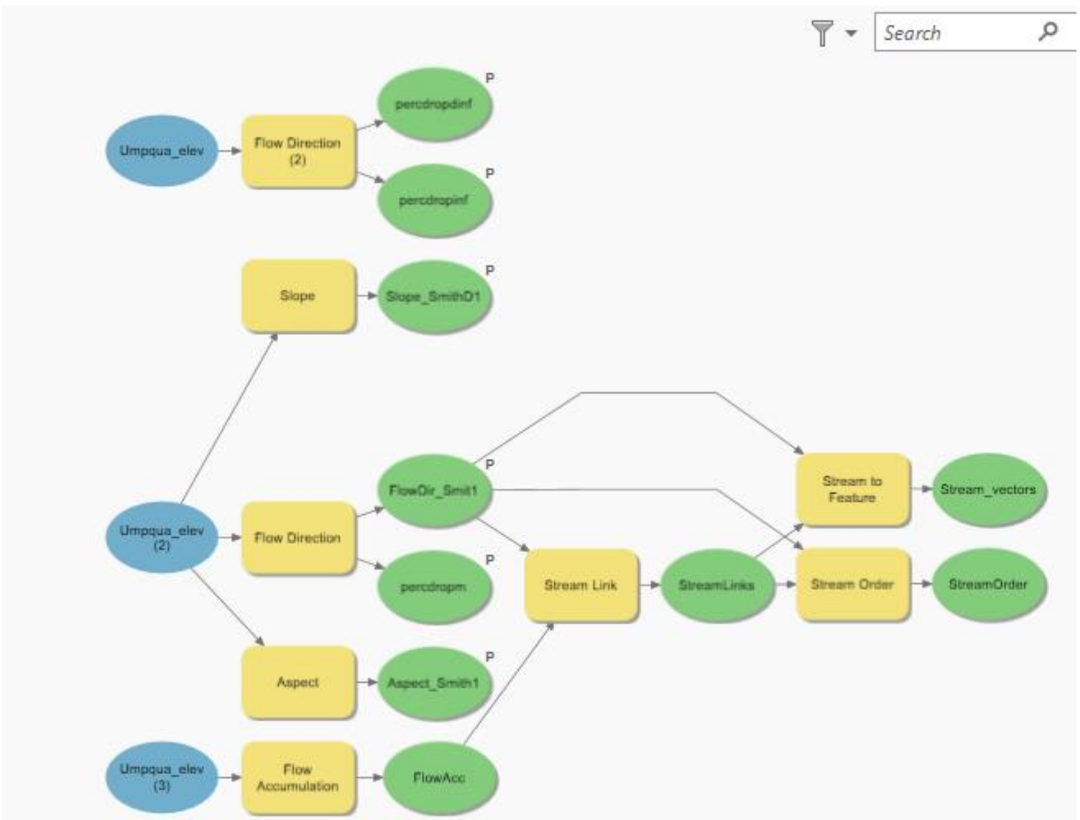


Figure 6. The model that was used to create the Stream Order raster layer.

The goal of the stream order analysis was to determine the accuracy with which GIS can map and predict suitable habitat for coho based on raster inputs. To validate the findings of the stream order delineation, I used the NHDFlowline data, clipped to the Umpqua River Basin, to determine the flow present in the three tributaries of the Smith River where salmon spawning surveys occur annually. The NHDFlowline data does not come with discharge data attached automatically, making it necessary to download the accompanying EROM_MA0001 table from the NHDPlus National Hydrography dataset. Once downloaded, I joined the flowline attributes by using the 'Add Join' tool to the EROM_MA0001 table using the common identifier ComID. Once joined, I adjusted the symbology for the flowlines layer to 'Graduated Symbols' using the Q0001C column as the value, as this is the discharge column.

To understand how stream order and stream flow impacted coho salmon habitats, I compared coho habitat to the flow accumulation raster that was calculated in the Model Builder. I first used the 'Split Line at Vertices' tool to split the polyline coho habitat layer into segments that would be easier to analyze using the tools in GIS. I then used the 'Zonal Statistics as Table' tool and set the segmented habitat lines as the feature layer input and the flow accumulation layer as the value raster. This tool calculated the mean, median, and range of the flow accumulations that were present in each of the 4 habitat types: Spawning, Rearing, Historical, and Migration. I used the 'Table to Excel' tool to export the statistic table to excel to compare the habitat-flow relations.

Outcomes

The first analysis of stream order within the Umpqua River resulted in the screenshotted map below in Figure 7. Zooming into the map reveals a motley of stream orders, with a majority of them being first order streams. The histogram in Figure 8 reveals that the majority of these stream orders are first order, pointing to the flaw that both stream and land raster layers were likely digitized and ordered, which would result in the overwhelming number of lines and first order streams.

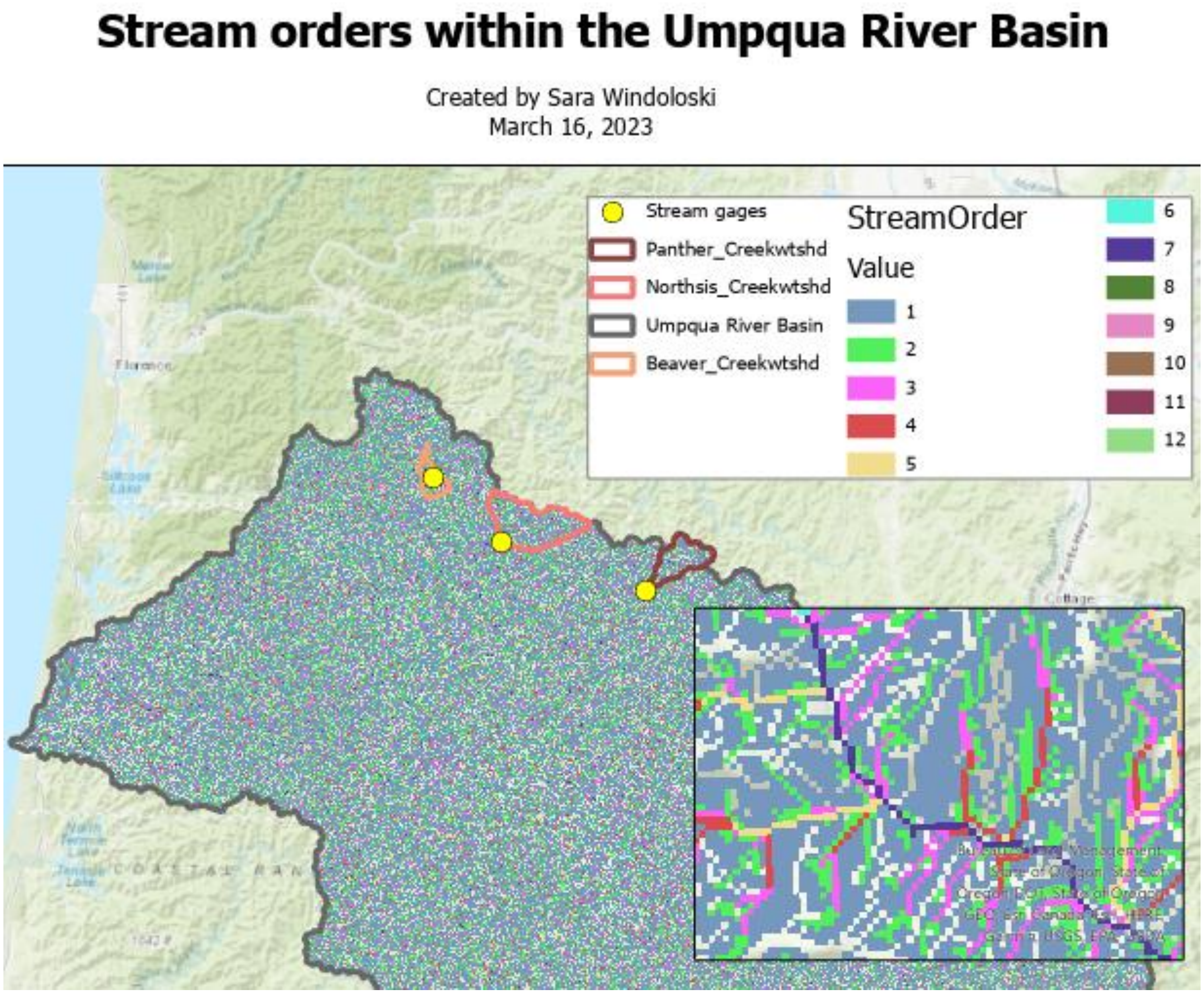


Figure 7. Stream orders within the Umpqua River Basin with a zoomed in image showing the detail and confluences of the stream segments.

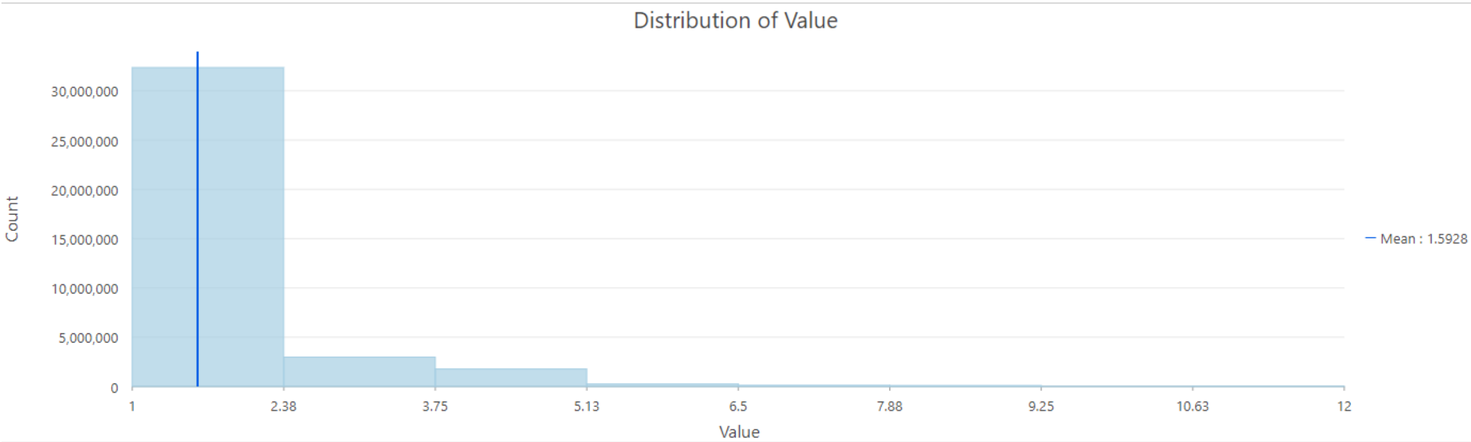


Figure 8. The distribution of stream orders in the Umpqua River Basin.

The goal with this analysis was to determine the accuracy of stream order delineations from a raster to identify potential first-order streams that might be habitable for coho. Since the overall result and implications from this analysis were blurry, I then used the NHDFlowlines to determine the size and flow of the streams within the Smith River tributary. Zooming in on the three tributaries and their accompanying flowlines show that these tributaries have low discharges compared to those seen downstream, as shown in Figure 9.

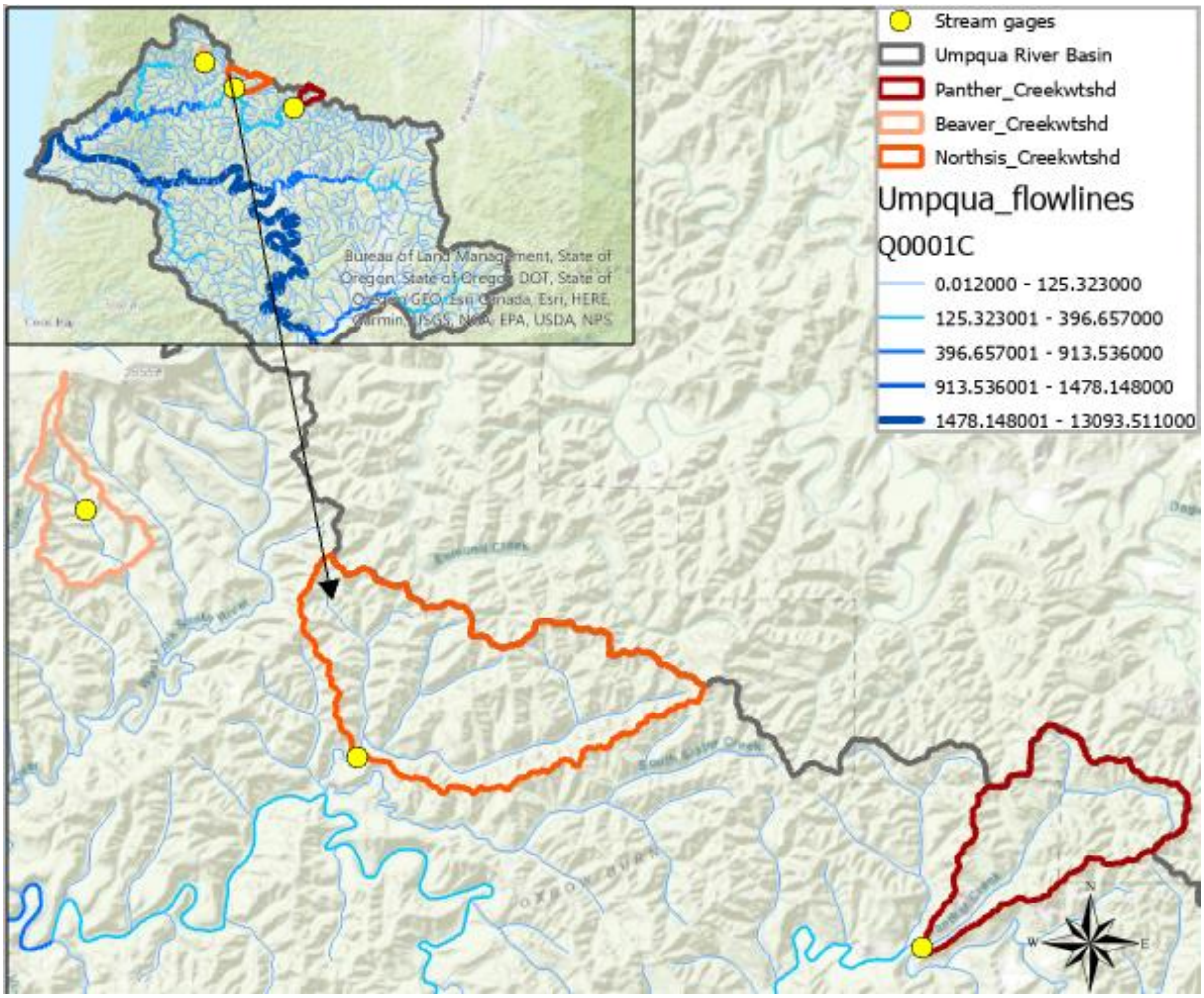


Figure 9. A snip from the map made to display the low flows within the three tributaries.

The presence of low flows in areas where coho spawn makes sense, as the eggs buried in the gravel need slow discharge conditions to prevent the eggs from scouring out. This stream discharge analysis combined with the stream order analysis shows that coho prefer spawning conditions in slower systems compared to the large-ordered, fast streams they use for migration.

The second task was to link flow conditions with the four coho habitat types. The results of this analysis showed that there are four distinct flow conditions that define the four coho habitat uses, which is shown in Figure 10 below.

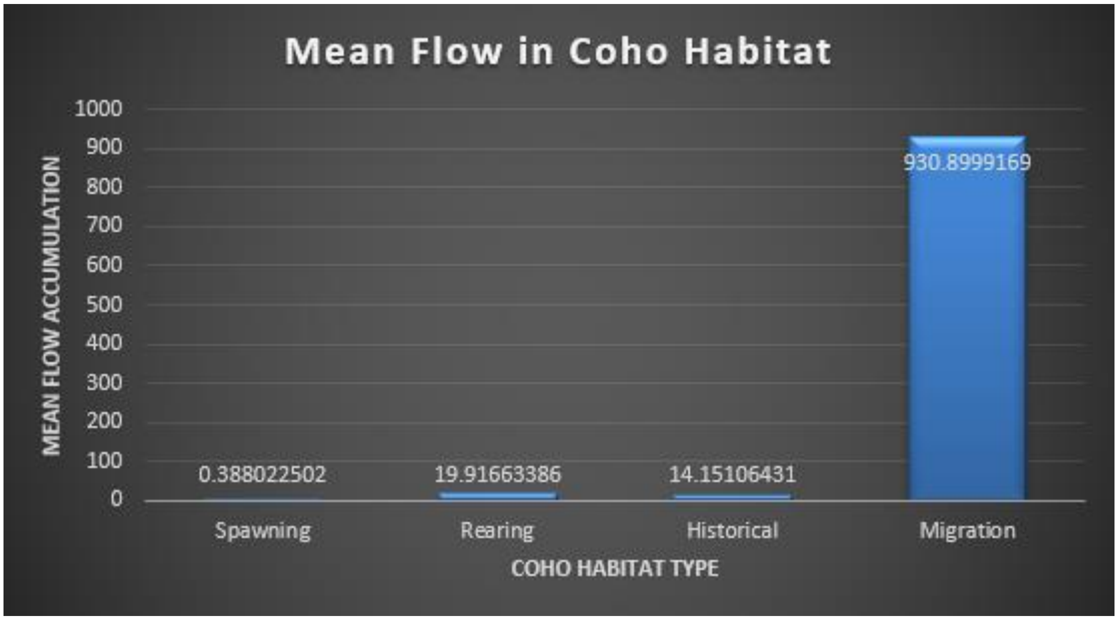


Figure 10. A chart showing the mean flow accumulation for each coho habitat use, derived from the flow accumulation raster and the coho habitat use polyline layer.

As shown in the chart, the migration routes have the highest mean flow accumulation. Coho migration routes start at the mouth of rivers where the strongest discharge and highest flow accumulation occurs. They then proceed to swim up the central rivers, such as the Umpqua and the Smith River in this case, to get to their spawning habitat in tributary streams where the flow is less. Another possible explanatory factor for this phenomenon is that the flow accumulation raster is not good at delineating headwater streams, where spawning occurs. This issue is not unique and has been cited in several GIS studies of headwaters, which have been solved using ridgeline delineations and stream network analyses (Pena et al., 2018).

Limitations

The first limitation to this study was the lack of stream temperature and coho count raster data. The initial thought for this project was to conduct a habitat suitability analysis combining raster datasets of stream flow, stream temperature, coho counts, and land cover to create a weighted statistic that could represent habitable areas of the streams within the Umpqua River Basin. There was coho count data in Oregon from ODFW, but it was not accessible to the public nor did it contain data in the Umpqua River Basin. Further research should expand my analysis of flow accumulation, stream order, and coho habitat by adding other hydrometrics such as stream temperature and land cover change to create a habitat suitability index that can be applied to restoration projects and initiatives. The second limitation to this analysis was the lack of headwater stream flow accumulation data that the filled in raster layer provided. The lack of streams delineated from the raster layer resulted in a disconnected stream network that was substituted for NHDPlus flowlines.

Conclusion

This analysis of coho habitat trends in relation to flow conditions and stream delineations showed that coho spawn in first-order stream areas with low discharge conditions. From using DEM stream delineation, the lack of flow accumulation shown demonstrated the need for alternative methods to highlight headwater stream systems in geospatial analyses. Altogether, this work has illuminated the site conditions of the three tributaries in the Smith River that I am working with for my thesis research and has shown the presence of coho is largely determined by specific hydrometrics. My future research will show how stream temperature regulates coho migration and spawning cycles and project how these changes will be impacted in future climate regimes, building off of this analysis of current coho and stream condition trends within the Umpqua River Basin.

Appendix

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