# GIS in Juvenile Salmonid Habitat Analysis

**An annotated bibliography project for Oregon State University's GEOG 560: GIScience 1 - Introduction to Geographic Information Science**

The continued decline of Pacific salmon is often attributed to four factors: habitat, hydropower, harvest, and hatcheries. I believe that the most important of these is juvenile rearing habitat. Estimating the productivity of individual reaches of rivers often is a time-consuming effort to collect data on fish abundances and distributions, land-use and habitat characteristics, abiotic factors such as temperature, slope, substrate type, and stream flow, and energy supply through the availability of food items. Geographic Information Systems (GIS) offer an alternative view by looking at landscape-scale data in place of or in conjunction with site-scale data. In some cases, landscape-level features may provide a more accurate assessment of the habitat available for juvenile salmonid rearing. The spatial analysis tools in a GIS also offer the potential to identify at-risk areas, areas that should be prioritized for restoration, areas where monitoring should be focused, or the potential effects of climate change.

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**Battin, J., Wiley, M.W., Ruckelshaus, M.H., Palmer, R.N., Korb, E., Bartz, K.K., and Imaki, H. 2007. Projected impacts of climate change on salmon habitat restoration. Proceedings of the National Academy of Sciences (PNAS) 104(16):6720-6725.**

Habitat restoration is one of the most popular components of salmon recovery plans. However, habitat restoration planning rarely accounts for future climate conditions which may negate restoration work. For restoration projects to have lasting impact on salmon recovery, they need to be applicable to future environmental conditions, particularly temperature and flow. Battin et al. (2007) used ArcGIS to create models to analyze the impacts of habitat restoration in predicted climatic conditions, focusing on warmer headwater stream temperatures, earlier snowmelt, and lower snow-based precipitation. Higher rain:snow ratio of precipitation may lead to more winter peak flows or floods, resulting in greater scouring, which destroys incubating eggs as well as benthic food sources for juvenile salmonids. Low snowpack levels are already known to result in lower base flows in summer, which increases summer water temperatures and decreases suitable habitat. Battin et al. (2007) modeled Chinook salmon distribution under various predicted climate change scenarios and under different levels of restoration effort. Under current land use, river temperature will be 0.69 to 0.74 degrees C higher in 25 years. However, under moderate or full restoration, 0.03 to 0.04 or -0.13 to -0.16 degrees higher, respectively. Peak flow will increase by 5.1 to 13% in 25 years under current land use but will only increase by 1.2 to 1.5% under moderate restoration and actually decrease by -1.1% under full restoration. ArcGIS was also used to create a land conversion model to predict urban growth and overlay the effect on juvenile salmonid rearing habitat.

**Brodeur, R.D., Suchman, C.L., Reese, D.C., Miller, T.W., and Daly, E.A. 2008. Spatial overlap and trophic interactions between pelagic fish and large jellyfish in the northern California Current. Marine Biology 154:649-659.**
When ocean currents and temperatures change, the geographic distribution of coastal fishes changes too, introducing novel interactions. Brodeur et al. (2008) used a GIS to analyze spatial overlap between jellyfish and several species of pelagic fish, including salmon, to determine if the range expansion of jellyfish had resulted in new interactions, particularly trophic overlap. They found that jellyfish diets were similar to small pelagic fishes (e.g. herring, anchovy), implying potential for feeding competition. Spatial overlap with juvenile Chinook and coho salmon was 15.1-48.1% and 8.5-36.3%, respectively. Diet overlap with juvenile salmonids was minimal. While direct diet overlap was a non-issue, the potential impact to juvenile salmonids still exists because the prey of juvenile salmonids feeds at a similar trophic level as the jellyfish and this competition could result in a decrease in salmonid prey items if there was a shortage of food for the jellyfish and herrings or anchovies.

**Creque, S.M., Rutherford, E.S., and Zorn, T.G. 2005. Use of GIS-derived landscape-scale habitat features to explain spatial patterns of fish density in Michigan rivers. North American Journal of Fisheries Management 25:1411-1425.**
By combining small-scale and landscape-scale patterns (geological features, chemical constituents, energy availability and flow), we can better understand the processes that shape the distribution, composition, and abundance of freshwater fishes. Creque et al. (2005) compared data collected on fish and habitats to see if landscape-scale habitat features would correspond to spatial distribution and density patterns for both juvenile and adult salmonids. Their GIS analysis provided a partial explanation of fish density patterns (18-69%) but did not exactly correlate with the smaller scale data, possibly because patches of suitable habitat result in high fish densities while surrounding area could be entirely unsuitable due to temperature or food availability. However, it was interesting that the site-scale habitat data explained even less (12-57%) of the variation in fish density patterns than the landscape-scale data variables did. So refugia seems to be less important than landscape-wide temperature, perhaps making the use of GIS technology more appropriate for predicting fish density in this system, offering a less costly way to estimate fish abundances across a large area.

**Ebersole, J.L., Colvin, M.E., Wigington, P.J., Leibowitz, S.G., Baker, J.P., Church, M.R., Compton, J.E., Miller, B.A., Cairns, M.A., Hansen, B.P., and LaVigne, H.R. 2009. Modeling stream network-scale variation in coho overwinter survival and smolt size. Transactions of the American Fisheries Society 138:564-580.**
While most studies on juvenile salmonid habitat use focus on summer rearing, overwinter survival is also strongly influenced by habitat. Ebersole et al. (2009) looked spatial patterns of juvenile coho overwinter survival and smolt size and found that basin area explained 57-63% of the spatial variation overwinter survival. They found that small headwater and intermittent streams had the highest juvenile coho survival rates. Interestingly, traditional habitat measurements such as pool area, substrate, and canopy cover did not predict overwinter survival. The scale at which restoration work is targeted focuses mainly on site-specific

variables, but this study found that basin-level variables, particularly basin area (as calculated with a GIS) may be more important coupled with access to headwater streams.

**Hatten, J.R., Batt, T.R., Connolly, P.J., and Maule, A.G. 2014. Modeling effects of climate change on Yakima River salmonid habitats. Climatic Change 124:427-439.**
Changes in the availability of suitable habitat for salmonids will play a large role in future productivity of these species. Hatten et al. (2014) produced a model combining watershed, river operations, hydrodynamic (discharge time series), and GIS models to test different climate regimes (baseline/last 25 years, 1 degree C increase in air temperature, and 2 degree C increase in air temperature). They looked at the impacts of these temperature increases on four life stages for coho and fall Chinook salmon for both main stem and side channels. Juvenile salmonid rearing habitats (fry and spring/summer rearing) showed the greatest potential for change due to warming and altered flow with a 7-16% decrease in habitat for juvenile Chinook and a 21-53% decrease in habitat for juvenile coho. They found that side channels provided more habitat than the main stem and could potentially benefit most from increased flow, which might mitigate climate change impacts, with their model predicting a 32-38% increase in spring/summer rearing habitat for both juvenile salmonid species when flows were increased.

**Heerhartz, S.M., and Toft, J.D. 2015. Movement patterns and feeding behavior of juvenile salmon (Oncorhynchus spp.) along armored and unarmored estuarine shorelines. Environmental Biology of Fishes DOI 10.1007/s10641-015-0377-5.**
Once juvenile salmonids migrate from their natal freshwaters to saltwater, most species spend time in nutrient-rich estuaries, growing large enough to survive ocean residence. Anthropogenic alterations to estuarine nearshore habitat threatens this essential growing phase. Heerhartz and Toft (2015) mapped and quantified feeding rates, movement rates, and path complexity of juvenile salmonids in both armored and unarmored shorelines. Using ArcGIS, they found that movement rates and path straightness varied between natural and altered shorelines, with greater movement diversity in unarmored shorelines.

**Holzapfel, P., Leitner, P., Habersack, H., Graf, W., and Hauer, C. 2017. Evaluation of hydropeaking impacts on the food web in alpine streams based on modelling of fish- and macroinvertebrate habitats. Science of the Total Environment 575:1489-1502.**
Changes in flow, particularly summer low/base flow and peak flow events (caused by flooding or hydropeaking from hydroelectric dam discharges) affect fish communities directly by creating adverse swimming conditions and indirectly by scouring away important prey items such as benthic macroinvertebrates. Holzapfel et al. (2017) used GIS-analysis to demonstrate the impact of hydropeaking on macroinvertebrates and fish as a negative relationship where juvenile salmonid feeding from the benthos is hindered in peak flow events, therefore shaping their primary feeding window to times of base flow only. They also found that base flow benthic feeding potential increased positively with morphological heterogeneity. In order to create their predictive model, they created digital terrain models (DTMs) from field surveys of geomorphologic structures (riffles, pools) and stream structure and depth measurements. They took bathymetry data during base flow as well.

**Hrachowitz, M., Soulsby, C., Imholt, C., Malcolm, I.A., and Tetzlaff, D. 2010. Thermal regimes in a large upland salmon river: a simple model to identify the influence of landscape controls and climate change on maximum temperatures. Hydrological Processes 24:3374-3391.**
Summer maximum temperatures are becoming a major threat to juvenile salmonids as more rivers reach fatal thresholds due to climate change. Hrachowitz et al. (2010) used a GIS to analyze relationships between landscape-scale controls and monthly maximum stream temperatures. They found that winter maximum stream temperature was controlled by elevation, catchment area, and hill shading but summer maximum stream temperature was driven by multiple variables, including site-specific riparian canopy cover and landscape-scale variables like distance to the coast. An increase of 4 degrees C could result in loss of approximately 5% of the small, inland, high elevation streams with little riparian shade included in this study of 25 salmonid bearing streams in Scotland.

**Isaak, D.J., Luce, C.H., Rieman, B.E., Nagel, D.E., Peterson, E.E., Horan, D.L., Parkes, S., and Chandler, G.L. 2010. Effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network. Ecological Applications 20(5):1350-1371.**
The effects of climate change will be especially dramatic in freshwater systems due to highly heterogenous systems providing niches for many species at different times during the year as well as during their lives. Isaak et al. (2010) looked at summer temperature data in a large river network in Idaho for 14 years and paired that data with spatial statistical models in ArcGIS (predictor variables included elevation, mean flow, radiation, and maximum air temperature), which explained up to 93% of the variation in thermal regime and maximum temperature. They found that wildfires also increased stream temperatures by 2-3 times when the streams were within the wildfire burn perimeter. When they compared these temperature shifts with the thermal requirements for bull trout, they found a loss of 11-20% of the headwater habitat essential for juvenile salmonid rearing and adult spawning.

**Keleher, C.J., and Rahel, F.J. 1996. Thermal limits to salmonid distributions in the Rocky Mountain region and potential habitat loss due to lobal warming: A Geographic Information System (GIS) approach. Transactions of the American Fisheries Society 125:1-13.**
Maximum thermal tolerance is a key limiting factor in the distribution of juvenile salmonids in freshwater rearing habitat. Global climate change is predicted to increased stream temperatures, reducing suitable habitat drastically. Keleher and Rahel (1996) used a GIS to predict the loss in suitable juvenile salmonid habitat based on increased of maximum summer temperatures (although they used air and not stream temperature data). They found that an increase of 1 degree C in July would result in a loss of 16.2% of suitable salmonid habitat in their study area (a section of Wyoming), equivalent to a 7.5% reduction in suitable stream length. An increase of 5 degrees C would result in a loss of 68% of salmonid habitat, with a 43.3% reduction in suitable stream length.

**Luck, M., Maumenee, N., Whited, D., Lucotch, J., Chilcote, S., Lorange, M., Goodman, D., McDonald, K., Kimball, J., and Stanford, J. 2010. Remote sensing analysis of physical complexity of North Pacific Rim rivers to assist wild salmon conservation. Earth Surface Processes and Landforms DOI: 10.1002/esp.2044**
Freshwater habitat loss due to anthropogenic degradation (through altered flow and increased pollution) is a major factor in the reduced survival and productivity of imperiled Pacific salmon. The underlying physical structure of landscape-scale geomorphological features can be measured with remote sensing and compared with field measures of biological productivity (juvenile salmonid abundance or density) to assess the potential productivity of rivers using GIS tools. Luck et al. (2010) analyzed over 1500 catchments and, where data were available, measured productivity and found that relationships between landscape features and empirical biological data were strongly related. They used digital elevation models (DEM) and satellite imagery in a GIS to calculate channel length, floodplain area, and density of river nodes. Remote sensing from Landsat was processed into landscape feature classes which was then broken down to instream habitat (large wood, water temperature, spawning and rearing habitat) to produce proxies for salmon abundance and riparian primary productivity (Luck et al. 2010). This study is important because it compares physical complexities in salmon-bearing streams using remote sensing to field data to produce a model of river productivity based on physical complexity on a large scale.

**Mantau, N., Tohver, I., and Hamlet, A. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102:187-223.**
The summer growing season for juvenile salmonids also presents some of the toughest environmental conditions. Climate change threatens to make this stressful period of time even more challenging for young salmon, potentially reducing their productivity. By evaluating temperature and flow, two important abiotic factors, Mantau et al. (2010) created a model that predicts loss of snowmelt dominated rivers by the 2080s, negatively impacting juvenile salmonid rearing habitat. They predict a shift to more rain-dominant streams that will be subject to higher summer temperatures and low summer flow coupled with increased winter flooding, possibly creating adverse conditions for juvenile salmonids. They used ArcGIS to visualize their model of temperature and flow changes over time coupled with upper thermal tolerances of 6 common salmonids, resulting in a stunning depiction of stressful and fatal conditions in much of the area currently occupied by salmonids. Additionally, they show that stressful stream temperature and low flow conditions will occur for more weeks each year due to a warming climate. This combination of a spread of temporal and spatial stress is very concerning.

**Mollot, L.A., and Bilby, R.E. 2008. The use of geographic information systems, remote sensing, and suitability modeling to identify conifer restoration sites with high biological potential for anadromous fish at the Cedar River Municipal Watershed in western Washington, U.S.A. Restoration Ecology 16(2):336-347.**

In addition to informing the current status of fish stocks, Geographic Information Systems (GIS) can be used to identify high priority areas for habitat restoration to improve freshwater productivity of salmonids. Riparian areas are directly linked to habitat suitability for juvenile salmonids due to the input of allochthonous food, large wood that alters stream flow and provides velocity refuge, shading to cool stream temperatures, and bank stabilization to control sediment inputs. Mollot and Bilby (2008) created a model combining remotely sensed data (riparian vegetation, geology, and habitat preferences of salmonids) to identify riparian areas with the greatest potential for aiding the recovery of important salmon populations. They used LiDAR digital elevation models (DEM), terrain data, and hyperspectral imagery to look at geomorphic layers, riparian forest cover, and gradient by classifying each layer with a focus on suitability/preference of juvenile steelhead and juvenile coho salmon. Their model is an exciting step in targeted habitat restoration.

**Sponseller, R.A., Benfield, E.F., and Valett, H.M. 2001. Relationships between land use, spatial scale and stream macroinvertebrate communities. Freshwater Biology 46:1409-1424.**
Surrounding land use practices and the availability of food are often used as proxies for evaluating the suitability of juvenile salmonid rearing habitat at large and small scales, respectively. While it is well known that land use influences aquatic invertebrate communities, Sponseller et al. (2001) present a spatial analysis that suggests that the magnitude of that influence may be mediated by the spatial distribution of different land uses within catchments. They used a GIS to compare land use as determined by land cover at varying scales with benthic macroinvertebrate community structure samples and stream temperatures. They suggest that interspersing forested sections of land in otherwise human-dominated land-use sections, may increase macroinvertebrate productivity and diversity within streams.

**Torgersen, C.E., Gresswell, R.E., and Bateman, D.S. 2004. Pattern detection in stream networks: quantifying spatial variability in fish distribution. GIS/Spatial Analyses in Fishery and Aquatic Sciences 405-420.**
The use of GIS tools to analyze spatial distribution of the heterogeneous, biotically and abiotically influenced, small-scale fish habitats that make up large freshwater networks is extremely difficult. Torgersen et al. (2004) used longitudinal profiles of steams overlayed with 3D digital elevation models, fish abundance survey data, and stream habitat/morphology data to analyze spatial patterns in cutthroat trout distribution, thus combining landscape-scale and site-scale data into one visualization.

**Webb, A.D., and Bacon, P.J. 1999. Using GIS for catchment management and freshwater salmon fisheries in Scotland: the DeeCAMP project. Journal of Environmental Management 55:127-143.**
By combining field data with computer-based analyses such as the tools provided by a GIS, fisheries managers can identify larger-scale priorities for surveying, habitat restoration, or fish recovery/stocking. Webb and Bacon (1999) created a GIS tool to look at physical features such as stream slope and width (derived in ArcGIS from digital terrain models), stream flow, and

water quality measurements combined with field survey data describing fish populations through electrofishing in order to identify key areas vital to salmon productivity as well as those areas that would benefit most from monitoring or restoration work in Scotland.

**Whited, D.C., Kimball, J.S., Lorang, M.S., and Stanford, J.A. 2011. Estimation of juvenile salmon habitat in Pacific Rim rivers using multiscalar remote sensing and geospatial analysis. River Research and Applications DOI: 10.1002/rra.1585**
Key components of juvenile salmonid habitat are often used to determine suitability of rivers and floodplains for rearing. Whited et al. (2011) used remote sensing data and digital elevation models to extract physical/geospatial habitat characteristics including channel sinuosity, nodes, and floodplain width and compare these characteristics at different spatial scales to look for correspondence between scales. The ability to utilize larger scale data would allow for effective habitat assessment without the need for expensive, time-consuming, highly specific local small-scale data needs currently used. They found that moderate and fine scale analyses corresponded well. This correspondence was used to predict juvenile salmonid habitat at a fine scale based on larger scale data. By identifying key juvenile salmonid rearing habitat, they hope to inform restoration efforts to focus on the most potentially productive areas. They used a GIS to analyze the distribution of these floodplain habitat abundances.

**Wissmar, R.C., Timm, R.K., and Bryant, M.D. 2010. Radar-derived digital elevation models and field-surveyed variables to predict distributions of juvenile Coho salmon and Dolly Varden in remote streams of Alaska. Transactions of the American Fisheries Society 139:288-302.**
The biggest limitation in estimating juvenile salmonid abundance and stream productivity is the man-power required to survey reaches, especially those in remote areas. Technological advances offer new tools to help predict fish distribution and abundance by pairing geological information with field surveys to identify predictive variables that can be analyzed remotely. Slope is often considered one of the key attributes of juvenile salmon habitat. Wissmar et al. (2010) used measurements of channel gradient from field surveys compared to gradients produced from analysis of digital elevation models (DEM) to explain the density distribution of juvenile coho salmon and Dolly Varden in remote Alaskan streams at a reach-level. They found the highest densities of juvenile salmonids in habitats with a high number of pools, low distances between pools, and an abundance of large wood. Channel gradients (slopes) explained most of this variation. Slope/gradient estimates, watershed area, and stream length were calculated with ArcGIS software using the DEM.