208-8009-6215 Integrated Dynamic Landscape and Coho Salmon Model

Interim Report (January 2008 – October 31, 2008)

E. Ashley Steel (NOAA), Kelly Burnett (USFS), Pete Lawson (NOAA)

We report progress between the date of contract signature (January for USFS and March for NOAA) and October 31, 2008. We have made significant progress on our first objective, developing statistical models for the entire Oregon Coast Range relating habitat and coho salmon to landscape characteristics. We have initiated work on the second task, developing dynamic models.

Statistical Modeling of Coho Salmon

We have completed all spatial data preparation and preliminary GIS analysis for four multi-year, multi-site fish and habitat datasets in the Oregon Coastal Province. Products include a dataset describing all coho salmon surveys at index reaches (about 40 sites) and all coho salmon surveys that were completed using a probabilistic sampling scheme (about 100 sites). We have also prepared a juvenile coho dataset from about 25 sites and a dataset on fish habitat (e.g. stream width, substrate composition, large woody debris) from about 50 sites. Each site with adult, juvenile, or habitat data, has been assigned to the appropriate reach within our stream network coverage. We have delineated watershed boundaries around the stream networks for each site and we have acquired, summarized, and characterized landscape data within each delineated watershed.

We have completed statistical analysis of the adult coho salmon data from index sites to answer the questions "How do landscape condition affect adult coho distribution?" and "At what scale are these relationships most evident?" We have compared our results to similar models developed for steelhead and Chinook salmon as well as to similar models for coho salmon in the Snohomish River. A draft manuscript has been prepared and sent through the full NOAA internal review process. It has begun the ODFW review process and should be submitted in early 2009 to Transactions of the American Fisheries Society. A current draft is attached.

We have completed the analyses for adult coho salmon at the randomly sampled sites. The analysis of this dataset required significantly more complex statistical analyses than anticipated because of the large number of sites with zero spawners in one or more years. These zeros may result because of population declines or because the randomly sampled sites cover a much wider range in site quality than previous datasets. For this dataset, we related estimates of adult coho salmon to landscape conditions using a simple linear regression based on site mean number of adults over all surveyed years, a hierarchical mixed model, and a rank-based analysis. To further investigate the impacts of the zeros on the analysis we also completed a two-step logistic model to predict the zeros, a negative binomial model, and a model on all non-zero observations. Because these models did not fit as well as previous analyses based on index sites, we also considered that potentially important landscape predictor variables might have been missing. To this end, we developed new flow variables, new marine survival variables, and incorporated variables describing intrinsic habitat potential (based on previous analyses by Burnett et al (2007) in Ecological Applications). None of these new variables were able to explain a substantial amount of variation.

To compare the probability dataset with spawner datsets used for other analyses (above index site data set and Pess et al. 2002 in Canadian Journal of Fisheries and Aquatic Sciences), we also did a variance partitioning analysis for all three datasets. These statistical analyses were completed mainly in Spring and Summer 2008 and required about 12 hours of conference calls as well as all available time of statistical consultant, David Jensen. Not all analyses will be reported, but a draft manuscript of key findings has been prepared and is in co-author review. A current draft is attached at the end of this report. It contains notes to co-authors, typos, and needs considerable work; however, it provides a summary of the statistical and spatial analyses completed.

Mapping of historical splash damming in the Oregon Coast Range

To provide context and help interpret results from the statistical modeling, Rebecca Miller, a MS student in the Department of Fisheries and Wildlife at OSU, is mapping the location of historical splash dams and comparing recent habitat conditions and coho salmon abundances between areas that have and have not been splash dammed. Splash dams were a common tool for log transport in western Oregon, beginning in 1884 until prohibited in 1957. Few formal studies have assessed the environmental legacy of stream modification and disturbance caused by historical splash dams; yet, much literature cites splash dams as one of the key historical culprits in the decline of salmon populations. A draft map and geodatabase of individual splash dams sites from 1884-1957 has been completed from historical records and museum accounts. A study plan (attached) was approved by Miller's graduate committee. The study plan includes field methods for evaluating accuracy of the splash dam map, spatial analysis methods for associating locations of splash dams with fish and habitat data in a GIS, and analytical methods for comparing stream habitat and fish abundances in areas that have and have not been splashed dammed.

Dynamic Landscape Model

The development of a spatially-explicit dynamic landscape and coho salmon model will depend on the results of the analyses above which are only recently completed. Post-doc Mark Meleason, who is just now completing the federal hiring process, will work with Dan Miller to build the new model.

The first step, aquiring composite models, has been completed in advance of Mark Meleason's arrival. Composite models that have been aquired:

- forest disturbance under natural regimes (Wimberly et al., 2000)
- forest disturbance under current and proposed management (Bettinger et al., 2005)
- landslide susceptibility (Miller and Burnett, 2007 and Miller and Burnett 2008)
- wood recruitment (Miller in prep; Gregory et al., 2003)
- instream sediment (Benda and Dunne, 1997a);
- and instream wood (Benda et al., 2003) fluxes.

We anticipate that Mark Meleason will be hired by mid-February 2009 and will begin the following steps:

1. Altering the current code to accept adjustable parameters.
2. Determining empirical parameter values for storm characteristics, soil production rates, sediment grain-size distributions, basin sediment yields, and sediment attrition rates. Geomorphic parameters can be obtained from the literature (e.g., Benda and Dunne 1997b, a); climatic parameters will be calibrated from regional hourly precipitation data.
3. Incorporating fire models appropriate for the Coast Range (Wimberly et al. 2000, Wimberly 2002).
4. Coupling the model forest growth and harvest models (Bettinger et al., 2005). These models will estimate stand characteristics and downed wood required for calculating rates of wood recruitment to stream channels. This will allow us to use the CLAMS scenarios of forest cover under human management as inputs to the sediment flux models (Johnson et al. in press).
5. Use wood recruitment to streams, sediment parameters, and flow to model reach-specific pool structure.

Coho Simulation Modeling

A reach-scale coho salmon life cycle model based on wood and pool structure will be constructed by Mark Meleason, Pete Lawson, and Dan Miller. This step depends on results from steps 1 and 2 and will begin in mid-2009.

Landscape models of coho salmon (*Oncorhynchus kisutch*) distribution in western Oregon: implications for management associated with spatial extent

J.C. Firman, E.A. Steel, D.W. Jensen, K.M. Burnett, K. Christiansen B.E. Feist, and D.P. Larsen

Abstract: We modeled the spatial distribution of spawning coho salmon (*Oncorhynchus kisutch*) as a function of landscape characteristics such as geology, road density, climate, land cover, and land use. We measured habitat using geospatial data layers at four spatial extents (100 m buffer, 500 m buffer, all adjacent hydrologic units: mean area =18 km^2, and the catchment upstream of the reach: mean area =17 km^2). Land use, land ownership, geology and climate variables described a significant ($r = 0.67$ to 0.75) proportion of the variation in the distribution of adult coho salmon in the study area, a portion of the Oregon Coastal Coho Evolutionarily Significant Unit (ESU). In general, coho densities were greatest in undeveloped forest land with less sedimentary geology, lower densities of cows and roads, and in areas with a greater range in daily maximum and minimum winter temperatures. Because salmon occupy large areas over which detailed habitat surveys are not feasible, the ability to predict the spatial distribution of coho salmon spawners has great utility in guiding conservation and restoration efforts.

Introduction

A broad spatial perspective is increasingly recognized as important for conserving freshwater ecosystems. High resolution, spatially extensive data on populations and habitats are necessary to understand and manage widely distributed species. Collecting field data with the necessary spatial extent is prohibitively expensive and time consuming; therefore, such data are generally lacking. To fill this gap, statistical relationships have been developed that can predict site-specific conditions from landscape characteristics. Characteristics of salmonid populations or their habitats have been successfully modeled from landscape characteristics (e.g., Burnett *et al.* 2006). Such modeling may benefit efforts to conserve many at-risk populations of migratory fish (NRC 1996) by predicting site-specific population performance or habitat conditions (Steel *et al.* 2004), describing broad-scale patterns of population distribution (Feist *et al.* 2003), and suggesting mechanisms by which landscape patterns may impact abundance and distribution of fishes (Pess *et al.* 2002).

Emphasis on these broad-scale landscape approaches has been increasing, with much of the attention given to identifying the best or most appropriate spatial scale for modeling efforts (e.g. Fausch *et al.*, 2002, Feist *et al.* 2003, Burnett *et al.* 2006). Watershed size and the assumed mechanism by which a landscape feature, such as road density, impacts in-channel conditions drive the a priori selection of analytical scale. Previous studies have also shown that a multi-scale approach can suggest the extent over which, and mechanisms by which, landscape conditions affect in-stream conditions (e.g. Feist *et al.* 2003; Torgersen and Close 2004, Burnett *et al.* 2006). Consequently, spatial approaches have been developed which summarize landscape characteristics at multiple spatial extents.

Previous efforts to identify the needs of stream-dwelling populations have usually focused on local in-stream and riparian conditions (Fausch *et al.* 1988). These studies have made a great deal of progress in characterizing relationships between in-stream habitat conditions and coho salmon populations. Habitat quality, specifically the abundance of woody debris and pools, can be used to predict the survival rate and carrying capacity for coho salmon smolts in Oregon streams (Nickelson and Lawson 1998). Coho salmon exhibit seasonal preferences for different types of habitat (Nickelson *et al.*, 1992b). During high winter flows, juvenile coho salmon are associated with beaver ponds, dammed pools and alcoves, and these types of habitat limit coho salmon production in most Oregon streams (Nickelson *et al*. 1992a, Nickelson *et al.* 1992b, State of Oregon, 2005). Addition of large woody debris, alcoves and dammed pools has resulted in increased abundance and over-winter survival of juvenile coho salmon (Solazzi *et al*., 2000, Johnson *et al*., 2005). In-stream relationships also depend on population dynamics; when marine survival is low and adult returns are few, only the best freshwater habitats will support viable coho salmon populations (Nickelson 1998).

Fine-grained habitat characteristics are dynamic; for example, wood and sediment can be washed away or deposited over the course of a season. The fact that fine-grained habitat features can be altered facilitates in-stream restoration projects, but the corollary is that conditions in the stream are not necessarily a good predictor of the potential productivity of a given stream reach. Fine-grained relationships can provide an understanding of which in-stream characteristics are desirable for a species and tell us where in-stream habitat is currently good or poor, but they cannot predict the potential of a particular reach or set of reaches to support fish. Broader-scale approaches tell us how watershed conditions over large areas may influence stream conditions and fish production, or where to prioritize restoration, even among areas where in-stream habitat is poor. Addressing these two needs is critical for conserving freshwater species. Many landscape characteristics are less mutable than in-stream characteristics when considered over short periods, and broad scale factors can be good predictors of the distribution and abundance of fish and aquatic invertebrates (Richards *et al.* 1996, Creque *et al.* 2005, and Burnett *et al.* 2007).

In this paper, we expand the current understanding of how animal populations are linked with landscape conditions by developing and comparing models which predict densities of adult coho salmon across a large region of western Oregon from landscape characteristics characterized over four spatial extents. We chose to focus on adult coho salmon in this area for several reasons. There are grave and pervasive public concerns about the persistence of coho salmon populations (State of Oregon, 2005). There is detailed knowledge about fine-grained associations between coho salmon and their stream habitats for many life-history stages (e.g. Nickelson *et al.* 1992b, Johnson *et al*., 2005, Burnett *et al.* 2007). Coho salmon provide an opportunity to adapt and expand on landscape modeling approaches that were developed for other salmonid species in other regions (e.g., Feist *et al.* 2003; Steel *et al.* 2004). This study provides a rare opportunity in that we have high quality data layers for both the predictor and the response variables. A large number of survey reaches (N=44) are evenly distributed over a large geographic area (20,305 km^2) and have been sampled consistently for decades; 17 of 50 years of data were used for this study. Finally, high-resolution geospatial habitat data are available for this region. Our approach also provides an opportunity to adapt, expand, and compare landscape modeling approaches that were developed for other salmonid species or in other regions (e.g. Pess *et al*. 2002, Feist *et al.* 2003; Steel *et al.* 2004). Our specific objectives are to identify landscape characteristics that predict densities of adult coho salmon; compare model results when landscape characteristics are summarized at four spatial extents; predict densities of coho salmon densities across the west slope of the Oregon Coastal Province, and consider the implications of our results for conservation and management

Materials and Methods

Study Area

We conducted our analyses in the region where the Oregon Coastal Coho Evolutionarily Significant Unit (ESU) (Weitkamp *et al.* 1995) overlaps the Oregon Coastal Province (Figure 1; 20,305 km^2). The Coastal Province of Oregon encompasses approximately 2.5 million ha and is underlain primarily by marine sandstones and shales or basaltic volcanic rocks. Except for interior river valleys and a prominent coastal plain in places, mountains dominate the area. Elevations range from 0 to 1250 m, though most coho salmon habitat occurs at lower elevations and in areas of lower gradient. Montane areas are highly dissected, with drainage densities up to 8.0 km/km2. The climate is temperate maritime with mild, wet winters and warm, dry summers. Peak stream flows are flashy following winter rainstorms, and base flows occur between July and October. The Nehalem and Umpqua Rivers drain the largest areas, with mean annual stream flows in the lower mainstems of 123.7 and 256.1 m^3/s, respectively. Although we address only coho salmon, four other salmonid species reside in the study area: coastal cutthroat trout (*O. clarki*), chinook salmon (*O. tschawytscha*), chum salmon (*O. keta*), and steelhead (*O. mykiss*) (Hoeoek *et al.* 2004). The study area supports a highly productive coniferous forest dominated by Douglas fir (*Psuedotsuga menziesii*)(Mirb.)Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), red alder (*Alnus rubra*) and along the coast, Sitka spruce (*Picea sitchensis* (Bong.) Carr). Typical additions in riparian areas are western red cedar (*Thuja plicata* Donn ex D. Don) and big leaf maple (*Acer macrophyllum* Pursh). Forests span early successional to old-growth seral stages due to a disturbance regime driven by timber harvest and recent fire suppression, and by past infrequent but intense wild fires and windstorms

(Franklin and Dyrness 1988). Most of the current forestland is in relatively young seral stands, but the larger river valleys have been cleared for agriculture (Ohmann and Gregory 2003).

The majority of the land is in private ownership and about a third is publicly managed (Spies *et al*. 2007). Close to 90% of the stream reaches with the highest potential to produce coho salmon occur on private lands (State of Oregon, 2005, Burnett *et al*. 2007). The legacy of past management practices, particularly those associated with logging, channelization, road building and conversion of forested lands to agriculture, has left coho salmon reaches with a scarcity of large wood in stream (Wing and Skaugset 2002), a lack of conifers in riparian areas, reduced interactions with off-channel alcoves and flood plains, and accumulations of fine sediment and gravels (State of Oregon 2005). Roughly half of the riparian areas adjacent to streams that support coho salmon is non-forested or has been recently logged (Burnett *et al*., 2007)

Index surveys of coho spawner abundance

The Oregon Coastal Coho ESU encompasses all coastal basins south of the Columbia River to Cape Blanco (Ecola Creek through Sixes River; Weitkamp *et al.* 1995). This includes 18 independent coho salmon populations, and another forty-one dependent populations (Lawson *et al.* 2004). Lawson *et al.* (2004) define an independent population as one that is able to sustain itself without inputs from other populations, and a dependent population as a population that is dependent on immigration from surrounding populations to persist. Adult coho salmon return to the region to spawn in their natal streams from October to February.

Spawning salmon in Oregon coastal streams have been continuously monitored by the Oregon Department of Fish and Wildlife (ODFW) since 1950 (Jacobs and Cooney 1997). Easily accessible stream reaches that consistently supported many coho salmon adults were selected to index abundances of spawners. They are not representative of the range of reaches that support spawning. Index reaches are annually surveyed every 7-10 days from mid October until late January. Live and dead coho salmon adults are recorded on each visit. Our analysis used annual counts of the maximum number of adult coho salmon observed on a single visit to a stream reach (peak counts) recorded at each of 44 index reaches. Surveys from the Lakes Basins were excluded (Siltcoos Lake, Tahkenitch Lake and Tenmile Lake) because coho salmon production in these basins is very high due to the high juvenile survival in coastal lakes in these watersheds (Nickelson 1998). The life histories of coho salmon in these basins are substantively different from the rest of the coast (Nickelson 1998), and we believed that including these reaches would decrease overall model performance. The data from 1981 to 1997 were selected because this coincided with the period represented by several of the geospatial data layers used in this study. The index reaches were georeferenced to the US Geological Survey 1:100,000 scale digital line graph (DLG) hydrographic layer using a geographic information system (GIS, Environmental Systems Research Institute ArcMap v. 9.1). Peak counts were standardized by dividing the number of fish present by the length of the index reach surveyed (fish / km).

Geospatial Data Layers

We used geospatial data layers that represented inherent (e.g. climate, topography, and rock type) and management-related (e.g., land cover, use, and ownership) characteristics of landscapes (Table 1). These characteristics are thought to influence the distribution and abundance of coho salmon in the Oregon Coastal Province. For example, coho salmon prefer small, low-gradient tributaries for building redds (Burner 1951), and thus stream gradient and mean annual flow were considered as potential predictor variables in our modeling. In addition, streams that contain deep, shaded pools with cover such as logs and tree roots are important to juvenile coho salmon (e.g. Hartman 1965; Narver 1978; Scrivener and Andersen 1982), and so we considered potential predictor variables reflecting land management that may influence such habitat attributes (e.g., Naiman and Bilby 1998). The geospatial data layers we used are similar to those examined in other studies of landscape modeling for streams (e.g., Van Sickle *et al*. 2004; Steel *et al*. 2004; Burnett *et al*. 2006).

The suite of landscape variables was summarized at each of four spatial extents (100-m streamside buffer, 500-m streamside buffer, 7th field Hydrologic Unit (HU): mean area =18 km^2, and the entire catchment flowing into a given study reach: mean area =17 km^2) centered on each index reach (Figure 2). Processes acting immediately adjacent to the channel (e.g., tree mortality in riparian stands) would be most important in the two streamside buffer extents, while the two larger extents would also be affected by hill slope processes (e.g., surface erosion and landslides). The streamside buffers extended 100 m or 500 m on either side of each index reach as delineated in GIS on the 1:100,000 USGS stream layer. The 100-m buffer was chosen because it approximates the average height of mature trees in the study region and is the width of riparian management areas for fish-bearing streams under the Northwest Forest Plan (USDA and USDI 1994). The watershed was chosen because conditions in a stream are a function of landscape characteristics in the surrounding catchment (Hynes 1975, Frissell *et al*. 1986, Naiman *et al*. 2000). The 500-m buffer was chosen primarily for consistency with previous work (Feist *et al.* 2003). The HU was chosen for to compare modeling outcomes between HUs and catchments. If results are similar, then existing HUs may be used in future modeling efforts, eliminating the need to delineate reach-specific catchments.

Model Development

Mixed models that included a random intercept and an autoregressive moving average (ARMA) correlation structure were fit using Proc Mixed in SAS (Littell *et al.* 1996). The dependent variable in all cases was the peak count of coho salmon adults/km, which was log-transformed to meet normality assumptions (hereafter called peak spawner densities). To select the set of best models from multiple potential predictors, we followed a four-step approach that was repeated for each of the four spatial extents.

First, we fit the null model (intercept only), then all one-variable models and all combinations of two-variable models. Quadratic terms were included as a potential second variable and at this stage models were fit both with and without intercepts. All two-variable models with an AIC less than that of the null model were retained. We also assessed whether the intercept term improved model fit. We then created and fit three-variable models from the retained two-variable models by singly adding all other variables.

Second, we identified a set of candidate models using the difference in Akaike information criterion (AIC) values between each model and the lowest AIC among all models, ΔAIC. Candidate models include all models with a ΔAIC less than four. Third, we applied three criteria to remove models from the candidate list because of various forms of model instability. A condition index (Belsley *et al*. 1982) was calculated for the set of variables in each model to identify those models with high collinearity. Models with a condition index > 10 were rejected. Cook's D was calculated for all models to identify unstable models due to data points with high leverage (Cook 1977). Models with data points for which Cook's D > 1.00 were eliminated. We then conducted a cross-validation analysis to eliminate models with low predictive power. We generated 1000 bootstrap validation sets by randomly selecting 90% of the observations. We then fit the model, predicted the response for the remaining 10% of the observations and calculated the correlation between these observed and predicted values, the mean correlation for the 1000 bootstrap samples, $\overline{V}$, and the mean of $\overline{V}$ across all candidate models, $\overline{\overline{V}}$. If ($\overline{V}_{max}$ - $\overline{V}_{min}$) < 0.01, models for which $\overline{V}$ < lower 95% CI of $\overline{\overline{V}}$ were eliminated. If ($\overline{V}_{max}$ - $\overline{V}_{min}$) ≥ 0.01, models in which $\overline{V} < \overline{\overline{V}}$ were eliminated.

Fourth, we selected the set of best models from those that met all three of the above criteria by ranking them according to ascending AIC and calculating AIC weights (Burnham and Anderson 2002). The set of best models are those such that the AIC weight of the next model is less than 0.05 or the AIC-weight of the next model is less than 0.10 and the sum of the AIC-weights for the current set of models is greater than 0.50. Final predictions of relative peak spawner densities used a weighted average of the predictions from each of the models in the best set. Weights in the weighted average were AIC weights, recalculated for the set of best models. We also estimated generalized R-squared values for each of the mixed models in the set of best models using the approach of (Nagelkerke 1991). This method quantifies the difference in the fit of the model with that of a "null" model, i.e. a model with an intercept only.

Results

Correlations

Correlation matrices for predictor variables are presented in Tables 2a and 2b. At each extent, predictor variables describing land management (e.g., percent area in agriculture and percent area in non-forest) or land management and ownership (e.g., percent area in big trees and percent area in USFS) tended to be highly correlated with each other. Predictor variables describing inherent characteristics (e.g., summer temperature range and maximum annual temperature) also tended to be correlated at each extent. Although patterns of correlation were similar among extents, some differences were apparent. For example, the percent area in large diameter trees was highly correlated ($r = -0.61$) with road density at only the 500-m buffer scale. The number of correlations we considered to be high ($r \geq |0.60|$) was larger for the watershed and HU extents than for the two buffer extents, and more high correlations were observed for the 500-m than for the 100-m buffers.

The response variable, peak coho salmon spawner density, was generally most correlated with Parameter-elevation Regressions on Independent Slopes Model (PRISM) Climate predictor variables at each extent examined, and most specifically with winter temperature range, maximum annual temperature, and mean annual precipitation. For each of the correlated groups of predictors, only the variable with the highest correlation (or partial correlation) with peak spawner density appears in a given final model because of the elimination of models with moderate to high condition indices.

Models

Twenty-one models to predict relative peak spawner densities met the criteria set out in the methods section (Table 3). Of these, five models described the 100 m buffer extent, four described the 500m buffer extent, six described the HU extent, and six described the watershed extent. The average correlations between observed and predicted values from bootstrap validation ranged from 0.67 to 0.75 (Figures 3a-d). The amount of variation explained by each model, R^2, ranged from about 38% to 44%, with models generally explaining the most variation at the HU extent and the least variation at the 500-m buffer extent.

No single variable appeared in all 21 models to predict the peak spawner densities, however winter temperature range occurred in 20 out of 21 models (Table 3). At each extent, the percent area in erosive rock types (weak rocks) appeared in multiple models. Models contained other rock types (percent area of intermediate rocks or percent area of resistant rocks) at only the watershed extent. Cow density appeared in models at each buffer extent, while road density appeared in models at each watershed extent. Land ownership variables (i.e., percent area in BLM, private non-industrial, or private industrial) appeared in models at all except the 500-m buffer extent. The management-related variable, percent area in non-forest, also appeared in models at all except one extent. At the 100-m buffer extent, the management-related variable, percent area in small diameter trees, appeared in one model.

Predicted versus observed responses were highly correlated at all extents (Figures 3a-d). In general, models had more predictive power at the broader spatial extents (HU and watershed) than at the finer spatial extents (100 m and 500 m buffers), but the differences were small.

Predictions

Geographic representation of predicted relative responses shows a great deal of homology among models (Figure 4). Relatively high values of predicted peak spawner densities were concentrated in the southern portion of the domain for both buffer extents and for the HU extent. For the watershed extent in the south central portion of the domain, values of many predictor variables were outside the range of those used in constructing the models and thus predictions were not made. Relatively low peak spawner densisites were predicted in the central portion and near the northern edge of the domain for each extent. More fine-scale variation was evident in predictions from the models at broader spatial extents (watershed and HU) than at the two buffer extents.

Discussion

This work contributes to a growing body of literature examining the relationships between landscape characteristics and in-channel conditions. Like earlier studies, we found that landscape characteristics could explain a substantial percentage of the variation in peak spawner densities of coho salmon across the Oregon Coastal Province. This was the first study to examine relationships between coho salmon and landscape characteristics across the Oregon Coastal Province.

It should be emphasized that we do not intended to explicitly predict coho salmon densities or to define mechanistic relationships between landscape variables and fish production. Rather our aim is to predict the relative density of adult coho salmon, and to identify testable hypotheses regarding relationships between salmon abundance and landscape characteristics. The response variable for modeling is based on the mean of fish densities over 17 years, consequently we interpret the results as indicating the relative productivity of stream reaches across western Oregon. Those sites with high average scores are expected to support higher densities of coho salmon spawners in both good and poor years, compared to those sites with low average scores.

Landscape factors associated with adult coho salmon distribution

Factors representing climate, geology and land management occurred in all reported models of relative peak spawner densities. At each spatial extent, the range of winter temperatures was a key predictor of peak spawner densities. The range of winter temperatures tends to be greatest in the south central portion of the study area. Peak spawner density was related to winter temperature range in all but one of our models. Because coho salmon are poikilotherms, temperature can influence growth and survival at all life-history stages. For example, warmer winter temperatures can accelerate juvenile growth, producing larger coho salmon smolts (Scrivener and Andersen 1982). Larger coho salmon smolts may survive better when ocean conditions are relatively poor (Holtby *et al*. 1990), a situation that marked the period for which we modeled peak spawner densities. More smolts may have returned as adults to areas of the Province experiencing wider ranges of winter temperatures that favored over-winter growth and larger smolts. It is also possible, that winter temperature range may simply be correlated with a key variable that we did not examine. Local ocean production might be partially responsible for the spatial patterns in peak spawner densities. Ocean recoveries of marked adult hatchery salmon display regional patterns (Weitkamp and Neely

2002) that are consistent with latitudinal patterns exhibited in winter temperature ranges and peak spawner densities.

Over half of all models at each of the four spatial extents contained a relationship between peak spawner densities and the percent of weak rock types. Coho salmon in western Oregon are thought to prefer sandstone streams, which are characterized by relatively low gradients and abundant pools (Hicks and Hall 2003). However, areas of weak rock types in the Oregon Coastal Province have gentle slopes with thick soils subject to deep-seated landslides that may contribute to reduced habitat suitability for coho salmon. Geology can influence numerous aspects of streams, such as water chemistry, temperature, and turbidity (Liu *et al*. 2000, Smith and Lavis 1975, Strayer 1983) as well as stream network configuration, geomorphic processes, and substrate composition (Benda *et al*. 2004). Geology has been shown to be an important variable in modeling a variety of in-channel indicators (Richards *et al*. 1996) that include salmon abundance. The density of chinook salmon redds was related to sedimentary geology in the Salmon River basin in Idaho (Feist *et al.* 2003). Salmon prefer to spawn in loose gravels, and the presence of fine sediments can reduce both water flow through spawning gravels and the survival of developing eggs (Cederholm and Reid 1987). Pess *et al.* (2002) and Steel *et al.* (2004) also found that geology was highly correlated with the distribution of coho salmon in Washington and of steelhead in the Willamette. Disparate geology categories used by Pess *et al.* (2002) do not allow for a direct comparison with our findings.

Characteristics reflecting land management were key variables for predicting peak spawner densities. The percent of land ownership held by the U.S. Bureau of Land Management (BLM), private non-industrial owners, or private industrial forest owners was a predictor in nine of the twenty-one models. Intrinsic habitat potential for coho salmon tends to be higher for streams on these ownerships than on lands managed by the United States Forest Service (USFS) (Burnett *et al.* 2007) and may account for the positive association we found. Note, however, that it is impossible to separate the importance of the distribution of lands owned by BLM versus the condition of the land owned by BLM with our current analyses.

Non-forested land appeared repeatedly as a predictor of peak spawner densities and may reflect that a substantial percentage (32%) of the area adjacent to reaches with high intrinsic habitat potential for coho salmon has been converted to uses other than forestry (Burnett *et al.* 2007). However, for steelhead in the Willamette Basin in Oregon, Steel *et al.* (2004) also found correlations between steelhead redd abundances and new forests, shrublands, and even clearcuts. They hypothesized that pulses of productivity associated with loss of forest cover may account in part for the positive correlations. By contrast, in a western Washington landscape that is more urbanized than the Oregon Coastal Province, abundances of coho salmon spawners were positively related to percent forested area (Pess *et al.* 2002). Many negative effects on stream ecosystems have been associated with conversion of forested lands to agricultural and developed uses (e.g., Independent Multidisciplinary Science Team 2002, Roy *et al.* 2003, Van Sickle *et al.* 2004), and these include lower densities of coho salmon (Beechie *et al.* 1994, Bradford and Irvine 2000, Pess *et al.* 2002).

Predictor variables indicative of land management, cow density and road density, were associated with peak spawner densities in many of our models. These results are consistent with a rich literature documenting the types of effects and pathways by which livestock grazing (e.g., Platts 1991, Belsky *et al.* 1999) and roads (e.g., Everest *et al.* 1987, Beechie *et al.* 1994, Paulsen and Fisher 2001) may harm salmon or their freshwater habitats. Low road densities were useful in identifying areas across the Interior Columbia River Basin with relatively healthy populations of salmon in general (Lee *et al.* 1997) or high densities of chinook salmon in particular (Thompson and Lee, 2000). The spatial extent for summarizing landscape characteristics determined which of the two variables appeared in a model; cow density was a negative predictor only in models using buffer extents and road density was a negative predictor only in HU and watershed models. We think this pattern occurs because in the Oregon Coastal Province cattle grazing is confined to low-gradient areas near streams and roads are concentrated in areas managed for timber. Thus, variation should be greatest and prediction more likely when cow densities are summarized within streamside buffers and road densities summarized to incorporate upslope timberlands.

Impact of spatial extent

We saw little evidence that the spatial extent at which landscape characteristics were summarized affected model results for peak spawner densities of coho salmon. Models at each spatial extent contained similar predictor variables, explained similar amounts of variation, and yielded similar predictions. There were only slight differences between buffers of 100 and 500 m. This may be because: 1) values of most predictor variables were fairly highly correlated among spatial extents given that the study area is managed predominantly for forestry with only small and isolated patches in other land uses; 2) peak spawner densities may respond to broad-scale influences (e.g., climate, ocean conditions) as well as local influences and thus may be less sensitive than other in-channel indicators to the spatial extent at which landscape characteristics are summarized for modeling; and 3) variation resulting from inaccuracies in geospatial datalayers and their associations with stream reaches may make relationships difficult to detect. For example, if a landscape feature is only available at a fairly coarse level, summaries of the geospatial data at the 100 m and 500 m buffer widths will be identical while on-the-ground conditions may be quite different at the two scales. Additionally, even tiny errors in stream location will cause high variance in buffer-scale summaries. Although spatial extent may influence the ability to model some in-channel indicators, such as large wood (Burnett *et al.* 2006, Feist *et al.*, 2003), it may have little influence on other in-channel indicators, such as cutthroat trout density (Van Sickle *et al.* 2004).

There was value in comparing the different spatial extents. In particular, it enabled us to distinguish indicators of potential management influence that are likely to be informative at local extents (cow density) from those that are likely to be informative over broader extents (road density). There was little difference between the HU and catchment extents, and models at the HU extent performed better than models at any other extent. This indicates that existing HUs may be used in future modeling efforts, eliminating the need to delineate reach-specific catchments.

Management Implications

The models we developed can assist in decision-making for coho salmon management. Mapped predictions of areas likely to support unusually high numbers of coho spawners (Figure 4) are informative for a wide range of purposes. For example, conservation and restoration activities may be targeted at areas predicted to be capable of sustaining high relative densities of coho salmon spawners. Several factors that appear as predictors in the models (such as road density and cow density) can be altered and doing so may facilitate restoration and enhancement of coho salmon production. Additionally, if a site is deemed suitable for a restoration project, our results could be used to better predict how well that restoration site would function, given the landscape conditions in the surrounding area. For example, Steel *et al.* (2004) were able to use similar models for steelhead to prioritize barrier removal projects by predicting relative redd density in the upstream habitat.

Our results also suggest key strata for developing monitoring plans and data collection efforts for coho salmon and their habitats. To monitor all factions of the population, it will be important to include samples from a wide range of geologies and climatic strata. To tease out the relative impact of land management, it would be informative to collect data on adult spawner abundances or juvenile densities in areas with similar geologic and climatic controls but which differ in cow density in riparian areas or road density in the upland watersheds.

Future Directions

This study represents a significant step forward in modeling fish densities based on landscape characteristics. Field datasets are rarely available that reflect such a favorable combination of factors for model building (a large number of sites (N = 44), evenly distributed throughout a large area (20,305 km^2), with a long and consistent history of data collection (17 of 50 years of data were used for this study). In addition, comprehensive, high-resolution landscape data enabled predictions of relative fish densities with a high degree of precision. These datasets allowed us to develop models with high correlations between landscape characteristics and peak spawner densities for coho salmon (r = 0.67 to 0.75). However, improvements are still possible. These models were based on index reaches that were not randomly selected. Models based on a statistical sample are expected to contain a greater range of fish densities and thus to better predict the relative response of spawner densities across the entire range of potential habitat. Another possible enhancement of the research is to model relationships between landscape characteristics and the abundance of juvenile salmonids. Abundances of adult coho salmon are strongly influenced by ocean conditions during the year of ocean entry. Ocean conditions have less direct influence on juvenile densities than in-stream habitat quality and quantity. Consequently, relationships between juvenile densities and habitat may be stronger than those between habitat and adults. Finally, it would be instructive to model relationships between in-stream habitat characteristics observed on the ground and landscape characteristics defined in geospatial data layers. This would allow us to hypothesize the mechanisms by which landscape scale characteristics influence in-stream habitat, and thus fish densities, and to predict habitat quality associated with landscape characteristics that may arise under different land management policies.

References

Beechie, T., Beamer, E., and Wasserman, L. 1994. Estimating Coho Salmon Rearing Habitat and Smolt Production Losses in a Large River Basin, and Implications for Habitat Restoration. N. Am. J. Fish. Manag. **14**: 797-811.

Belsky, A.J., Matzke, A., and Uselman, S. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. J. Soil Water Conserv. **54**: 419-431.

Belsley, D.A., Kuh, E., and Welsch, R.E. 1982. Regression diagnostics: identifying influential data and sources of collinearity. John Wiley, New York.

Benda, L., Poff, L.R., Miller, D., Dunne, T., Reeves, G., Pess. G., and Pollock, M. 2004. Network dynamics hypothesis: How channel networks structure riverine habitats. BioScience **54**: 413-427.

Bradford, M.J. and Irvine, J.R. 2000. Land use, fishing, climate change, and the decline of Thompson River, British Columbia, coho salmon. Can. J. Fish. Aquat. Sci. **57**: 13-16.

Burner, C.J. 1951. Characteristics of spawning nests of Columbia River salmon. Fish. Bull. Fish Wildl. Serv. **61**: 97-110.

Burnett, K.M., Reeves, G.H., Clarke, S., and Christiansen, K. 2006. Comparing riparian and catchment influences on stream habitat in a forested, montane landscape. American Fisheries Society Symposium 48. American Fisheries Society, Bethesda, Maryland, USA. pp. 175-197.

Burnett, K.M., Reeves, G.H., Miller, D.J., Clarke, S., Vance-Borland, K., and Christiansen, K. 2007. Distribution of salmon-habitat potential relative to landscape characteristics and implications for conservation. Ecological Applications **17**: 66-80.

Burnham, K.P. and Anderson, D.R. 2002. Model selection and multimodel inference: A practical information-theoretic approach. Springer-Verlang, New York, NY.

Cederholm, C.J. and Reid, L.M. 1987. Impact of forest management on coho salmon (*Oncorhynchus kisutch*) population of the Clearwater River, Washington: a project summary. University of Washington, College of Forest Resources, Seattle pp. 373-397.

Cook, R.D. 1977. Detection of influential observations in linear regression. Technometrics **19**: 15-18.

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. N. Am. J. Fish. Manag. **25**: 1411-1425.

Everest, F.H., Beschta, R.L., Scrivener, J.C., Koski, K.V., Sedell, J.R., and Cederholm, C.J. Fine sediment and salmonid production: A paradox. *In* Forestry and fishery interactions. *Edited by* E.O. Salo and T.W. Cundy. College of Forest Resources, University of Washington, Seattle, WA, USA. pp. 98-142.

Fausch, K. D., Hawkes, C. L., and Parsons, M. G. 1988. Models that predict standing crop of stream fish from habitat variables: 1950-85. US Department of Agriculture, Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-213, Portland, OR, USA.

Fausch, K.D., Torgersen, C.E., Baxter, C.V., and Li, H.W. 2002. Landscapes to Riverscapes: Bridging the gap between research and conservation of stream fishes. BioScience **52**.

Feist, B.E., Steel, E.A., Pess, G.R., and Bilby, R.E. 2003. The influence of scale on salmon habitat restoration priorities. Animal Conservation **6**: 271-282.

Franklin, J.F. and Dyrness, C.T. 1988. Natural vegetation of Oregon and Washington. USDA Forest Service PNW Gen. Tech. Rep. PNW-8.

Frissell, C.A., Liss, W.J., Warren, C.E., and Hurley, M.D. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environ. Manage. **10**: 199-214.

Hartman, G.F. 1965. The role of behaviour in the ecology and interaction of underyearling coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). J. Fish. Res. Board Can. **22**: 1035-1081.

Hicks, B.J. and Hall, J.D. 2003. Rock type and channel gradient structure salmonid populations in the Oregon coast range. Trans. Am. Fish. Soc. **132**: 468-482.

Hoeoek, T.O., Rutherford, E.S., Brines, S.J., Geddes, C.A., Mason, D.M., Schwab, D.J., and Fleischer, G.W. 2004. Landscape scale measures of steelhead (*Oncorhynchus mykiss*) bioenergetic growth rate potential in Lake Michigan and comparison with angler catch rates. J. of Great Lakes Res. **30**: 545-556.

Independent Multidisciplinary Science Team. 2002. Recovery of wild salmonids in western Oregon lowlands. Technical Report 2002-1 to the Oregon Plan for Salmon and Watersheds. Governor's Natural Resources Office, Salem, Oregon, USA.

Jacobs, S. E. and Cooney, C. X. 1997. Oregon coastal spawning surveys, 1994 and 1995. Oregon Department of Fish and Wildlife, Information Reports (Fish) 97-5. Portland, OR, USA.

Johnson, S.L., Rodgers, J.D., Solazzi, M.F., and Nickelson, T.E. 2005. Effects of an increase in large wood on abundance and survival of juvenile salmonids (*Oncorhynchus spp.*) in an Oregon coastal stream. Can. J. Fish. Aquat. Sci. **62**: 412-424.

Lawson, P. W., Bjorkstedt, E., Chilcote, M., Huntington, C., Mills, J., Moore K., Nickelson, T., Reeves, G. H., Stout, H. A., and Wainwright, T. C. 2004. Identification of historical populations of coho salmon (*Oncorhynchus kisutch*) in the Oregon coast evolutionary significant unit. NOAA/NMFS/NWFSC.

Lee D.C., Sedell, J.R., Rieman, B.E., Thurow, R.F., and Williams, J.E. 1997. Broadscale assessment of aquatic species and habitats. *In* An assessment of ecosystem components in the interior Columbia basin and portions of the Klamath and Great Basins: Volume 3, *Edited by* T.M. Quigley and S.J. Arbelbide. USDA Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-405; Portland, OR, pp. 1057-1496.

Littell, R.C., Milliken, G.A., Stroup, W.W., and Wolfinger, R.D. 1996. SAS® system for mixed models. SAS Institute Inc, Cary, N.C.

Nagelkerke, N.J.D. 1991. A note on a general definition of the coefficient of determination. Biometrika **78**: 691-692.

Naiman, R.J. and Bilby, R.E. 1998. River ecology and management in the Pacific Coastal Ecoregion. *In* River Ecology and Management: Lessons from the Pacific Coastal Ecoregion. *Edited by* R.J. Naiman and R.E. Bilby. Springer, pp. 1-12.

Naiman, R.J., Elliott, S.R., Helfield, J.M., and O'Keefe, T.C. 2000. Biophysical interactions and the structure and dynamics of riverine ecosystems: the importance of biotic feedbacks. Hydrobiologia **410**: 79-86.

Narver, D. W. Ecology of juvenile coho salmon - Can we use present knowledge for stream enhancement? *In* Proceedings of the 1977 Northeast Pacific Chinook and Coho Salmon Workshop. *Edited by* B.G. Shepherd and R.M.J. Ginetz. Fish. Mar. Serv. (Can) Tech. Rep. 759. pp. 38-43.

Nickelson, T.E. 1998. A habitat-based assessment of coho salmon production potential and spawner escapement needs for Oregon coastal streams. Fish Division, Oregon Department of Fish and Wildlife, Information Report 1-15.

Nickelson, T.E. and Lawson, P.W. 1998. Population viability of coho salmon, *Oncorhynchus kisutch*, in Oregon coastal basins: application of a habitat-based life cycle model. Can. J. of Fish. Aquat. Sci. **55**: 2383-2392.

Nickelson, T.E., Rodgers, J.D., Johnson, S.L., and Solazzi, M.F. 1992. Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Can. J. of Fish. Aquat. Sci. **49**: 783-789.

Nickelson, T. E., Solazzi, M. R., Johnson, S. L. , and Rodgers, J. D. 1992. An approach to determining stream carrying capacity and limiting habitat for coho salmon (*Oncorhynchus kisutch*). *In* Proceedings of the coho workshop, May 26-28, 1992, Nanaimo, B.C., Canada. *Edited by* L. Berg and P.W. Delaney. pp. 251-260. 92.

Ohmann, J.L. and Gregory, M.J. 2002. Predictive mapping of forest composition and structure with direct gradient analysis and nearest-neighbor imputation in coastal Oregon, U.S.A. Can. J. For. Res. **32**: 725-741.

Paulsen, C.M. and Fisher, T.R. 2001. Statistical relationship between Snake River spring/summer chinook salmon parr-to-smolt survival and indices of land use. Trans. Am. Fish. Soc. **130**: 347-358.

Pess, G.R., Montgomery, D.R., Steel, E.A., Bilby, R.E., Feist, B.E., and Greenberg, H.M. 2002. Landscape characteristics, land use, and coho salmon (*Oncorhynchus kisutch*) abundance, Snohomish River, Wash., USA. Can. J. of Fish. Aquat. Sci. **59**: 613-623.

Platts, W.S. 1991. Livestock grazing. *In* Influences of forest and rangeland management on salmonid fishes and their habitats. *Edited by* W.S. Platts. Am. Fish. Soc. pp. 389-423.

Richards, C., Johnson, L.B., and Host, G.E. 1996. Landscape-scale influences on stream habitats and biota. Can. J. Fish. Aquat. Sci. **53**: 295-311.

Roy, A. H., Freeman, M. C., Meyer, J. L., and Leigh, D. S. 2003. Patterns of land use change in upland and riparian areas in the Etowah River Basin. *In* Proceedings of the 2003 Georgia Water Resources Conference. *Edited by* K.J. Hatcher. Institute of Ecology, University of Georgia, Athens, Georgia, USA. pp. 331-334.

Scrivener, J. C. and Andersen, B. C. 1982. Logging impacts and some mechanisms which determine the size of spring and summer populations of coho salmon fry in Carnation Creek. *In* Proceedings of the Carnation Creek Workshop: a ten year review. *Edited by* G. F. Hartman. Pacific Biological Station, Nanaimo, BC, Canada. pp. 257-272.

Smith, K. and Lavis, M.E. 1975. Environmental influences on the temperature of a small upland stream. Oikos **26**: 228-236.

Solazzi, M.F., Nickelson, T.E., Johnson, S.L., and Rodgers, J.D. 2000. Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. Can. J. of Fish. Aquat. Sci. **57**: 906-914.

State of Oregon. 2005. Oregon Coastal Coho Assessment. Parts 1,2,3A and 3B. Oregon Department of Fish and Wildlife, Salem, Oregon, USA.

Steel, E.A., Feist, B.E., Jensen, D.W., Pess, G.R., Sheer, M.B., Brauner, J.B., and Bilby, R.E. 2004. Landscape models to understand steelhead (*Oncorhynchus mykiss*) distribution and help prioritize barrier removals in the Willamette basin, Oregon, USA . Ca. J. Fish. Aquat. Sci. **61**: 999-1011.

Strayer, D. 1983. The effects of surface geology and stream size on freshwater mussel (*Bivalvia:Unionidae*) distribution in southeastern Michigan,U.S.A. Freshwater Biology **13**: 253-264.

Thompson, W.L. and Lee, D.C. 2000. Modeling relationships between landscape- level attributes and snorkel counts of Chinook salmon and steelhead parr in Idaho. Can. J. Fish. Aquat. Sci. **57**: 1834-1842.

Torgersen, C.E. and Close, D.A. 2004. Influence of habitat heterogeneity on the distribution of larval Pacific lamprey (*Lampetra tridentata*) at two spatial scales. Freshwater Biology **49**: 614-630.

USDA Forest Service and USDI Bureau of Land Management. 1994. Standards and guidelines for management of habitat for late-successional and old-growth related species within the range of the Northern Spotted Owl. Attachment A to the Record of Decision. USDA Forest Service, USDI Bureau of Land Management, Portland, Oregon, USA.

Van Sickle, J., Baker, J., Hierlihy, A., Bayley. P., Gregory, S., Haggerty, P., Ashkenas, L., and Li, J. 2004. Projecting the biological conditions of streams under alternative scenarios of human land use. Ecological Applications **14**: 368-380.

Weitkamp, L. and Neely, K. 2002. Coho salmon (*Oncorhynchus kisutch*) ocean migration patterns: insight from marine coded-wire tag recoveries. Can. J. Fish. Aquat. Sci. **59**: 1100-1115.

Weitkamp, L. A., Wainwright, T. C., Bryant, G. J., Milner, G. B., Teel, D. J., Kope, R. G. , and Waples, R. S. 1995. Status review of coho salmon from Washington, Oregon and California. U.S. Dep. Commer., NOAA Tech. Memo No. NMFS-NWFSC-24.

Wing, M.C. and Skaugset, A. 2002. Relationships of channel characteristics, land ownership, and land use patterns to large woody debris in western Oregon streams. Can. J. Fish. Aquat. Sci. **59**: 196-807.

Table 1. Geospatial data layers used in habitat analysis.

Data Layer	Categories	Map scale or Gridcell size	Description
Catchment area	Size of Area of Interest (AOI)	1:24,000	Polygon representation of total area upslope of the downstream end of any given index reach. Generated from a US Geological Survey (USGS) 1:24,000 10 m digital elevation model (DEM) using ArcGIS
DEM	Mean Hill Slope	10 m	Hillslope gradient generated from USGS 10 m DEM for every grid cell using ArcGIS and summarized for the area of interest.
PRISM Climate Data (Daley *et al*. 1994)	Maximum Annual Temperature Minimum Annual Temperature Annual Temperature Range* Summer Temperature Range** Winter Temperature Range***	Unknown 4000 m	Air temperature. * difference between the annual minimum air temperature and the annual maximum air temperature. ** difference between the Jun/Jul/Aug minimum air temperature and the Jun/Jul/Aug maximum air temperature. *** difference between the Jan/Feb/Dec minimum air temperature and the Jan/Feb/Dec maximum air temperature.
	Mean Annual Precipitation (mm)	Unknown 500 m	
Forest cover (Ohmann and Gregory, 2002)	%Large Confiers (>50 cm) %Medium Trees %Small Trees %Hardwoods	Multiple	Predictive mapping of forest composition using direct gradient analysis and nearest neighbor imputation. Thirty-four original vegetation types were generalized to four.
Land Ownership	%US Bureau of Land Management (BLM) %US Forest Service %Private Industrial (Industrial Forests) %Private Non-Industrial	Multiple	Described in Burnett *et al*. (2007).
Disturbance (Lennartz 2005)	%Not cut before or during spawner count %Cut prior to spawner counts %Cut during the period of study? %Non Forest	25 m	Landsat imagery for a period of over 30 years (to 2004) was used to identify change from timber harvesting and fire in western Oregon. Twelve categories were generalized to four.
Geology	%Granitics (HUC scale only), Resistant Sedimentary or Resistant Other (all scales) %Intermediate Sedimentary %Weak rocks - Pyroclastic, schists %Unconsolidated deposits-landslides, glacial	1:500,000	USGS classification of geologic map units according to major lithology. Generalized to four classes form the original twenty-five.
Land Use	%Agricultural %Rural %Urban %Natural %Forest	25 m	Described in Burnett *et al*. (2007).
Cow Density	Cow Density	30 m	Cow head counts divided by the area of available grazing land by county based on the 1997 Agricultural Census and the National Land Cover Data, NLCD)
Roads	Road Density (km/km^2)	1:24,000	US BLM coverage of roads in Oregon. Road length divided by the area of the catchment of the area of interest.
CLAMS stream layer (Burnett *et al*. 2007)	Stream Flow (m^3/sec)	10 m	Estimated mean annual stream flow at the bottom of the index reach in cubic feet per second (cfs).
	Stream Gradient	10 m	Calculated using USGS 10 m DEM. Defined as upstream elevation minus downstream elevationdivided by length of index reach and multiplied by 100.

Table 2a. Correlations between predictor variables at the 100 meter buffer and 500 meter buffer extents. Correlation coefficients for the predictor variables summarized in 100m buffers appear in the upper right half of the table. Correlation coefficients for predictor variables summarized in 500m buffers appear in the bottom left half of the table. Response = the natural log of the peak spawner count. All other variables are defined in Table 1. Dark grey outlined cells indicate r ≥ 0.6 (N = 44). Light grey cells indicate r ≤ -0.6.

100m Buffer Extent (upper right) / **100m Buffer Scale**; **500m Buffer Extent** (lower left) / **500m Buffer Scale**

Name	Response	Aoi_area	Flow	Gradient	Slope	CowDensity	RoadDen	Cut	NoDisturb	NonForest	BigTrees	SmallTrees	Hardwoods	Remnant	MaxTemp	MinTemp	AnnualRange	SumRange	WinRange	Precip	Ag	Rural	BLM	PrivateInd	PrivateNI	USFS	Weak	Intermediate	Resistant	Unconsol
Response	1.00	-0.10	-0.21	-0.30	-0.31	-0.30	0.05	-0.18	0.06	0.01	0.28	-0.46	0.13	-0.05	0.55	0.45	0.34	0.40	0.56	-0.53	0.10	-0.35	0.37	0.01	0.08	-0.13	-0.38	0.22	0.20	-0.41
Aoi_area	-0.13	1.00	0.25	-0.08	-0.10	-0.03	-0.19	0.26	-0.17	0.05	-0.12	0.19	0.16	0.10	-0.11	-0.15	0.02	-0.03	0.03	0.09	0.04	-0.15	0.02	-0.14	-0.03	0.02	0.35	-0.08	-0.14	-0.14
Flow	-0.21	0.23	1.00	-0.04	-0.01	0.32	0.15	-0.02	0.04	-0.07	-0.36	0.21	0.06	-0.03	-0.51	-0.50	-0.13	-0.34	-0.21	0.45	-0.15	0.04	-0.10	-0.10	-0.10	-0.24	0.42	0.06	-0.35	0.04
Gradient	-0.30	-0.05	-0.04	1.00	0.96	0.34	-0.07	0.15	-0.17	0.09	-0.01	0.30	-0.33	-0.14	-0.38	-0.33	-0.06	-0.21	-0.34	0.19	0.06	0.21	0.04	0.08	-0.28	0.05	0.35	0.10	-0.35	0.10
Slope	-0.31	-0.06	-0.01	0.96	1.00	0.31	-0.07	0.12	-0.17	0.13	0.01	0.25	-0.31	-0.12	-0.34	-0.27	-0.14	-0.26	-0.28	0.16	0.08	0.27	-0.05	0.00	-0.20	0.07	0.29	0.12	-0.33	0.15
CowDensity	-0.30	-0.02	0.32	0.34	0.31	1.00	0.16	-0.16	-0.11	0.09	-0.22	0.30	-0.05	0.10	-0.39	-0.39	-0.18	-0.23	-0.04	0.23	-0.12	0.42	-0.07	-0.03	-0.01	-0.25	0.12	0.03	-0.18	0.29
RoadDen	0.15	-0.02	0.26	0.22	0.15	0.23	1.00	-0.09	0.07	-0.10	-0.38	0.20	-0.11	0.02	-0.02	-0.12	0.13	0.06	0.28	-0.18	-0.15	0.13	0.14	0.06	0.00	-0.47	0.01	0.26	-0.23	0.09
Cut	-0.21	0.09	-0.15	0.07	0.02	-0.13	0.17	1.00	-0.20	-0.07	-0.23	0.22	-0.04	0.08	-0.19	-0.19	-0.17	-0.15	-0.01	0.21	-0.10	0.01	0.01	0.15	-0.09	-0.06	0.42	-0.12	-0.21	0.05
NoDisturb	0.03	-0.03	0.05	-0.19	-0.13	-0.13	-0.40	-0.41	1.00	-0.87	0.09	-0.12	0.19	-0.66	-0.03	0.02	0.05	-0.05	-0.20	0.05	-0.49	-0.44	0.16	-0.01	-0.41	0.12	-0.17	-0.07	0.27	-0.37
NonForest	0.02	0.01	-0.14	0.16	0.20	0.07	-0.02	0.02	-0.60	1.00	0.05	0.00	-0.21	0.51	0.15	0.16	-0.09	0.04	0.13	-0.09	0.60	0.44	-0.20	-0.20	0.53	-0.03	-0.04	0.15	-0.16	0.31
BigTrees	0.18	-0.03	-0.43	-0.14	-0.12	-0.25	-0.61	-0.32	0.33	0.03	1.00	-0.50	0.00	-0.23	0.38	0.46	0.00	0.08	0.08	-0.10	0.01	-0.01	0.29	-0.46	0.06	0.62	-0.39	-0.08	0.36	-0.12
SmallTrees	-0.17	0.01	0.00	0.41	0.37	0.08	0.55	0.58	-0.43	0.08	-0.61	1.00	-0.41	-0.05	-0.34	-0.41	0.16	0.08	-0.38	0.10	-0.20	0.33	-0.05	0.34	-0.22	-0.25	0.50	-0.06	-0.37	0.29
Hardwoods	0.14	0.13	-0.01	-0.21	-0.19	-0.05	-0.21	0.09	0.05	-0.06	0.05	-0.20	1.00	0.03	0.23	0.26	-0.16	-0.09	0.31	0.09	0.01	-0.21	-0.06	-0.16	0.30	0.06	-0.30	-0.28	0.46	-0.14
Remnant	-0.06	-0.06	0.08	-0.03	-0.08	0.18	0.32	0.22	-0.83	0.33	-0.29	0.22	-0.03	1.00	0.09	0.05	-0.17	-0.04	0.36	-0.04	0.18	0.21	-0.16	-0.08	0.47	-0.15	0.08	-0.12	-0.02	0.25
MaxTemp	0.56	-0.12	-0.51	-0.38	-0.34	-0.38	-0.06	-0.07	0.07	0.14	0.37	-0.16	0.24	-0.10	1.00	0.93	0.37	0.65	0.54	-0.58	0.34	-0.17	0.29	-0.10	0.39	0.12	-0.61	0.03	0.43	-0.13
MinTemp	0.45	-0.15	-0.50	-0.33	-0.27	-0.39	-0.24	-0.07	0.16	0.17	0.49	-0.21	0.27	-0.23	0.93	1.00	0.06	0.37	0.40	-0.46	0.32	-0.08	0.24	-0.18	0.39	0.27	-0.66	0.02	0.47	-0.08
AnnualRang	0.35	0.02	-0.12	-0.07	-0.14	-0.18	0.31	-0.21	0.05	-0.15	-0.12	-0.01	-0.14	0.02	0.36	0.06	1.00	0.90	0.08	-0.43	0.12	-0.35	0.32	0.10	-0.04	-0.30	-0.03	0.07	0.03	-0.25
SumRange	0.41	-0.02	-0.33	-0.22	-0.27	-0.23	0.21	-0.14	-0.03	0.00	0.01	-0.04	-0.05	0.07	0.65	0.37	0.90	1.00	0.23	-0.53	0.23	-0.25	0.28	0.13	0.15	-0.20	-0.21	0.01	0.18	-0.17
WinRange	0.56	0.00	-0.21	-0.34	-0.29	-0.04	0.26	0.12	-0.24	0.10	0.03	0.00	0.32	0.24	0.54	0.40	0.08	0.22	1.00	-0.45	0.18	-0.08	0.11	-0.08	0.36	-0.07	-0.30	0.16	0.10	-0.07
Precip	-0.53	0.08	0.45	0.20	0.18	0.25	-0.07	0.07	-0.05	-0.10	-0.09	-0.01	0.01	0.19	-0.57	-0.46	-0.42	-0.52	-0.44	1.00	-0.15	0.01	-0.26	0.00	-0.19	0.10	0.52	-0.30	-0.14	0.02
Ag	0.11	0.00	-0.19	0.23	0.26	-0.01	0.01	-0.08	-0.42	0.76	0.11	0.03	-0.03	0.09	0.22	0.27	-0.05	0.07	0.04	-0.13	1.00	-0.05	-0.13	-0.09	0.39	-0.05	-0.11	0.22	-0.07	-0.07
Rural	-0.41	-0.13	0.00	0.18	0.22	0.36	0.04	0.29	-0.37	0.39	-0.14	0.22	-0.13	0.24	-0.14	-0.08	-0.28	-0.19	-0.05	0.03	0.06	1.00	-0.09	-0.06	0.24	0.01	-0.05	0.11	-0.26	0.84
BLM	0.36	0.00	-0.15	-0.01	-0.14	-0.03	0.18	0.03	0.20	-0.25	0.08	-0.05	0.09	-0.26	0.33	0.26	0.36	0.36	0.07	-0.29	-0.17	-0.11	1.00	-0.18	-0.26	-0.18	-0.16	0.10	0.05	-0.07
PrivateInd	0.08	-0.17	0.04	0.14	0.08	-0.03	0.52	0.25	-0.37	-0.16	-0.49	0.53	-0.28	0.35	-0.13	-0.26	0.17	0.14	0.06	0.00	-0.13	0.01	-0.07	1.00	-0.47	-0.24	0.19	0.00	-0.13	0.00
PrivateNI	0.00	-0.04	-0.09	-0.25	-0.16	0.03	-0.07	0.05	-0.32	0.60	0.00	-0.15	0.41	0.27	0.31	0.31	-0.11	0.07	0.40	-0.17	0.35	0.36	-0.28	-0.39	1.00	-0.04	-0.24	-0.02	0.13	0.18
USFS	-0.15	-0.01	-0.32	-0.02	0.01	-0.31	-0.51	-0.11	0.19	0.00	0.68	-0.30	-0.02	-0.15	0.21	0.40	-0.29	-0.15	-0.19	0.11	0.14	-0.09	-0.30	-0.32	0.01	1.00	-0.17	-0.18	0.27	-0.08
Weak	-0.39	0.34	0.42	0.38	0.32	0.21	0.39	0.20	-0.31	-0.01	-0.41	0.38	-0.35	0.31	-0.63	-0.68	-0.05	-0.24	-0.32	0.51	-0.02	-0.04	-0.18	0.25	-0.22	-0.21	1.00	-0.16	-0.56	-0.07
Intermediate	0.23	-0.08	0.04	0.13	0.14	0.03	0.29	-0.25	0.11	0.08	-0.14	-0.06	-0.29	-0.20	0.05	0.02	0.12	0.05	0.17	-0.30	0.09	0.08	0.08	0.07	0.00	-0.22	-0.17	1.00	-0.69	0.16
Resistant	0.22	-0.14	-0.35	-0.39	-0.37	-0.25	-0.49	-0.02	0.21	-0.12	0.44	-0.25	0.51	-0.12	0.46	0.49	0.04	0.20	0.12	-0.14	-0.03	-0.30	0.10	-0.25	0.08	0.35	-0.56	-0.67	1.00	-0.32
Unconsol	-0.39	-0.15	0.07	0.08	0.13	0.27	-0.03	0.24	-0.26	0.27	-0.17	0.10	-0.15	0.19	-0.15	-0.08	-0.30	-0.21	-0.07	0.01	-0.09	0.94	-0.10	0.05	0.28	-0.11	-0.09	0.16	-0.34	1.00

Table 2b. Correlations between predictor variables at the 7th field Hydrologic Unit (HU) and watershed extents. Correlation coefficients for at the 7th field HU extent appear in the upper right half of the table. Correlation coefficients for the watershed extent appear in the lower left half of the table. Response = the natural log of the peak spawner count. All other variables are defined in Table 1. Dark grey outlined cells indicate r ≥ 0.6. Light grey cells indicate r ≤ -0.6.

HUC Extent (upper right) / HUC Scale; Watershed Extent (lower left) / Watershed Scale

Name	lnPeak	Aoi_area	Flow	Gradient	Slope	CowDensity	RoadDen	Cut	NoDisturb	NonForest	BigTrees	SmallTrees	Hardwoods	Remnant	MaxTemp	MinTemp	AnnualRange	SumRange	WinRange	Precip	Ag	Rural	BLM	PrivateInd	PrivateNI	USFS	Weak	Intermediate	Resistant	Unconsol
lnPeak	1.00	0.03	-0.21	-0.30	-0.31	-0.30	-0.03	-0.01	-0.17	0.19	0.14	0.01	0.20	0.18	0.55	0.45	0.32	0.37	0.57	-0.51	0.14	-0.17	0.34	0.24	0.06	-0.20	-0.39	0.21	0.20	-0.29
Aoi_area	0.13	1.00	0.37	-0.34	-0.33	-0.07	-0.11	-0.12	-0.24	0.34	-0.14	-0.12	0.25	0.31	-0.17	-0.17	-0.16	-0.23	0.21	0.11	0.13	0.21	-0.31	0.00	0.36	-0.12	0.06	-0.04	-0.02	-0.06
Flow	-0.21	0.77	1.00	-0.04	-0.01	0.32	0.22	-0.11	-0.02	-0.07	-0.46	0.00	-0.13	0.00	-0.50	-0.49	-0.09	-0.29	-0.20	0.47	-0.03	-0.05	-0.23	0.23	-0.06	-0.33	0.37	0.06	-0.36	0.21
Gradient	-0.30	-0.18	-0.04	1.00	0.96	0.34	0.17	0.17	-0.06	-0.12	-0.18	0.45	-0.22	-0.04	-0.39	-0.34	-0.07	-0.24	-0.36	0.23	-0.02	0.01	-0.04	0.03	-0.24	-0.03	0.39	0.26	-0.49	0.06
Slope	-0.31	-0.14	-0.01	0.96	1.00	0.31	0.10	0.08	0.03	-0.11	-0.17	0.42	-0.21	-0.08	-0.37	-0.29	-0.14	-0.30	-0.31	0.24	0.00	0.04	-0.15	0.02	-0.21	0.01	0.34	0.28	-0.47	0.14
CowDensity	-0.30	0.16	0.32	0.34	0.31	1.00	0.33	-0.09	0.05	-0.07	-0.16	0.08	-0.05	-0.06	-0.38	-0.39	-0.15	-0.22	-0.08	0.34	-0.03	0.25	0.05	-0.12	-0.12	-0.25	0.24	-0.02	-0.19	0.13
RoadDen	-0.16	0.39	0.35	0.21	0.15	0.31	1.00	0.54	-0.51	-0.14	-0.35	0.31	-0.16	0.30	-0.15	-0.31	0.23	0.20	0.16	-0.01	-0.16	0.18	0.26	0.40	-0.10	-0.37	0.48	-0.02	-0.40	0.26
Cut	-0.01	-0.10	-0.08	0.11	0.02	-0.11	0.43	1.00	-0.58	0.01	-0.21	0.56	0.03	0.23	-0.04	-0.08	-0.10	0.00	0.09	0.00	-0.07	0.14	0.19	0.32	-0.03	-0.13	0.50	-0.16	-0.29	-0.09
NoDisturb	-0.09	-0.02	0.06	-0.13	-0.02	0.03	-0.54	-0.70	1.00	-0.43	0.38	-0.45	-0.19	-0.86	0.00	0.13	-0.11	-0.18	-0.30	0.14	-0.33	-0.25	0.06	-0.42	-0.38	0.30	-0.41	0.17	0.23	-0.03
NonForest	0.12	-0.07	-0.14	0.00	0.01	-0.09	-0.16	-0.11	-0.06	1.00	0.07	-0.04	0.47	0.35	0.22	0.29	-0.22	-0.05	0.11	-0.16	0.82	0.47	-0.07	-0.21	0.62	-0.02	-0.10	-0.17	0.18	0.02
BigTrees	0.21	-0.24	-0.48	-0.18	-0.14	-0.16	-0.45	-0.35	0.42	0.18	1.00	-0.45	0.15	-0.24	0.52	0.62	-0.11	0.04	0.16	-0.32	0.14	-0.09	0.23	-0.62	-0.01	0.63	-0.40	-0.17	0.46	-0.32
SmallTrees	-0.03	0.02	0.06	0.43	0.39	0.08	0.38	0.64	-0.54	-0.17	-0.51	1.00	-0.18	0.20	-0.08	-0.12	-0.02	0.01	0.01	0.02	-0.07	0.18	-0.03	0.56	-0.11	-0.26	0.30	0.35	-0.47	0.01
Hardwoods	0.14	-0.17	-0.26	-0.15	-0.12	-0.09	-0.23	0.10	0.06	0.13	0.21	-0.16	1.00	0.26	0.38	0.42	-0.20	-0.02	0.40	-0.21	0.41	0.18	0.17	-0.41	0.69	-0.01	-0.35	-0.31	0.49	-0.16
Remnant	0.11	0.06	-0.07	0.10	0.04	-0.07	0.34	0.36	-0.84	0.13	-0.25	0.25	-0.03	1.00	0.11	-0.03	0.16	0.20	0.41	-0.21	0.23	0.18	-0.19	0.25	0.47	-0.18	0.24	-0.23	-0.05	0.01
MaxTemp	0.54	-0.14	-0.53	-0.39	-0.36	-0.38	-0.32	-0.06	0.10	0.22	0.54	-0.13	0.34	-0.01	1.00	0.94	0.29	0.61	0.51	-0.65	0.19	-0.02	0.39	-0.20	0.28	0.23	-0.61	-0.10	0.58	-0.27
MinTemp	0.45	-0.19	-0.50	-0.33	-0.28	-0.38	-0.43	-0.09	0.26	0.21	0.62	-0.15	0.38	-0.18	0.95	1.00	0.01	0.35	0.39	-0.55	0.27	0.03	0.29	-0.33	0.28	0.41	-0.62	-0.09	0.58	-0.23
AnnualRang	0.34	0.17	-0.10	-0.11	-0.19	-0.17	0.19	-0.15	-0.21	0.02	-0.12	-0.06	-0.21	0.28	0.27	0.02	1.00	0.88	0.04	-0.41	-0.18	-0.36	0.39	0.16	-0.11	-0.31	-0.11	0.12	0.04	-0.28
SumRange	0.38	-0.05	-0.37	-0.27	-0.32	-0.23	0.06	-0.04	-0.25	0.16	0.06	-0.04	-0.05	0.28	0.60	0.36	0.86	1.00	0.17	-0.53	-0.03	-0.22	0.45	0.10	0.07	-0.15	-0.28	-0.03	0.27	-0.25
WinRange	0.56	0.10	-0.25	-0.37	-0.33	-0.09	-0.03	0.11	-0.19	0.06	0.27	-0.03	0.41	0.25	0.52	0.40	0.03	0.18	1.00	-0.45	0.01	0.12	0.16	0.16	0.30	-0.22	-0.30	-0.03	0.27	-0.12
Precip	-0.50	-0.06	0.51	0.21	0.21	0.38	0.12	0.04	-0.01	-0.12	-0.33	0.08	-0.18	-0.07	-0.65	-0.57	-0.42	-0.53	-0.43	1.00	-0.12	0.03	-0.41	0.14	-0.21	0.05	0.44	-0.13	-0.30	0.25
Ag	0.00	-0.07	-0.14	0.05	0.06	-0.17	-0.10	-0.12	-0.03	0.71	0.17	-0.22	0.08	0.09	0.30	0.28	0.18	0.31	-0.01	-0.15	1.00	0.14	-0.02	-0.27	0.61	0.07	-0.04	-0.16	0.13	0.04
Rural	-0.19	-0.07	0.01	0.25	0.30	0.42	0.20	0.02	0.00	0.16	0.05	0.13	0.01	-0.11	-0.11	-0.05	-0.29	-0.18	-0.08	0.18	-0.07	1.00	-0.14	0.01	0.23	-0.11	-0.06	-0.08	0.06	0.37
BLM	0.41	0.07	-0.11	-0.10	-0.21	0.03	0.29	0.13	-0.01	-0.12	0.10	0.00	0.16	-0.07	0.38	0.29	0.40	0.40	0.17	-0.40	0.00	-0.13	1.00	-0.14	-0.13	-0.36	-0.18	0.00	0.16	-0.15
PrivateInd	0.11	0.22	0.25	0.13	0.10	-0.07	0.44	0.36	-0.53	-0.26	-0.63	0.59	-0.42	0.26	-0.32	-0.41	0.14	0.03	-0.04	0.18	-0.23	-0.03	-0.04	1.00	-0.31	-0.44	0.23	0.34	-0.42	0.21
PrivateNI	0.07	0.07	-0.08	-0.27	-0.22	-0.06	-0.05	-0.06	0.00	0.32	0.06	-0.15	0.44	0.10	0.26	0.16	0.12	0.26	0.37	-0.21	0.31	0.03	-0.10	-0.31	1.00	0.00	-0.14	-0.20	0.24	0.03
USFS	-0.19	-0.34	-0.33	0.01	0.05	-0.24	-0.38	-0.17	0.27	0.14	0.62	-0.27	0.07	-0.21	0.26	0.43	-0.32	-0.12	-0.20	0.04	0.19	0.15	-0.38	-0.40	-0.05	1.00	-0.10	-0.21	0.23	-0.13
Weak	-0.38	0.08	0.38	0.39	0.35	0.25	0.52	0.44	-0.44	-0.05	-0.41	0.34	-0.37	0.39	-0.60	-0.60	-0.14	-0.29	-0.31	0.46	-0.09	0.18	-0.20	0.23	-0.17	-0.08	1.00	-0.12	-0.75	0.22
Intermediate	0.18	0.12	0.06	0.27	0.29	-0.03	-0.02	-0.19	0.12	-0.08	-0.18	0.32	-0.28	-0.19	-0.16	-0.14	0.09	-0.07	-0.08	-0.09	-0.02	-0.03	-0.04	0.32	-0.09	-0.20	-0.14	1.00	-0.56	0.08
Resistant	0.20	-0.15	-0.37	-0.51	-0.48	-0.20	-0.45	-0.25	0.29	0.10	0.48	-0.50	0.49	-0.20	0.62	0.60	0.08	0.31	0.31	-0.34	0.09	-0.14	0.20	-0.42	0.20	0.21	-0.75	-0.55	1.00	-0.32
Unconsol	-0.06	0.03	0.13	-0.13	-0.04	0.02	0.27	-0.08	0.05	-0.06	-0.24	-0.04	-0.01	-0.11	-0.07	-0.04	-0.25	-0.16	0.09	0.10	0.00	0.10	-0.04	0.24	0.04	-0.16	-0.12	0.14	-0.06	1.00

Table 3. Results of model development to predict the natural log of peak spawner counts. BLM = ownership by Bureau of Land Management; Intermediate = intermediate sedimentary geology (intermediate between resistant and weak); NonForest = percent of land that is not forested from the forest cover layer; PrivateInd = private industrial forest; PrivateNI = private non-industrial ownership; SmallTrees = percent small trees; Resistant = percent resistant sedimentary rocks or other resistant rocks; RoadDen = road density; Weak = percent weak rocks; WinRange = winter temperature range from PRISM Climate Data (see Table 1 for more details).

Extent	Model	AIC	R^2 *	$\bar{\bar{V}}$ **	Wt. ***
100 m. Buffer	0.0067*BLM - 0.00018*CowDensity + 0.036*WinRange	1953.33	43.59	0.6912	0.3343
	-0.016*SmallTrees + 0.0070*BLM + 0.035*WinRange	1953.93	42.82	0.6943	0.2482
	-0.0050*Weak – 0.00017*CowDensity + 0.038*WinRange	1954.99	41.41	0.6895	0.1455
	0.0090*BLM + 0.0050*PrivateNI + 0.031*WinRange	1955.01	41.39	0.6933	0.1441
	-0.033*Weak + 0.00030*Weak^2 + 0.035*WinRange	1955.25	41.07	0.6938	0.1278
500 m. Buffer	-0.030*Weak – 0.00027*Weak^2 + 0.035*WinRange	1954.93	41.49	0.6933	0.2985
	-0.00016*CowDensity – 0.0051*Weak + 0.038*WinRange	1955.16	41.19	0.6906	0.2666
	-0.00020*CowDensity + 0.011*NonForest + 0.037*WinRange	1955.44	40.81	0.6914	0.2313
	-0.00019*CowDensity + 0.038*WinRange	1955.70	37.70	0.6921	0.2037
HUC	-0.037*Weak + 0.00039*Weak^2 + 0.036*WinRange	1952.52	44.61	0.6957	0.2641
	0.0075*PrivateInd – 0.011*Weak + 0.033*WinRange	1953.37	43.53	0.6946	0.1730
	0.0084*PrivateInd – 419.2*RoadDen + 0.043*WinRange	1953.51	43.35	0.6921	0.1612
	0.046*NonForest + 0.0071*PrivateInd + 0.029*WinRange	1953.65	43.17	0.6933	0.1503
	2.21 + 0.051*NonForest + 0.012*PrivateInd – 0.015*Weak	1953.94	45.34	0.6911	0.1303
	0.035*NonForest – 0.0079*Weak + 0.034*WinRange	1954.08	42.61	0.6908	0.1212
Watershed	0.0077*PrivateInd – 385.61*RoadDen + 0.043*WinRange	1952.89	44.14	0.6909	0.3271
	-0.033*Weak + 0.00032*Weak^2 + 0.036*WinRange	1953.20	43.75	0.6925	0.2803
	-0.035*Resistant + 0.00031*Resistant^2 + 0.041*WinRange	1955.17	41.18	0.6918	0.1048
	-258.44*RoadDen + 0.0081*Intermediate + 0.041*WinRange	1955.24	41.08	0.6942	0.1010
	0.086*NonForest – 0.0079*Weak + 0.035*WinRange	1955.29	41.01	0.6950	0.0986
	0.0051*PrivateInd – 0.0098*Weak + 0.034*WinRange	1955.52	40.71	0.6945	0.0882

* Generalized R-square (Nagelkerke 1991)
** Average correlation from bootstrap validation (see methods for details)
*** Model averaging weight derived from AIC (Burnham and Anderson 2002)

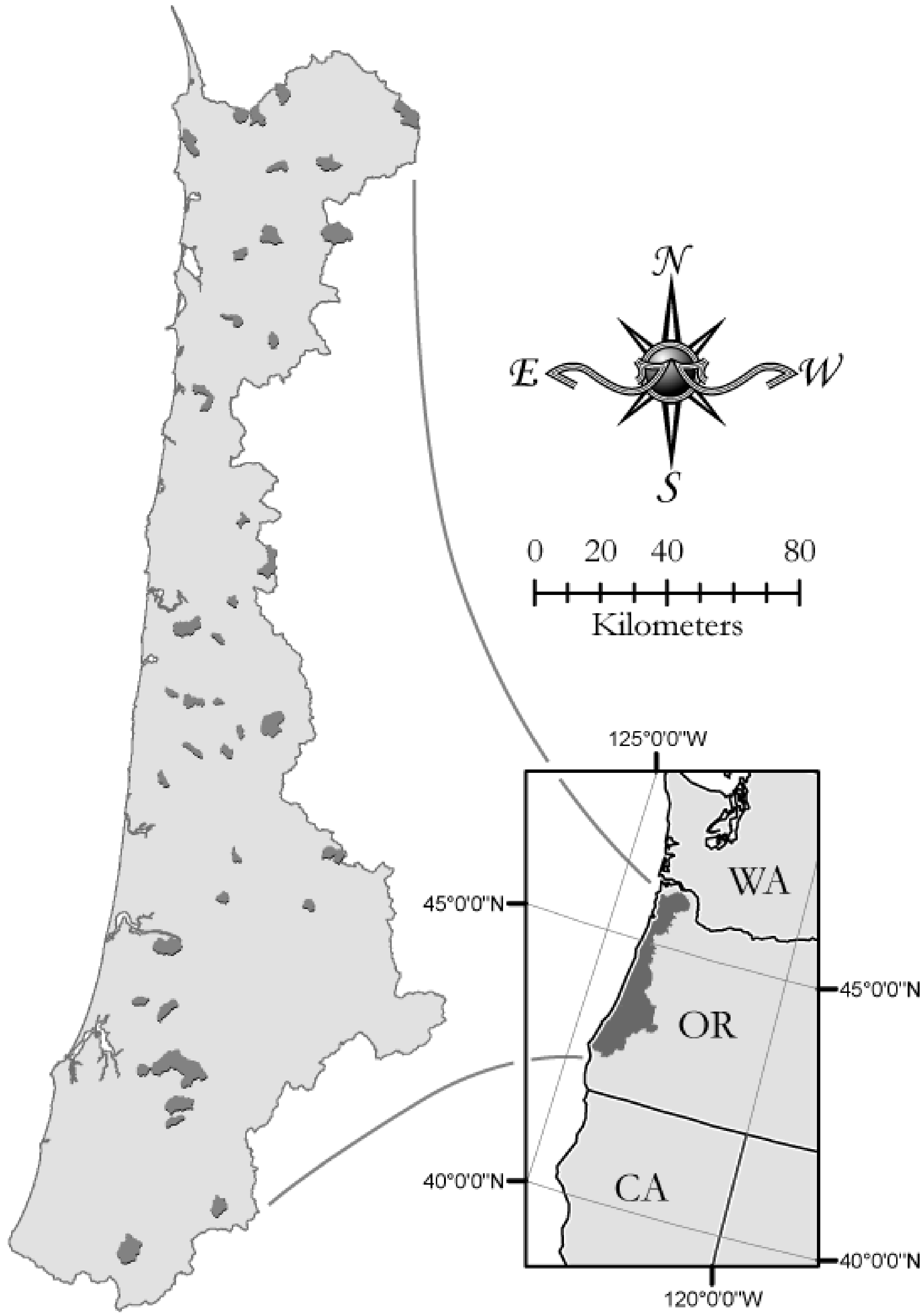

N
E
W
S
0
20
40
80
Kilometers
125°0'0"W
45°0'0"N
45°0'0"N
40°0'0"N
40°0'0"N
120°0'0"W
WA
OR
CA

Figure 1.

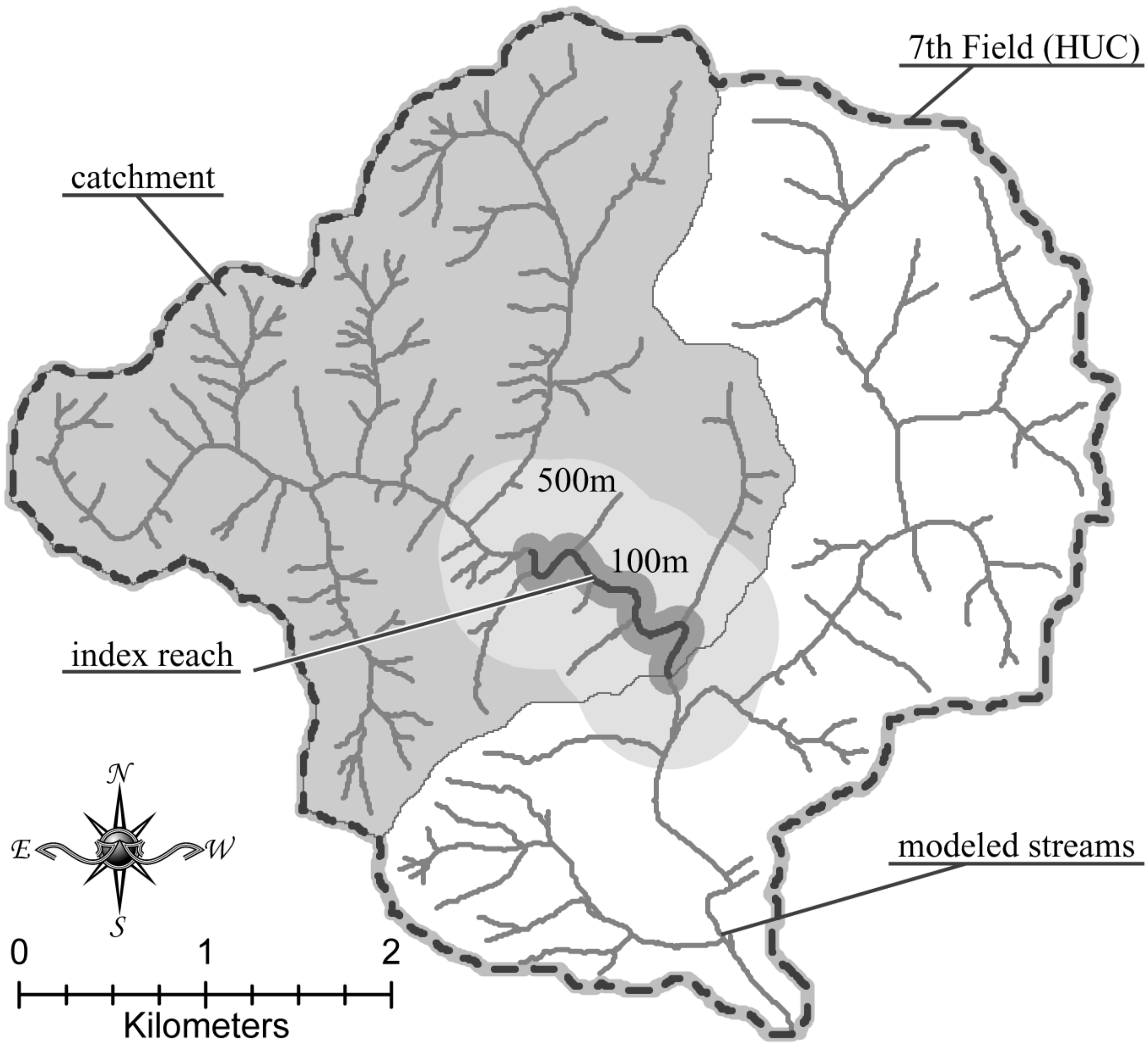

7th Field (HUC)
catchment
500m
100m
index reach
modeled streams
N
E
W
S
0
1
2
Kilometers

Figure 2.

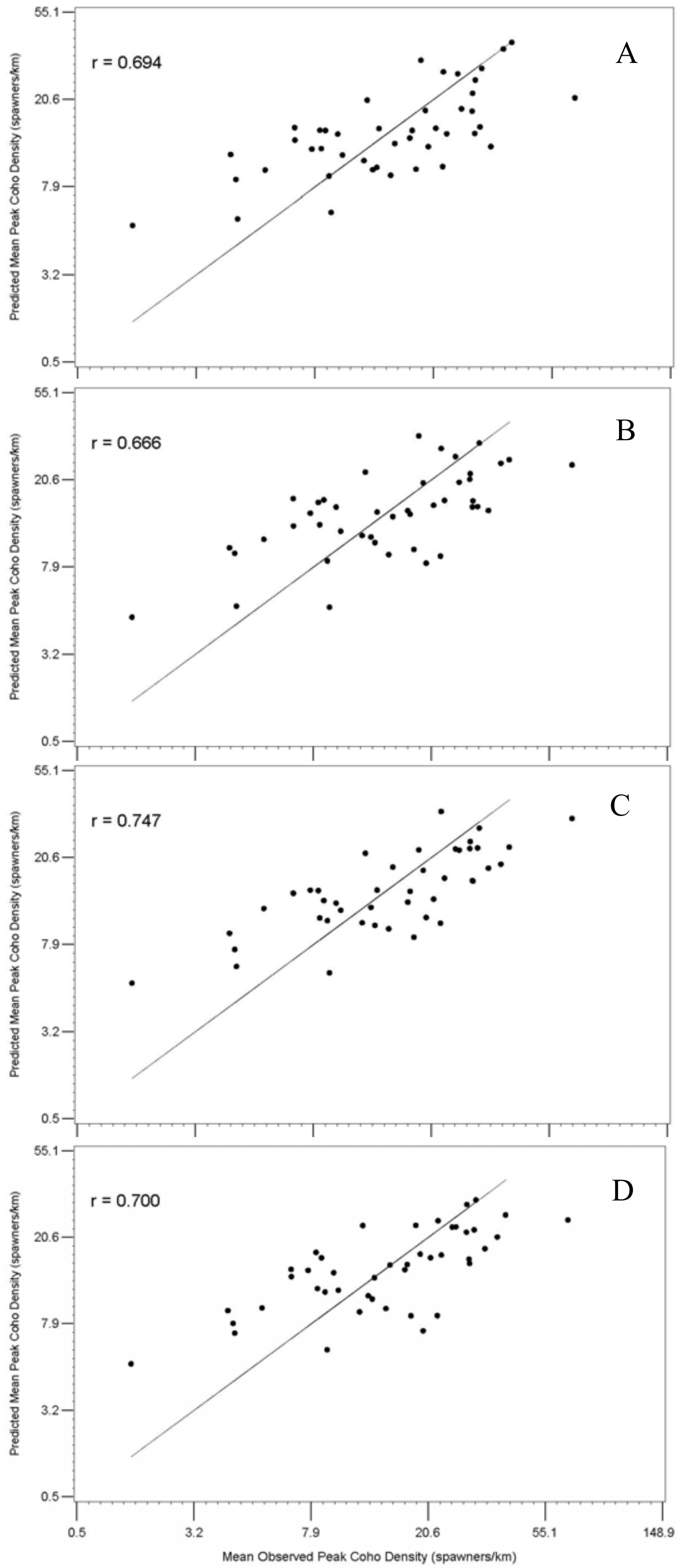

A
r = 0.694
B
r = 0.666
C
r = 0.747
D
r = 0.700
55.1
20.6
7.9
3.2
0.5
Predicted Mean Peak Coho Density (spawners/km)
0.5
3.2
7.9
20.6
55.1
148.9
Mean Observed Peak Coho Density (spawners/km)

Figure 3.

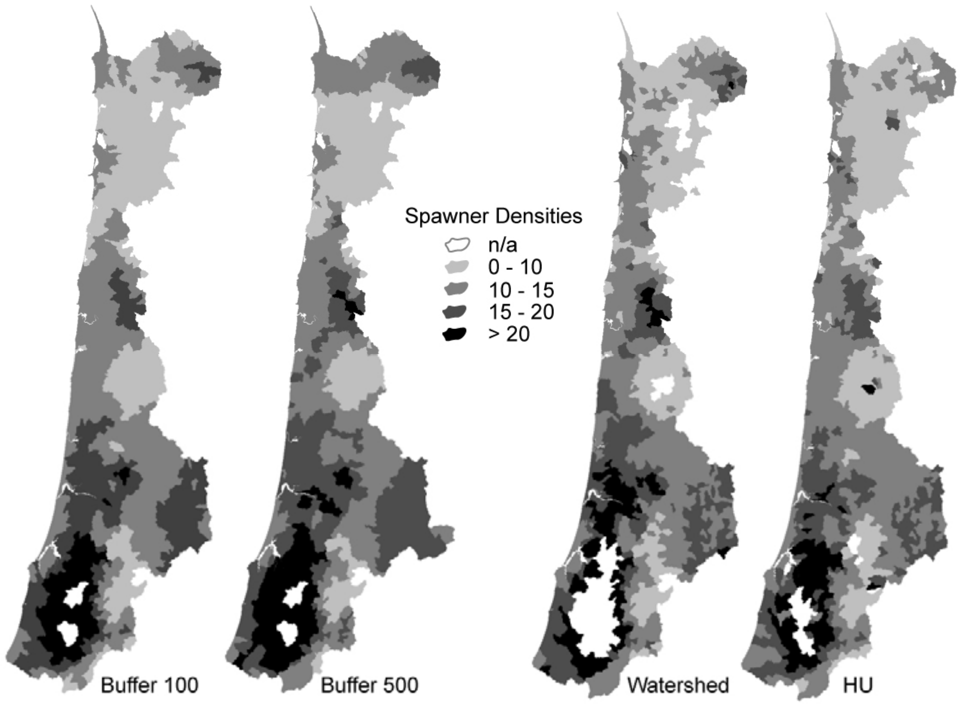

Spawner Densities
n/a
0 - 10
10 - 15
15 - 20
> 20
Buffer 100
Buffer 500
Watershed
HU

Figure 4.

Figure 1. Extent of the area included in the models. Delineated watersheds for coho spawner Index Sites are indicated by the dark grey areas.

Figure 2. Illustration of the four spatial scales used for modeling: 100 and 500 meter buffers around the surveyed stream reach, an amalgamation of all 7^{th} field hydrologic units intersected by the stream reach, and the entire watershed draining to the downstream end of the surveyed stream reach. In this illustration the collection of 7^{th} field hydrologic units is larger than the watershed, but in some cases the watershed encompassed a greater area than the hydrologic units.

Figure 3a. Plot of the modeled averaged mean coho density predicted at the 100 meter buffer scale vs. the observed mean coho density. Observed densities were averaged over the 17 years of data for each sample reach. A 1:1 line is included for reference. [r] is the correlation between the observed densities and the predictions.

Figure 3b. Plot of the modeled averaged mean coho density predicted at the 500 meter buffer scale vs. the observed mean coho density. Observed densities were averaged over the 17 years at each sample reach. A 1:1 line is included for reference. [r] is the correlation between the observed densities and the predictions.

Figure 3c. Plot of the modeled averaged mean coho density predicted at the 7^{th} field HU scale vs. the observed mean coho density. Observed densities were averaged over the 17 years at each sample reach. A 1:1 line is included for reference. [r] is the correlation between the observed densities and the predictions.

Figure 3d. Plot of the modeled averaged mean coho density predicted at the watershed scale vs. the observed mean coho density. Observed densities were averaged over the 17 years at each sample reach. A 1:1 line is included for reference. [r] is the correlation between the observed densities and the predictions.

Figure 4. Map of predicted values at four spatial scales. Values for spawners / km were determined using a weighted average of the predictions from each of the models in the best set (Table 3). AIC weights recalculated for the set of best models were used in the weighted average. a) Results for models based on a 100m buffer of the sampled reach, b) results for for models based on a 500m buffer of the sampled reach, c) results for models built based on all 7^{th} field HUs that are intersected by the sampled reach, d) results for models based on the watershed upstream of the sampled reach.

Comparing riverine landscape models across populations and sampling designs to understand spawning distributions of coho salmon (*Oncorhynchus kisutch*)

E.A. Steel, D.W. Jensen, K.M. Burnett, K. Christiansen, J.C. Firman, B.E. Feist, and D.P. Larsen

Key words: zeros, probability sampling

For submission to:

- Journal of Agricultural, Biological, and Environmental Statistics
- River Research and Applications
- Canadian Journal of Fisheries and Aquatic Sciences

Nothing is quite right – I would like a general ecological perspective (as opposed to fish-centric), an international journal if possible, and still reach readers interested in sampling salmon and managing salmon. Other suggestions?

Abstract:

Introduction

Human activities and environmental gradients over landscape-scale extents impact a wide range of instream features from physical habitat to macroinvertebrate communities to fish distribution (Allan 2004). Correlative analyses on many species and across a wide range of ecosystems have attempted to use landscape condition to improve predictions about the distribution and abundance of aquatic species and to generate hypotheses about how landscape structure and content drive aquatic systems. Salmonids, in particular, have been a focus of these landscape riverine analyses because they inhabit a tremendously large range and migrate over long distances. Possibilities for landscape-scale ecological research have been greatly expanded by recent developments in geographical information systems (GIS) and by the proliferation of and improvements in spatial data. However, collecting biological data remains costly and time intensive. As a result, many large-scale analyses are hampered by an over-reliance on existing biological data, small data sets, and non-random sample-site selection. Using 9 years of coho salmon spawner estimates, collected at 100 probabilistically-sampled sites, we explore both the ecology of coho salmon and the biases of previous riverine landscape approaches.

Landscape approaches to understanding aquatic ecosystems have proliferated dramatically since they were first synthesized by Johnson and Gage (1997). The theoretical framework underlying these analyses is that the local habitat conditions on which aquatic species depend are, in turn, controlled by patterns of land-use, land-form, climate, and geology over broad spatial extents (Frissell et al. 1986; Imhof et al. 1996; Richards et al. 1996; and Davies et al. 2000). This landscape perspective implies holistic thinking and a careful consideration of geomorphic controls, environmental gradients, and relationships between instream habitat and biological communities (Ward, 1998). Linkages among landscapes and associated physicochemical and biological characteristics of rivers have long been recognized (Karr & Gorman 1975); however, the development of conceptual frameworks and tools for measuring and synthesizing such linkages is relatively recent (e.g. Allan and Johnson, 1997; Fausch et al., 2002; Hughes et al., 2006; Robinson et al., 2002; Schlosser, 1991; Wang et al., 2006a; Wang et al., 2003). Many studies have documented the statistical associations between land use and stream condition using multisite comparisons and empirical models. Collectively, these studies provide strong evidence of the importance of the surrounding landscape and of human activities to a stream's ecological integrity (Durance et al., 2006).

Collecting or compiling consistent data on biological responses over landscape scales is a major challenge. Much of the research on correlations between salmon and landscapes (e.g, Pess et al 2002, Feist et al. 2003, Steel et al. 2004) has relied on index site data. Index sites are usually handpicked to monitor areas of particularly high fish production. For example, trends in coho salmon stocks along the Oregon Coast have been estimated from spawning fish surveys conducted in index reaches since 1950 (Cooney and Jacobs 1995). Population estimates from index sites can be biased (Thurow XXXX) for estimating population abundances or trends in population performance over time. We now explore the implications of using index site data to link salmon performance with landscape conditions.

Those landscape conditions that drive coho salmon production should be linked to their instream habitat needs. Coho salmon spawn in small, low-gradient tributaries (Burner 1951). We would therefore expect that stream gradient, precipitation and mean annual flow might be correlated with their abundance and distribution. Land management such as forest harvest and agriculture also clearly impact the abundance of deep, shaded pools (Bilby ref) that are important for juvenile rearing (e.g. Hartman 1965; Narver 1978; Scrivener and Andersen 1982). How habitat use changes in years of high versus low adult returns has yet to be quantified.

Our analysis is different from previous riverine landscape studies because of the probabilistically sampled biological response and the large sample size. Like so many ecological data sets (ref), these data are, however, plagued by an overabundance of zeros. An innovation of our approach is a focus on what these zero observations can tell us about the processes linking landscapes to rivers and about coho salmon ecology. Our analyses are organized around two questions: (1) What are the landscape features most highly correlated with coho salmon spawner abundance and how do our ecological conclusions compare to those based on data from other basins and based on index site data from the same basin; (2) What landscape conditions drive the distribution of zero counts, surveys in which no spawners are observed at a particular site and in a particular year?

Methods

Study Area

All survey sites are within the Oregon Coastal Province (Figure 1; 20,305 km^2). The region is dominated by mountains (maximum elevation = 1250 m) and underlain primarily by marine sandstones and shales or by basaltic volcanic rocks. The temperate, maritime climate provides mild, wet winters and dry summers. Base flows predominate in late summer; peak flows occur in the fall, following winter rainstorms and rain-on-snow events.

The study area supports a productive coniferous forest dominated by Douglas fir (*Psuedotsuga menziesii*)(Mirb.)Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), red alder (*Alnus rubra*) and, along the coast, Sitka spruce (*Picea sitchensis*). Western red cedar (*Thuja plicata*) and big leaf maple (*Acer macrophyllum* Pursh) are also found in riparian areas. Local disturbance regimes have been driven by timber harvest and recent fire suppression, and by past infrequent but intense wild fires and windstorms (Franklin and Dyrness 1988). Most of the current forestland is in relatively young seral stands, but the larger river valleys have been cleared for agriculture (Ohmann and Gregory 2003). The majority of the land is in private ownership and about a third is publicly managed (Spies *et al*. 2007). Roughly half of the riparian areas adjacent to streams that support coho salmon is non-forested or has been recently logged (Burnett *et al*., 2007).

Five salmonid species reside in the study area: coho salmon, coastal cutthroat trout (*O. clarki*), chinook salmon (*O. tschawytscha*), chum salmon (*O. keta*), and steelhead (*O. mykiss*) (Hoeoek *et al.* 2004). Most coho salmon habitat occurs at lower elevations and in areas of lower gradients within the study region.

Coho salmon data

Coho salmon in the study region belong to the Oregon Coastal Coho Evolutionarily Significant Unit (ESU) (Weitkamp *et al.* 1995). Coho salmon abundance was measured as XXX. Sampled reaches were designed to be a standard 1 km length; however, not all reaches were exactly 1 km because tributary junctions forced additional reach breaks. Observed counts were standardized by observed reach length.

Site selection was based on the survey design for the Oregon Plan (http://nrimp.dfw.state.or.us/OregonPlan/). The goal of the plan was to collect a spatially balanced, random sample that produces unbiased estimates and that can provide associated estimates of precision (Stevens 2002). The surveys feature a rotating panel design. The rotations occur every 4 years so as not to coincide with the 3-year life cycle of coho salmon. One quarter of the sites are sampled each year (N=); one quarter of the sites are sampled every 3 years (N=); one quarter of the sites are sampled every 9 years (N=); and, one quarter of the sites are sampled only once (N=). The rotating panel design is intended to balance the need to estimate population abundance in each year, for which precision improves by sampling more sites within a year, and the need to detect trends over time, for which power improves by revisiting the same sites year after year. For our analysis, we excluded all sites with fewer than XX years of observation, 4 sites that were shorter than XX km, and 4 sites on lakes. Our total sample size was 53 sites sampled in all years and XX sites sampled in XX-XX years.

Because all possible spawning sites were included in the sampling frame, this data set contains many more observations with zero fish than previous data sets based on index sites. Only 23 of the XX sites had fish in every year surveyed. About half of the sites were observed to have no spawners in at least 2 years.

Landscape Data

We used geospatial data layers describing climate, geology, land form, and landuse and focused on those landscape characteristics thought to influence the distribution and abundance of coho salmon in the Oregon Coastal Province (Table 1). Landscape attributes included catchment size, hillslope, air temperature, tree composition and history of forest management, geology, land-use (e.g. agriculture), cow density, road density, land ownership, stream flow, and stream gradient. We focused on those attributes identified in previous analyses of index site data for this same region (Firman et al, In review) and of index site data for the Snohomish River in Washington State (Pess et al, 2002). These geospatial data layers are similar to those used in other riverine landscape studies on other species or life-stages (e.g., Van Sickle *et al*. 2004; Steel *et al*. 2004; Burnett *et al*. 2006).

For each survey site, we delineated the entire catchment flowing into that reach and summarized the landscape conditions within that catchment. To create the final set of predictor variables, we summarized catchment conditions using area-weighted means for continuous variables (i.e. air temperature or road density) and fraction of total area for categorical variables (i.e. geology, land cover).

Additional Independent Variables

In our efforts to increase the explanatory power of our models, we developed or incorporated several additional independent variables. (1) *Intrinsic potential*: We estimated intrinsic potential using methods described in Burnett et al (200X). Intrinsic potential combines stream gradient, stream width, and XX to estimate reach spawning suitability in the absence of anthropogenic impacts. For each reach, we calculated the mean intrinsic potential, weighted by reach length. (2) *Marine survival*: XXX (3) *Flow*: We downloaded mean monthly flow data from 12 USGS gauging stations in operation between 1995 and 2006 and within the study area. We averaged these mean monthly flows over each year of the study and developed annual regression models ($89\% \leq R^2 \leq 0.98$ for all years except 2001 with $R^2 = 0.68$) of flow as a function of drainage area. We applied the model to provide flow predictions for all sites in all years.

Statistical Methods

Variance partitioning

We applied variance partitioning methods (ref) to compare the site-to-site and year-to-year variation in our data and we estimated signal to noise rations ($S:N = \sigma^2_{site} / \sigma^2_{error}$)(Faustini et al. 2007) for our coho salmon counts (spawners per km). Based on the S:N and sample size (?) we estimated the maximum r-squared value that could be achieved using simple linear regression methods (???) (Faustini et al. 2007). We also applied variance partitioning and estimated S:N for coho salmon counts (spawners per km) from index sites in the same study region as reported in Firman et al (In review) and to fish day estimates (fish days per km) for coho salmon from index sites in the Snohomish River basin, WA (fish days per km). None of the data sets contained replicate observations for a particular site in a given year, therefore it was impossible to estimate the site-by-year interaction and it was simply lumped with the error variance.

Regression models that assume normality

Mean density model: To meet normality assumptions, we built a model based on mean spawner densities across years. For sites with at least 7 years of observation (N=81), we estimated the mean spawner density across years using a two-step process. First, to account for differences in return rates in different years, we standardized site observations in a given year by the mean spawner density across all sites in that year. In the second step, we averaged the standardized data for each site across all surveyed years. We then fit a simple linear regression model. To manage for uncertainty in model selection, we present the best 5 models as the set of best models.

Mixed model: To compare models based on this data set to those based on index sites in the same region, we fit a mixed model that included a random intercept and an autoregressive moving average (ARMA) correlation structure using Proc Mixed in SAS (Littell *et al.* 1996) and model selection methods described in Firman et al (In review). The dependent variable for these models was the peak count of coho salmon adults/km, which was log-transformed to meet normality assumptions.

Hierarchical linear model: To compare models from this data set with those based on fish days/km in the Snohomish River basin, WA, we fit hierarchical linear models following the methods of Pess et al (2002) and Feist et al. (2003). All possible subsets up to three variables, including a quadratic term, were fit to each year of spawner density data.

Explicitly modeling the zeros

Site classification: We applied logistic regression models to all years of data in combination and to each individual year in an attempt to identify and predict observations with no spawners. We also fit a mixed logistic model to all years of data, with year and $year^2$ as covariates. This approach is akin to the first step of a two-step procedure (ref) in which the first step is to model presence/absence and the second step is to model the actual response for non-zero (presence) observations. Many variations on two-step approaches are described (e.g., ref and ref) as they are commonly recommended for datasets with many zeros (ref). Plots revealed that zero counts and very low spawner counts occurred across the range of estimated flows. Does this go here?

Negative binomial: Generalized linear regression models were fit to the (rounded) AUC estimates, assuming a negative binomial distribution. Reach length was included as an offset and year as a fixed effect. The response variable, XXX, was log transformed for comparison with other approaches. AIC is not useful in comparing different models because the data used to fit this model is modified during the fitting process. Instead, p-values were used to select the set of best models using a modified stepwise approach.

Explicitly ignoring the zeros

Mixed model for non-zero observations: The mixed model for non-zero observations assumes that the zero spawner counts were the result of a process independent of the landscape, e.g. returning spawners absent from particular reaches and in particular years due to chance. This approach is akin to the second step of a two-step procedure (ref) as described above. We used only the non-zero observations and fit mixed models as summarized above and as described in detail in Firman et al. (In review). Did you log transform the data? You used a normality-based mixed model? AUC, peak counts?

Testing models built on random surveys

We used the models built with this random survey data to make predictions for 44 index sites in the same area. We compared model output to the observed mean spawner density over the years XXXX. These years are later than those used in Firman et al (In review) and comparable to the years used for model building.

Results

Variance partitioning

Most of the variation in this data set occurs between sites, though significant variation also occurs between years (Table 2). The signal to noise ration (S:N) is small (1.1) suggesting that high precision models are not feasible. The maximum R^2 we can achieve for this data set is 0.52 given a perfect correlation between landscape conditions and coho spawning site selection in a given year.

Variance partitioning results were comparable for all three data sets but variance attributable to year (σ^2_{year}) does differ (Table 2). Differences in σ^2_{year} may result from differences is fish behavior or from differences between data sets in the length of the time series and the actual time period surveyed. That σ^2_{year} appears to decrease with the number of years surveyed supports the conclusion of Wiley et al. (1997) that very long time series may be required (~ 10 generations for trout in Michigan streams) to stabilize the variance of estimates of mean fish density.

Regression models that assume normality

Model fit for all three approaches was very poor (right columns of Table 2). When comparing the performance of modeling approaches used on index data (bottom rows, Table 2), even for the same region, to the performance of the random survey sites, we observe a much worse fit. At least two explanations are possible. First, in later years there were generally fewer fish and relationships between landscape conditions and fish density may break down at very low densities (ref?). Second, index sites are generally handpicked, high performance sites. The same relationships between landscape conditions and fish performance may not hold across a wider gradient of site quality. The increased number of observation of zero spawners likely results from both lower densities of fish and a wider gradient of site quality; these zero observations may reduce model fit even further simply because the data fail to meet the assumptions of previous approaches. The mean model, for which the zeros are less problematic, is less powerful because it does not capture the year-to-year variance.

Explicitly modeling zeros

The logistic models were unable to correctly predict observations of zero spawners (Table 3). The proportion of observed zero counts that were correctly predicted as zero counts ranged from 0 – 35% depending on the year. As further confirmation that we are unable to model these zero counts, we note that the set of predictors in the best logistic model varied every year. Only channel gradient appeared in the best model in more than one year. But, it appeared in only 4 out of the 8 years. On average, the models predicted non-spawning sites with 32% accuracy (range: 0 – 63%).

For the mixed logistic model that captured all years of data, many models failed to converge, including all models with two landscape covariates. Overall, channel gradient was the best predictor of spawning versus non-spawning sites. Non-spawning sites were predicted with an even lower accuracy than with the single year model. Prediction accuracy ranged from 8-33% with an average of 19%. (are the numbers for the mixed logistic from results without short reaches?)

The negative binomial model fit adequately as judged by generalized chi-square (but this value isn't provided) (Table 4). Many different landscape factors were included in the set of best models. These included summer temperature range, percent alluvium, precipitation, BLM ownership, % of catchment in forested land with small trees, and gradient (note only in one model), as well as mafic and sedimentary geologies. Unlike in the logistic models above, gradient was not a strong predictor of spawner density and appears in only one of the top 5 models.

Explicitly ignoring zeros

Models using only non-zero observations performed very well (Table 5). There were only two models in the set of best models. They had an r-squared value nearing 0.60, markedly higher than the performance of any other approach. Key landscape predictors were ownership by BLM, percent agriculture, and intrinsic potential. The strong performance of this approach suggests that the zero observations were not providing significant information about the relationship between landscape conditions and spawner density.

Testing models built on random surveys

Correlations with observations at index sites were higher than expected, especially given poor model fit to the survey data. For example, correlations between observations and predictions from the simple linear regression model (using corrected means for sites with at least 7 years of data) was 0.48. Correlation between observations and predictions from the hierarchical linear model and the no zero model were 0.50 and 0.42 respectively. These observed correlations are in the range of the maximum that we might expect given the amount of year-to-year variability and noise in the data (Table 2).

Impacts of additional independent variables

Help Dave – where did these variables get used or not used in above.

1. Intrinsic potential. Once gradient was in the model, no significant additional effect of intrinsic potential was significant. (But it is in no-zeros models)
2. Marine survival?
3. Plots revealed little evidence of a relationship between spawner density and flow, nor between non-spawning and flow. Low or no spawning occurred across the range of flow.
Dave – did flow stay in a candidate predictor or did you remove it after this?

Discussion

Ecological Conclusions from this data set alone

Differences between landscape data and models for predicting salmon on distribution

Comparison of our results to data, models, and results form Firman and pess (and Feist and Steel – ecological comparisons only)
Where is the noise in salmon data – populations, sites, years???
Faustini et al. (2007) state: "It is clear from these values that sampling error and ⁄or short-term fluctuations (within the index period) limit the usefulness of metrics with signal-to-noise ratios below about 3 for associational analyses involving regression or correlation techniques, since such metrics would yield low r^2-values even if they were strongly correlated with some predictor variable(s)." The comment was based on a different model than we have. Their model included site differences, year effects, site by year interaction and residual variation, which could be estimated because the response was subsampled. We have only a single measure of abundance per year, so there is no estimate of variation within sites and years. Our residual variation is pooled year-to-year variability within sites. However, the fact remains that S:N is small for the spawner counts suggesting that high precision models are not feasible.

Marine survival impact? Intrinsic potential?
many SWAM models have been fit in many basins, all used non-randomly sampled data. All were relatively successful. These are generally a subset of possible sites: accessible and known for spawning.

Comparison of modeling techniques for managing high numbers of zeros
Not what is the best technique but what did we learn from each to help understand the ecological conclusions)

Common limitations of ecological data – discuss the problem of lots of zeros and the current lack of a solution. References here would be helpful.

What have we learned from a large probability –sampled data set

We didn't see same patterns as for Index sites (maybe because of random zeros)
Working over very large area now – not enough or too much heterogeneity in landscape predictors?

An enhanced model of coho salmon spawning site selection

From all these techniques, we conclude that landscape impacts exist but only for spawning sites? That there is some random process by which perfectly good sites are not selected. Propose a synthetic view of key factors and management implications? Where is the noise?

References

Jacobs, S.E. and C.X. Cooney. 1994. Improvement in methods used to estimate the spawning escapement of OregonCoastal Natural coho salmon. Oregon Department of Fish and Wildlife, Fish Research Project F-145-R-1. Annual Progress Report, Portland

Figure Legends

Figure 1: Study area with watersheds draining to each survey site identified.

Table 1. Geospatial variables used in analysis and source datalayers with associated scale. Full descriptions of these datalayers can be found in Firman et al. (In review). Variable names are provided only for those variables that ended up in a final model (Tables 2,3,4,5).

Variable Name	**Variable Description**	**Datalayer**	**Map Scale or Gridcell Size**
	Catchment Area Mean hillslope	DEM	1:24,000 10m
	Maximum Annual Temperature Minimum Annual Temperature Annual Temperature Range* Summer Temperature Range** Winter Temperature Range*** Mean Annual Precipitation (mm)	PRISM Climate Data (Daley et al. 1994)	Unknown, 4000m, 500m
	%Large Confiers (>50 cm) %Medium Trees %Small Trees %Hardwoods	Forest cover (Ohmann and Gregory, 2002)	multiple
	%US Bureau of Land Management (BLM) %US Forest Service %Private Industrial Forests %Private Non-Industrial Forests	Land Ownership	multiple
	%Not cut before or during spawner survey %Cut prior to spawner survey %Cut during the period of study? %Non Forest	Disturbance (Lennartz 2005)	multiple
Ag Rural Urban	%Agricultural %Rural %Urban %Natural %Forest	Land-Use	25 m
	%Granitics (HUC scale only), Resistant Sedimentary or Resistant Other (all scales) %Intermediate Sedimentary %Weak rocks - Pyroclastic, schists %Unconsolidated deposits-landslides, glacial	Geology	1:500,000
Cow Density	Cow Density	Cow Density	30 m
Road Density	Road Density (km/km^2)	Roads	1:24,000
 Gradient	Stream Flow (m^3/sec) Stream Gradient	CLAMS stream layer (Burnett *et al*. 2007)	10 m

Table 2: Comparison of variance structure and landscape models for three adult coho salmon datsets. Site variance (σ^2_{Site}) describes the amount of variance between sites and σ^2_{Year} describes the amount of variation between years; S:N = σ^2_{site} / $\sigma^2_{error.}$ Maximum r-squared (Faustini et al. 2007) is an estimate of maximum model strength for a simple regression model explaining observations across sites, given the noise and yearly variation. Note that the comparison analyses used more advanced modeling techniques that explicitly incorporated the annual structure of the data. For definitions of predictors in analysis of Snohomish River index site data, see original reference; definitions of predictors for Oregon Coast index data are identical to those for Oregon Coast random survey site data (Table 1). Results for original analyses only include watershed-scale results; The average R^2 reported for simple linear regressions and for hierarchical linear models are adjusted R^2; those reported for mixed models are the average of a generalized R^2 (Nagelkerke 1991). Comparison analyses are analyses on the random survey site data using the published analysis technique for the index site data from Oregon and Washington. For the random site data, results of the original and comparison analysis are identical but presented in both columns for easy comparisons across both approaches and datasets. Model fit was estimated as the average model fit across the set of best models for both the original and the comparison analysis. No strongest predictors were identified for the HLM of the random survey site data because no statistically significant predictors could be identified using this approach. Mixed geology (mixed geol) indicates that several different geology variables came up in the best set of candidate models but no one geology variable stood out as particularly important. SLR = Simple linear regression on the mean response corrected for annual variation; MM = mixed model; HLM = hierarchical linear modeling.

Data Set	σ^2_{Site}	σ^2_{Year}	S:N Max R^2	Original Analysis: Strongest Predictors	Original Analysis: Model Fit (Average R^2) Modeling approach	Comparison Analysis On Random Survey Data: Strongest Predictors	Comparison Analysis On Random Survey Data: Model Fit (Average R^2) Modeling approach
Random Sites N_{sites}=; N_{years}=9 Oregon Coast, OR 1998-2006	1.3	0.8	1.1 0.52	%BLM $\%BLM^2$ mixed geol cow density	0.19 SLR	%BLM $\%BLM^2$ mixed geol cow density	0.19 SLR
Index Sites N_{sites}=; N_{years}=17 Oregon Coast, OR 1981-1997 Firman et al. In review	0.6	0.1	0.8 0.45	road density %non-forest %private ind win T range mixed geol	0.42 MM		
Index Sites N_{sites}=54; N_{years}=15 Snohomish River, WA 1984-1998 Pess et al. 2002	2.3	0.4	0.9 0.48	%agriculture %till %bedrock %urban	0.18* HLM	-NA-	0.10 HLM

*estimated from data reported in a figure

Table 3. Observed and predicted observations of zero spawners (0) and at least one spawner (+) from single year logistic models. The column total for any given year would be the observed data. The proportion of sites correctly classified is provided for both observations of zero spawners (bold) and observations of spawners (plain text). The overall proportion of correctly classified sites includes but sites with zero spawners and sites with spawners.

Year	**Predicted**	**Observed**		**Proportion Correctly Classified (0 vs +)**	**Proportion Correctly Classified Overall**
		0	+		
1998	0	10	3	**0.345**	0.725
	+	19	48	0.941	
1999	0	4	3	**0.222**	0.798
	+	14	63	0.955	
2000	0	3	4	**0.188**	0.800
	+	13	65	0.942	
2001	0	0	1	**0.000**	0.910
	+	6	71	0.986	
2002	0	1	1	**0.250**	0.956
	+	3	85	0.988	
2004	0	0	1	**0.000**	0.872
	+	10	75	0.987	
2005	0	0	1	**0.000**	0.909
	+	6	70	0.986	
2006	0	2	2	**0.250**	0.905
	+	6	74	0.974	

Table 4: Negative Binomial models on the original scale.

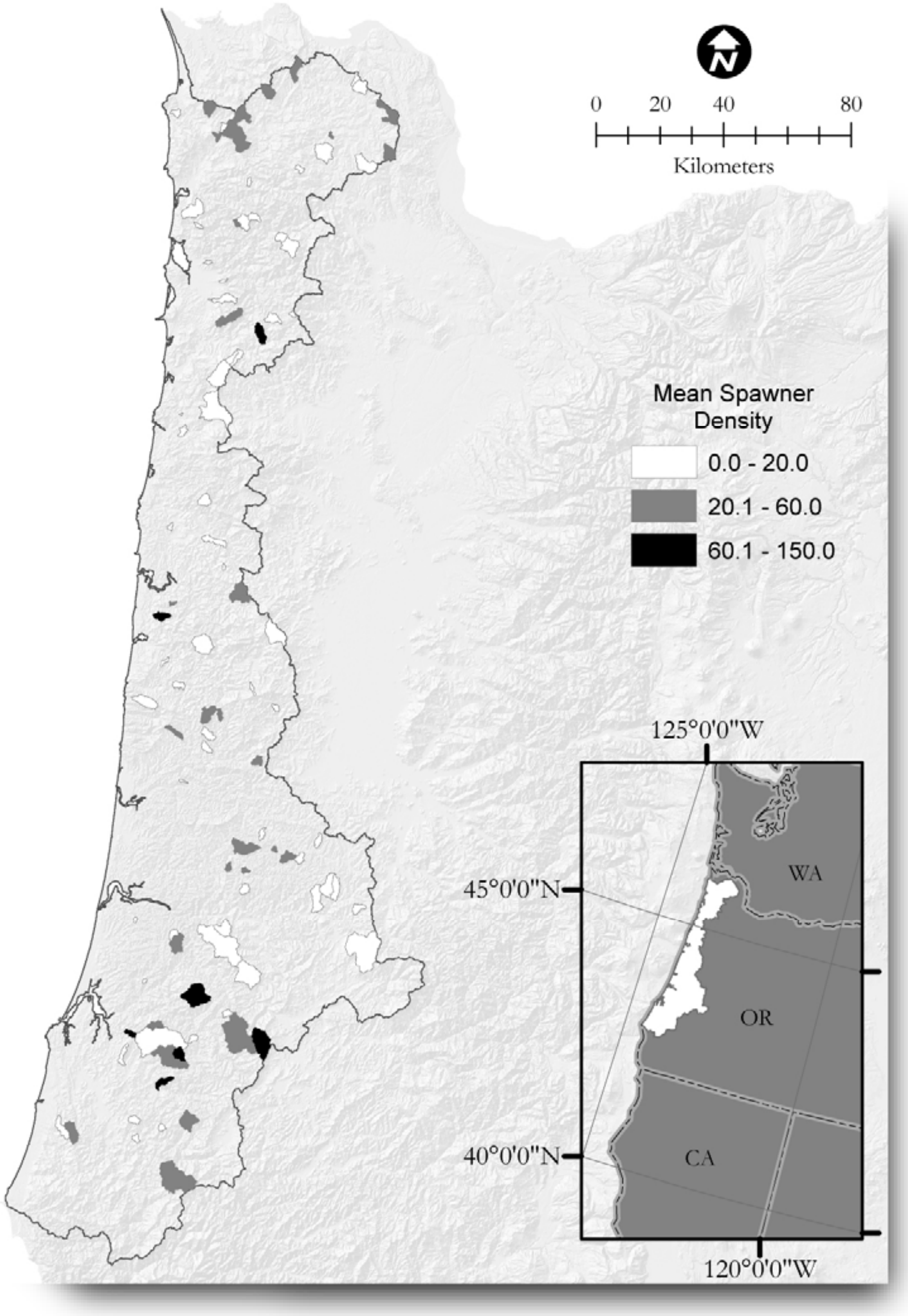
Model	t_1 $Pr(t_1)$	t_2 $Pr(t_2)$	t_3 $Pr(t_3)$
3.683 + 1.067*Year - 0.0878*Year^2 – 0.000554*Precip - 0.0257*SumRange - 0.0714*Alluvium	-3.568 0.0004	-3.766 0.0002	-4.172 < 0.0001
1.568 + 1.058*Year - 0.0864*Year^2 - 0.0630*Alluvium - 0.0119*Mafic - 0.0175*SumRange	-4.140 < 0.0001	-4.573 < 0.0001	-3.560 0.0004
-1.884 + 1.044*Year - 0.0851*Year^2 - 0.0370*BLM + 0.000764*BLM^2 + 0.00864*Sedimentary	-2.978 0.0030	3.572 0.0004	3.538 0.00044
2.046 + 1.085*Year - 0.0887*Year^2 + 0.0130*BLM - 0.0241*SumRange - 0.0108*Mafic	3.524 0.0006	-4.431 < 0.0001	-4.224 < 0.0001
-2.060 + 1.052*Year - 0.0861*Year^2 + 0.121*SmallTrees - 0.00217*SmallTree^2 - 0.191*Gradient	4.140 < 0.0001	-3.700 0.0002	-3.523 0.0005

t_i and $Pr(t_i)$, I = 1, 2, 3, refer to the t and its p-value for the coefficients for each of the three landscape covariates.

Table 5: Results of the mixed model using only positive observations. AIC weights (AIC wt) indicate the relative strength of the two models. They are also provided so that model users can used a weighted average of the predictions from the two best models. Variable definitions are in Table 1.

Model	**R^2**	**AIC**	**AIC wt**
$2.530 - 0.0398*BLM + 0.000873*BLM^2 + 0.543*IntPotential$	0.593	1798.5	0.760
$2.540 - 0.190*Ag + 0.00652*Ag^2 + 0.856*IntPotential$	0.568	1800.89	0.240

Figure 1


0
20
40
80
Kilometers
Mean Spawner Density
0.0 - 20.0
20.1 - 60.0
60.1 - 150.0
125°0'0"W
45°0'0"N
40°0'0"N
120°0'0"W
WA
OR
CA

Historical Splash Dam Stream Disturbance Detection in the Oregon Coast Range

Proposal for Master Thesis
Department of Fisheries and Wildlife Science

Rebecca Miller
December 11, 2008

Major Professors:
Dr. Kelly Burnett & Dr. Joe Ebersole

Minor Advisor
S. Mark Meyers

Signatures

____Major Professor

____Major Professor

____Minor Advisor

____Graduate Representative

ABSTRACT

Splash dams are an efficient method of transporting lumber to downstream mills throughout world history. In Oregon, the splash dams were first constructed in 1884 and utilized until prohibited in 1956. Historic anecdotal observations from fisheries biologists, historians and local landowners describe how splash dams altered physical stream characteristics and how those alterations adversely impact salmon. The environmental legacy of splash dams will be measured by comparing summarized stream habitat and salmon abundance data in basins that were splash dammed with basins that were not. Splash dammed basins are anticipated to show a decreased amount of large wood, percentage of spawning gravel substrates and salmon abundance.

Introduction:

Environmental legacy studies are increasingly recognized as an important tool to identify whether past actions shape and influence current ecosystem condition and function. For example, in the Yucatan Peninsula, deposition of "Mayan Clay" in lakes and lowlands can be traced back to the civilization's 700-900 AD population explosion and ensuing deforestation which resulted in rapid soil erosion (Foster, 2003). In the United States, a study of watersheds in North Carolina determined that land use practices forty years prior could explain the amount of present day aquatic macroinvertebrate species diversity(Harding, 1998).

Few formal studies have assessed the environmental legacy of stream modification and disturbance caused by historical splash dams (Napolitano, 1998, IPSFCommission, 1966). Yet, much literature cites splash dams as one of the key historical culprits in the decline of salmon populations (Taylor, 1999, Lichatowich, 1999, Northcote, 2004). Preliminary data analysis conducted by the Aquatic and Land Interactions Program (ALI) of the Pacific Northwest Research Station suggests that the density of wood in streams may differ between basins that were splash dammed compared to basins that were not (Vance-Borland per. communication).

Splash dams spanned the width of the stream; logs were stored behind the dam and released in large freshets to downstream mills. The dams were a common tool for log transport in Oregon, beginning in 1884 until prohibited in 1957(Beckham, 1990). While effective at moving logs, the log drives caused considerable damage to streams and salmon habitat (Bell, 1941, Wendler, 1955, Shotton, 1926, IPSFCommission, 1966). Anecdotal evidence has been documented by fisheries biologists, historians and local landowners that persistent splash dam use substantially changed stream composition and reduced salmon populations.

A primary product of this research will be a centralized, publically available, geodatabase and map of individual splash dams sites from 1884-1957. The map will add a layer of historical knowledge to help understand current instream conditions and guide salmonid and watershed restoration strategies. The data may also help unravel unexplained environmental relationships. For example, in the Oregon Coast Range densities of pool habitats or large wood in streams were only weakly related to land use and land cover characteristics(Burnett et al. in prep). However such landscape characteristics have explained significant variation in steam habitats or fish populations in other areas (Burnett, 2006, Hughes, 2006).

Project Question: Can the environmental legacy of splash dams be detected by examining instream characteristics?

Project Objectives:

1) Locate, identify, map and field evaluation of historical splash dam sites.

2) Compare stream characteristics and salmon density between splash dammed basins and non-splash dammed areas.

Hypotheses:

a) Within splash dam watersheds, streams will be less complex downstream than upstream of a dam site.

b) Stream habitat complexity will be lower in splash dammed watersheds than in non-splash dammed watersheds.

c) Fish density will be lower in splash dammed watersheds than in non-splashed dammed watersheds.

Expected Products:

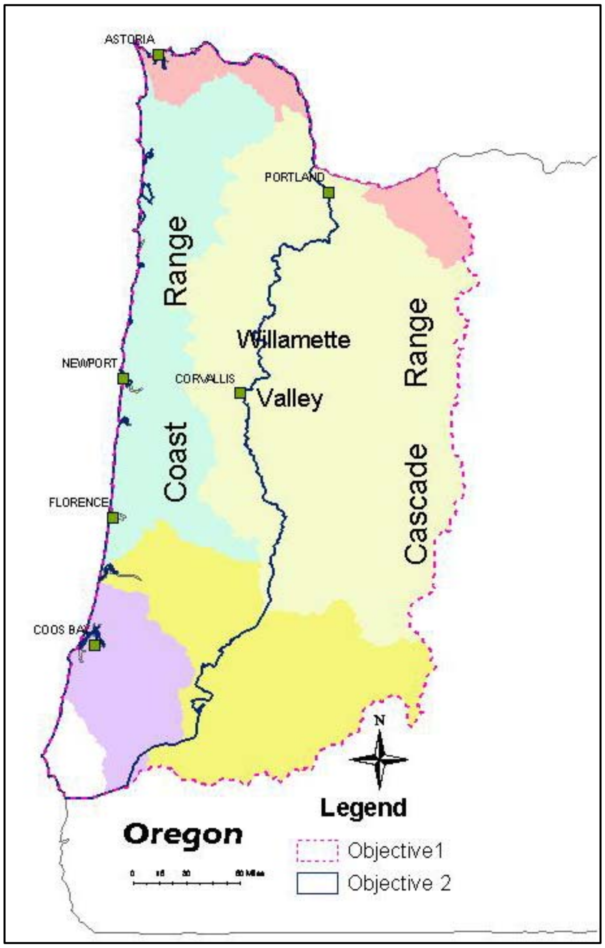
1) A GIS geodatabase of western Oregon splash dam sites.

2) A pdf. map of western Oregon splash dams.

3) An article published in a peer-reviewed journal

Study Area:

The study area is a nested approach with Objective 1 at larger western Oregon scale (6 million ha) and Objective 2 at the Coastal Province of Oregon scale (2.5 million ha)(Map 1). Western Oregon is flanked by the Coast (0-4,100 ft) and Cascade (0-11,000ft) Mountain ranges with the Willamette Valley nestled between. The climate is a mild maritime; precipitation observed at both mountain range locations can be over 100 inches per year. The underlain geology in the Coast Range is primarily marine sandstone and shale, with basalts dominant in the northern portion of the Coast Range. The Cascade Range is primarily underlain by basalts, with the Willamette Valley primarily underlain by silt and clay. Dominate land use in the mountain ranges is forestry, while the Willamette Valley is agriculture. Since pioneer settlement, western Oregon is the population center for the state, with more than 70% of the state's population.



__Background:__

Long-term 'press' and short-term 'pulse' disturbances can cause physical or biological attributes to change (Yount, 1990). The duration of the active press/pulse must be considered relative to the time scale of the physical or biological processes of interest (Glasby, 1996). Pulse disturbances occur during one phase of the physical or biological process, while press disturbances exceed the time scale of a physical or biological process. For example, natural stream flood disturbances generally rearrange stream habitat every 1-10 years (Frissell, 1986), however splash dams disrupted this natural disturbance frequency for 70 years. A biological example of a pulse disturbance is a 3-day 100 year flood event flushing a cohort of salmon downstream; while a press disturbance is a splash dam operating on a stream for 40 years, disrupting 10 generations of coho salmon (*Oncorhynchus kisutch*). Thus, this project categorizes splash dams as a press disturbance.

When the press is inactive, two responses will result. Over time, the biological and physical response variables will either return to a pre-press condition (discrete) or maintain disturbed attributes even when the press is inactive (protracted) (Figure

2)(Glasby, 1996). This project will address whether the legacy of press disturbed splash dammed watersheds have a present-day protracted or discrete disturbance response.

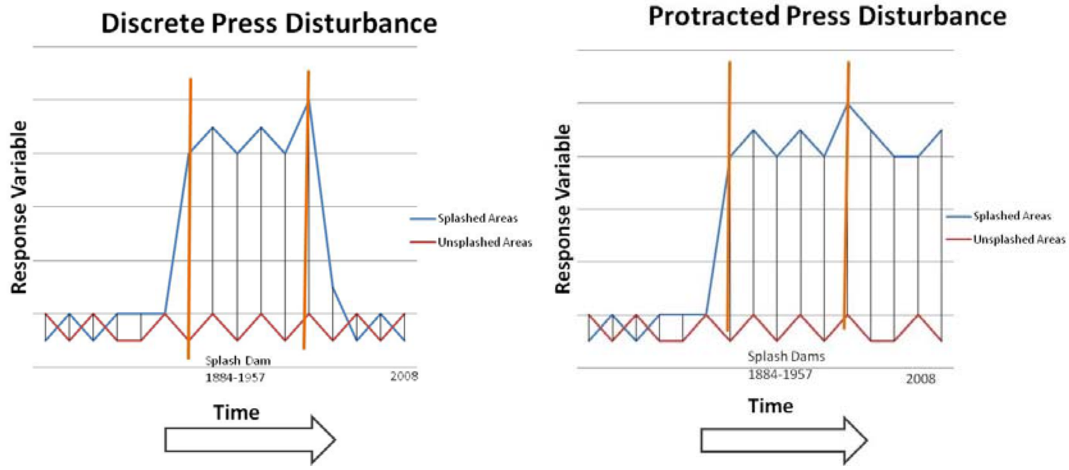


Figure 2 : Adapted from Glasby, 1996

At the turn of the century, transportation of logs to mills was the most problematic and costly limiting factor for Oregon timber operators. Overland road networks were sparse, thus splash dams were considered a practical way to move timber in a cost and time efficient manner (Brown, 1936). For example on the Middle Fork Coquille in 1924 the Middle Fork Boom Company drove forty-four million board feet out of the surrounding timberlands in just one year (Farnell, 1979). Splash dams were first constructed in Oregon in 1884 along the Coos River(Beckham, 1990). By 1900, more than 160 splash dams were used along the Oregon Coastal and Columbia tributaries (Sedell, 1985).

A splash dam would span the width of the stream impounding water behind it (Photo 1). Logs were cut, placed in the stream and stored in the rising water behind the dam. Typically, gates would control flow. The floating logs were released under ideal flow and weather conditions, when water velocity and volume were sufficient to move the logs downstream without creating overbank flooding and loss of logs to the surrounding area(Beckham, 1990). On larger river systems such as the Coquille and Coos, multiple splash dams were constructed and each gate opening had to be coordinated to help push the logs downstream (Beckham, 1990). The rivers proved to be an effective mechanism for log transport.

Photo 2: Aasen Brothers Splash Dam in 1912 on Middle Creek, Oregon. Photo courtesy of the Coos County Historical Society. http://www.cooshistory.org

Downstream of the dams, the stream had to be prepared and 'improved' for splash dam operations. Improvement hastened the movement of logs and prevented large log drive jams; some troublesome log drive jams over one mile in length were reported (Coy, 1992). In Oregon and Washington between 1880 and 1905, intensive and extensive 'stream improvement' for navigation and logging was conducted by timber companies, private stream cleaning companies (130 registered in Washington) and the United States Army Corps. of Engineers (Sedell, 1981b). Proper stream cleaning instruction called for the removal of natural log jams, boulders or other obstacles within the main channel. Side channels and wetlands were to be blocked by wooden cribs (Brown, 1936). By 1910, much of the stream complexity in the United States was removed from a majority of streams and rivers(Sedell, 1981a). In effect, a splash dammed stream became a giant chute for log transport.

Although splash damming was an effective tool for the timber industry, it had disastrous effects on salmon and their habitat. Splash dams blocked fish migration and reduced stream flow, while splash dam log drives gouged and swept away spawning gravels, rearing areas and food sources greatly simplifying habitats (Photo 2). Stream 'improvement' removed natural large wood, alcoves and side channels. Log drives also caused physical harm to fish. Testimony from Mrs. Olive Moore at the Nehalem Boom Company Hearing in (Oregon, 1924) describes splash dam effects on the Nehalem. Before the log drives

> *Millions of salmon were below the dam. When they would let the splash loose that would throw the fish all out on the banks. Mr. Wallula picked up about five gunny sacks full of nice salmon. …I went among the logs and there were nice salmon mashed up between the logs. …It destroys the small fish…there was a small pool and after a splash of water went down it left a bunch of salmon. They just stayed right there in that pool. The water left them and they were dead.*

Photo 2: Calapooia River August 2008. Near river mile 50-52, where 2 splash dam sites from 1906-1911 were located

In Oregon, little formal attention was given to coastal fisheries resources south of the Columbia River or splash dam operations, until the report by Gharrett and Hodges (Gharrett, 1950). It briefly notes that splash dams, particularly on the Coos and Coquille, had blocked fish passage, sluiced gravel downstream and destroyed spawning grounds. By 1956, state biologists took a stronger view on splash dams. A letter from the Oregon Fish Commission reports streams facilitating splash dams 'resulted in almost complete annihilation of salmon and steelhead runs' (James, December 7, 1956)

In Washington, a fisheries department report on splash dams describes observations of splash dam effects on fish (Wendler, 1955):

> *"The actual splashing of a dam affected fish in several ways. If fish were spawning, sluiced logs and tremendously increased flows would drive them off their nests. On the day prior to the splashing of one of the large Stockwell dams on the Humptulips River, an observer had noted a large number of steelhead below the apron of the dam. After splashing, no fish were seen, nor were any seen the following day.*
>
> *"Besides harming the fish physically, the stream environment was often adversely affected by splashing. Moving logs gouged furrows in the gravel and many instances the suddenly increased flows scoured or moved the gravel bars, leaving only barren bedrock or heavy boulders…Dam operators have stated that fish runs reaching the dams were reduced within 3-4 years after initial construction."*

Mounting evidence indicated splash dams harmed salmonid fisheries. Opposition to the practice grew and by 1956 the Oregon legislature prohibited splash dams and the use of rivers for log drives (Beckham, 1990). The dismantling of splash dams improved fish passage(Morgan, May 31, 1957) and stream flow. However, spawning gravel and large wood would not recover as quickly.

At Adams River, British Columbia, a survey was conducted in 1940, eleven years after the splash dam was decommissioned. The report observed

> *The effects of driving logs down a salmon stream are illustrated well in the Adams River. Bars and shallows are deepened and pools are filled due to gouging of the bottom. Curves on the course are straightened by the impact floating logs and the stream tends to become a swift straight raceway of uniform depth and velocity. When driving ceases, the river begins to return to the natural conditions, but the process is slow. Eleven*

years later the Adams River still shows markedly the alterations due to the movement of logs. (Bell, 1941)

In California, a 1998 study examined the amount of large wood in the North Casper Creek watershed which was splash dammed 94 years prior, in 1904. The control, Upper Little Man watershed was not splash dammed and contains old growth redwood. Large wood loading of North Casper Creek was approximately 24 kgm^{-2}, while the old growth stream had a large wood loading of 141 kgm^{-2}. Before the splash damming, North Casper Creek more likely resembled stream conditions that are observed above the splash dam site, where banks are less than 0.6 m high. Downstream of the splash dam site the banks are typically 1-2 m above channel thalwag (Napolitano, 1998).

The British Columbia description and California study show that historic splash dam practices can have long lasting effects on stream dynamics and large wood loading. This M.S. thesis project will examine whether this environmental legacy applies to Oregon coastal basins.

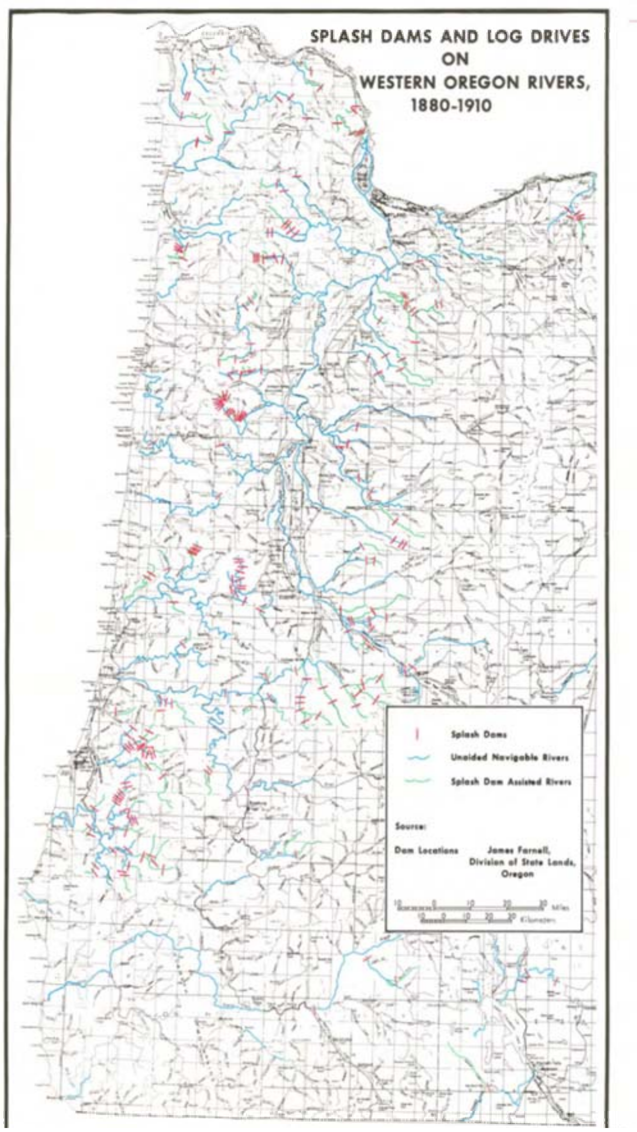
Objective 1: Locate, identify and map historical splash dam sites using ARCMap

Currently, there is no peer reviewed GIS data layer of historical splash dam sites or log drive sections in Western Oregon. The information is critical for this study to identify watersheds for comparing instream characteristics between splash dammed and non-splashed areas. Essentially, the 'treated' watersheds will have historical splash dam sites, while the 'control' watersheds will have no record of stream log transport. Streams that facilitated log drives, but not via splash dams, will be mapped concurrently, to ensure control basins have not been affected by log transport.

Information on historical splash dam sites and log drive sections in Western Oregon (Map 1) will be compiled from multiple sources (Table 1). The two main sources of information come are a series of reports on river navigability and public waterway ownership, referred to as the 'Farnell Reports' and the Public Utilities Commission Files which are located in Salem, Oregon.

Potential Splash Dam Sources	Location	Potential Data Type
Farnell Reports	Corvallis	Photos, T/R/S, River Mile and Verbal Location Description
State of Oregon Archives (Public Utilities Commission)	Salem	Splash Dam and Stream Lease Requests, Maps, Court Records
Oregon Historical Society	Portland	Photos, Maps, Personal Memoirs, Timber Company Documents
Coos Historical and Maritime Museum	North Bend	Photos, Maps, Personal Memoirs, Timber Company Documents
Agencies (Ore. Dept. Forestry, BLM, USFS)	Various	Local Knowledge of Splash Dam Sites
Watershed Councils	Various	Local Knowledge of Splash Dam Sites
Timber Companies	Various	Local Knowledge of Splash Dam Sites
Watershed Assessments	Various	Maps, Photos
The Valley Library	Corvallis	Books, Journal Articles
County Courthouses	Various	Splash Dam and Stream Lease Requests, Maps, Court Records

Table 1: Potential Splash Dam Sources



Map 1: Splash dams of Western Oregon 1880-1910, (Sedell, 1985)

<u>Farnell Navigability Reports:</u> Dr. James E Farnell and Stephen Moser of the Oregon Division of State Lands (DSL) conducted extensive research for the navigability and public waterway reports. Splash dam and log drive sites were found by interviewing former 'river rats,' searching through industry journal articles (e.g. *The*

Timberman), court testimony, logging liens, port and county records, local news clippings and photographs. A map (Figure 1) produced in 1985 was derived from these reports and identifies splash dam sites in western Oregon between 1880 and 1910 (Sedell, 1985). This map has an accompanying GIS point layer created by Aquatic and Landscapes and Interactions Program of the USFS PNW Research Station in Corvallis, Oregon.

However, this GIS layer has not been peer reviewed and each data point is associated with limited attribute information. Data fields are stream name, whether the stream was assisted, un-assisted or unknown, and whether the dam was 'new' or 'old.'

<u>Public Utilities Commission:</u> The Oregon Public Utilities Commission kept records of franchised log boom companies beginning in 1917. Boom company franchises leased portions of the river from the state. The companies prepared streams, built and operated splash dams and provided expertise and manpower for dangerous log drives. Timber operators within the basin would then pay a fee to the companies for the transport of their logs to downstream mills. The franchises submitted applications to the state, with detailed maps of splash dam locations and stream sections leased for log driving. However, non-franchised dams did not need to report splash dam locations to the State. Farnell navigability reports are the best source of location and attribute information on splash dams that were not registered to the Public Utilities Commission.

Mapping Protocol: All splash dam sites from 1880-1957 found from examined data sources will be mapped electronically using Geographic Information Systems 9.2 ARCMap in the Oregon Lambert Conic coordinate system. This coordinate system is the agency standard for the state of Oregon. Splash dams will be mapped at the 1:100,000 scale. A base layer of electronic USGS topographical maps, digital orthoquads, plss (Township/Range/Section) and rivers will help identify splash dam locations. Museum collections must be reviewed on site; therefore a laptop computer will be taken to each museum's research room for data collection. The most precise location for each dam will be mapped as a point. Additionally, any reported stream log driving sections will be mapped as a line.

A geodatabase will contain the fields in Table 2. It may not be possible to fill in all data fields for each splash dam, as the information may have been lost or never existed. However, data for certain fields will be recorded for each dam (Table 2).

GEO DATA FIELDS

points -splash dams

Stream	Owner	Dam Name	Date of Use	Dam Construction	Dam Height	Calculated Water Volume	Data Reliability (h,m,l)	Location Confidence (h,m,l)	Notes	Source Citation	Secondary Source Location	Photo Reference	Photo Reference	Point on 1985 map (y/n)

lines-log drives

Stream	Date of Use	Lessee	Lessor (permissioning body)	Data Reliability (h,m,l)	Location Confidence (h,m,l)	Notes	Log Drive (y,n, unknown.)	Board Feet	Source Citation	Secondary Source Location	Photo Reference	Photo Reference	Shape Length	Point on 1985 map (y/n)

Blue = Required fields

Table 2: Geodatabase Fields

Field Evaluation: A random sub-sample of 10 splash dam sites in each location confidence type (H, M, L) will be ground-truthed for location accuracy and present-day detection. Locations will be evaluated for historical splash dam evidence; this evidence could include remnant dam structures, channel widening from historical log ponds, or geomorphic abnormalities. Once each location is evaluated, a GPS waypoint and photo point will be taken, along with a narrative description (Table 3).

Location Confidence	H	M	L
Detected in Field			
Evidence Type (Narrative Description)			
GPS Waypoint			
Mapped Accurately (Distance from Archived Location)			
Photo point			
Time (CPUE)			

Table 3: Splash Dam Field Evaluation Data Sheet

<u>Objective 2:</u> Compare stream habitat and salmon density between splash dammed and non-splash dammed areas.

Hypothesis 1. *Within splash dammed watersheds, streams will be less complex downstream than upstream of a dam site.*

Splash Dam Site Selection:

Splash dams will be selected using an Arc/GIS Query. An initial set of splash dams will be identified as those in areas dominated by sedimentary geology and rated 'High' for data reliability and location confidence. The subset of these splash dams for which stream habitat data are available upstream and downstream of a site will be chosen for analysis.

Data Sets:

Response Data: Stream habitat data from the Oregon Department of Fish and Wildlife(ODFW) Aquatic Inventories Continuous Habitat Surveys are easily accessible by downloading website E.00 files(Jones, 2007). Field data from 1990 to present are available on several physical stream habitat characteristics. To assess the signal to noise ratio for these characteristics, 12% of 1998-2000 habitat sites were resurveyed. Instream characteristics relevant to this study that yielded the most reliable data(S:N >10) percent pools (S:N=17), deep pools per km (S:N=9.3) and percent bedrock (S:N = 13.9). Wood counts can be used, but some caution must be used with the data set ; the most reliable wood counts are wood jams per km (S:N =4.5) and wood volume per 100 m (S:N = 3.6) (Flitcroft, 2002)

Ancillary Data: Several datasets are available if needed for prior stratification of the splash dam data or as covariates in analysis. The geology layer is necessary to select splash dams in the sedimentary rock types(Ludington, 2006) and was generated from the 1:500,000 scale Quaternary geologic map of Oregon(Walker, 1991). Data on stream gradient, drainage area, and annual mean flow were modeled from 10m DEMs for all coastal streams in the Oregon Coast Range(Clarke, 2008) and are in a GIS dataset.

Data Analysis: Data for each examined stream habitat parameter will be summarized in two groups: above or below splash dam site. Stream habitat characteristics evaluated are located in Table 1. The mean difference (residuals) between habitat characteristics above and below splash dams will be compared using a paired t-test with data paired by splash dam. A paired t-test will show whether the means of the downstream response variables are different from the means of the upstream variables (Figure 2). The model assumes that there is normal variance, equal standard deviations, with independent observations. Data will be checked for extreme outliers and if needed, a transformation will be conducted. The statistical analysis will show explanatory significance if the p-value is smaller than 0.1 with a 90% Confidence Interval.

An example of the paired t-test equation is below.

t-statistic =[(above dam mean-below dam mean) – (hypothesis null (0)]/ Standard Error

Response Variable	Hypothesis I	Hypothesis II	Hypothesis III
% Bedrock	x	x	
% Gravel	x	x	
Wood Volume	x	x	
Habitat Units/100m	x	x	
Number of Pools > 1m	x	x	
Percent Pools		x	
Fish Abundance			x

Table 4: Response Variables by Hypothesis Type

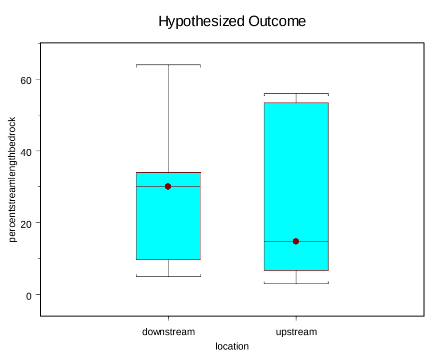


Figure 3: Hypothesized Outcome

Hypothesis 2. *Stream habitat complexity will be lower in splash dammed watersheds than non-splash dammed watersheds.*

Splash Dam Watershed and Control Watershed Selection:

Splash dam watersheds will be selected using an Arc/GIS Query. An initial set of splash dam watersheds will be dominated by sedimentary geology, contain stream habitat data, rated 'High' for data reliability and a high or medium location confidence. To control for geography, overlay quadrats of 30x30 miles on the study site will be established. Each splash dam and control site pairing must be located within the same quadrat. Splash dam and control watersheds will be stratified as follows; watersheds will contain a similar length of stream habitat data, similar stream order and gradient. Both sites will have a dominant forestry land cover (Kline, 2003)

Data Sets:

Response Data: Response data is the same set as Hypothesis 1. In the event of limited ODFW stream habitat data, other probabilistic habitat databases can be acquired (ODEQ, EPA, Oregon Plan, AREMP).

Ancillary Data: Ancillary data is the same as Hypothesis 1 and includes land cover data. Land cover data is included so that all compared watersheds are more likely to have similar land cover- both historically and present day. Both watershed will have a dominate forestry cover of 75%. The basin will be excluded if it is less than 75% forestry.

Data Analysis: Data will be stratified during the site selection stage, therefore the targeted variable of splashed 'treated' and non-splashed 'control' watersheds are relatively homogeneous. Habitat data (Table 1) will be summarized and divided into two groups with a categorical variable set for either 'treated' splash dam watershed or control watershed. Mean habitat characteristics in control and treated watersheds will be compared using a linear regression. A linear regression slope will show whether the control watershed response variables are different from the means of the treated watershed variables. The model assumes that there is normal variance, equal standard deviations, with independent observations. Data will be checked for extreme outliers and model fit will be tested by the Extra Sum of Squares F-test. The statistical analysis will show explanatory significance if the p-value is smaller than 0.1 with a 90% Confidence Interval. An example of a regression model is as follows.

Percent Bedrock I Treated + Gradient + Stream Order +Flow

Wood Volume I Treated + Gradient + Stream Order +Flow

Hypothesis 3. *Fish will be less abundant in splash dammed watersheds than in non-splash dammed watersheds.*

Splash Dam Watershed and Control Watershed Selection:

Splash dammed watersheds will be selected using an Arc/GIS Query. An initial set of splash dam watersheds will be dominated by sedimentary geology, contain fish abundance data, rated 'High' for data reliability and a high or medium location confidence. Overlay quadrats of 30x30 miles on the study site will be established. Each splash dam and control site pairing must be located within the same quadrat. Splash dam and control watersheds will be stratified as follows; watersheds will contain a similar stream length, similar stream order and gradient. Both sites will have a dominant forestry land cover (Kline, 2003).

<u>About the Data:</u> The Oregon Plan for Salmon and Watersheds requires an ODFW status and trend census of juvenile coho populations. Sites are randomly selected in each 5 coastal Gene Conservation Areas. At each sampled reach site, a snorkel crew counts the number of coho juveniles in pools greater than 6 m^2 surface area and a depth greater than 40 cm. Random resurveying is conducted for quality control and ODFW strives for a less than 20% error rate (Jepsen, 2007). If there are too few matching sites with this population data set, the population dataset can be expanded outward to include EPA, ODEQ or Rapid-Bio Assessments conducted by Bio-Surveys LCC.

<u>Data Analysis:</u> Fish abundance will be summarized for each watershed and divided into two groups with a categorical variable set for either 'treated' dam site or control. Mean fish abundance for each control and treated watersheds will be compared using a linear regression. A linear regression slope will show whether the control watershed response variables are different from the treated watershed variables. The model assumes that there is normal variance, equal standard deviations, with independent observations. Data will be checked for extreme outliers and model fit will be tested by the Extra Sum of Squares F-test. The statistical analysis will show explanatory significance if the p-value is smaller than 0.1 with a 90% Confidence Interval.

Example of statistical model is seen below.

Fish abundance I Treated + Gradient + Stream Order +Flow

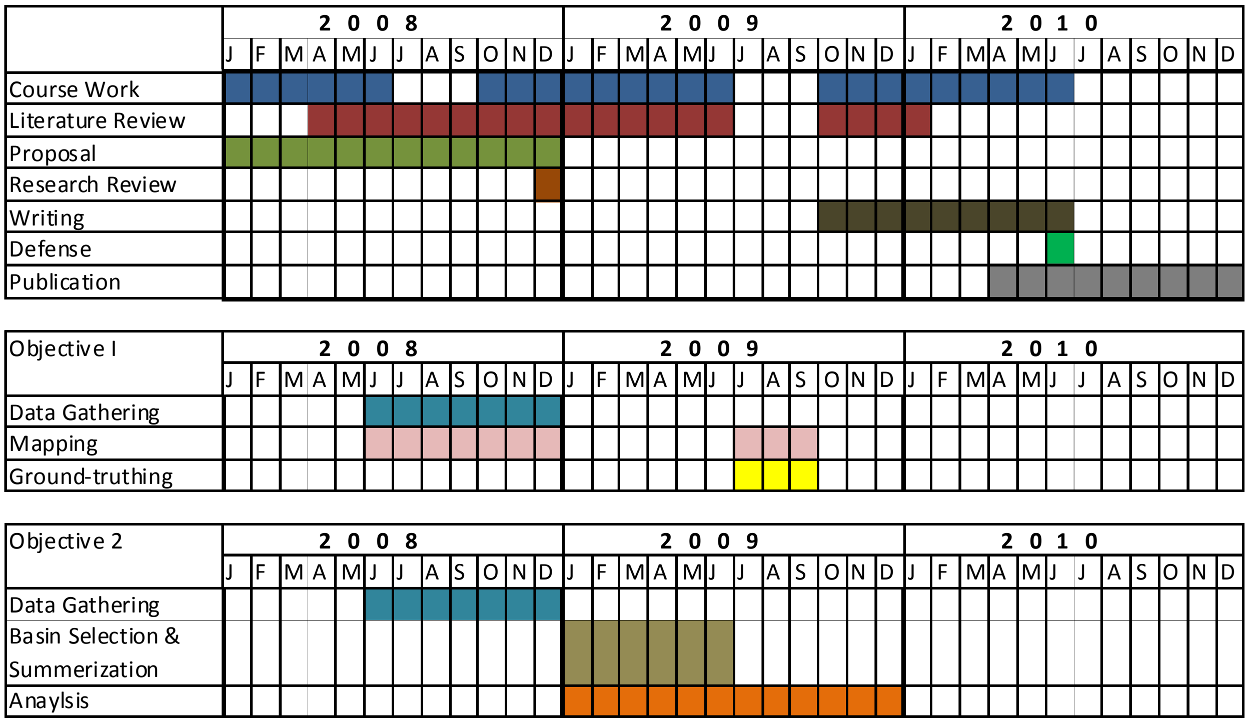
Anticipated Results:

This project will illuminate whether the environmental legacy of historic splash dam operations in salmonid stream habitat still persist today. Historic observations from local landowners and fish biologists describe high water flow and velocity released during log drives. These events swept away bed gravel, soil and any remaining large wood in the stream channel. Additionally, key wood, which would normally trap sediments and sort gravels was removed by humans through drive preparation. This resulted in a bedrock substrate for streams. Since spawning gravels and quality habitat have been historically missing, lower densities of salmonids are projected in splash dammed basins.

I think my results will provide a piece to the environmental legacy puzzle. Results will either show lower habitat or fish abundance response variables in splash dam basins, which indicates the basins are experiencing a protracted disturbance response. Alternatively, results may show a negligible difference between splash dammed and non-splash dammed basins. This could indicate the historic use of splash dams do not currently influence salmonid habitat. However, detection of historic splash dams may be dampened by subsequent stream events, such as floods, landslide stream input or habitat restoration projects. Additionally, it may be plausible that control streams did in fact have splash dams or drives, but were never recorded and/or no visible signs remain.

Fifty years have passed since the prohibition of splash dams in Oregon. I predict splash dam disturbances altered the streams so significantly that the process of recovery will be slow, as was indicated by the Napolitano study. The abiotic environment recovery time may vary and the biological response will then follow, however it may take many, perhaps one-hundred years or more to reach this new equilibrium (Nilsson, 2005). I anticipate the M.S. project will show basins that received splash dam practices have not been able to retain high quality salmonid habitat. This may signify that intensive whole watershed restoration in these basins is necessary. If salmon restoration is a priority, reversing of historic actions may necessary. Just as intentionally as previous generations engineered streams for log transport, future generations may need to facilitate the streams back towards a pre-splash dam condition.

Timeline



Budget

Item	Funding Source	Amount
Tutiton	OWEB/USFS	3042/term
Stipened	OWEB/USFS	~1500/month
Travel-museums, field ground truthing	OWEB/USFS	2000
Museum- fees, copies, documentation	OWEB/USFS	100
Office\Phone	USFS	0
Field work equipment (borrow GPS)	Dept. Geoscience	0
Data Analysis\Computer program	OWEB/USFS	500

References

Beckham, D. (1990) *Swift Flows the River: Log Driving in Oregon.* Arago Books, Coos Bay.

Bell, M. C., R.I. Jackson, (1941) Adams River Dam. pp. 19. International Pacific Salmon Fisheries Commission.

Brown, N. C. (1936) *Logging-Transportation.* John Wiley and Sons, Inc., New York.

Burnett, K. M., Gordon H. Reeves, Shannon Clarke, Kelly R. Christiansen (2006) Comparing riparian and catchment influences of stream habitat in a forested montane landscape. *American Fisheries Society Symposium 48* (ed A. F. Society).

Clarke, S. E., Burnett, Kelly M., Miller, Daniel J. (2008) Modeling Streams and Hydrogeomorphic Attributes in Oregon from Digital and Field Data. *Journal of the American Water Resources Association,* 44, 459-477.

Coy, F. E. J., Tom Fuller, Larry G. Meadows, Don Fig (1992) Splash Dam Construction in Eastern Kentucky's Red River Drainage Area. *Forest & Conservation History,* Vol. 36, No. 4, 5.

Farnell, J. E. (1979) Coos and Coquille Rivers Navigability Studies. (ed D. o. S. Lands), pp. 85. Salem.

Flitcroft, R., Kim Jones, Kelly Reis, Barry Thom (2002) Year 2000 stream habitat conditions in western Oregon. (ed O. D. o. F. a. Wildlife). State of Oregon, Portland.

Foster, D., Frederick Swanson, John Aber, Ingrid Burke, Nicholas Brokaw, David Tilman, Alan Knapp (2003) The Importance of Land-Use Legacies to Ecology and Conservation. *BioScience,* 53, 77-88.

Frissell, C. A., Liss, William J., Warren, Charles E., Hurley, Michael D. (1986) A Hierarchical Framework for Stream Habitat Classification: Viewing Streams in a Watershed Context. *Environmental Management,* 10, 199-214.

Gharrett, J. T., John I. Hodges (1950) Salmon fisheries of the coastal rivers of Oregon south of the Columbia. (ed O. F. Commission). Oregon Fish Commission, Portland, Or.

Glasby, T. M., Underwood, A.J. (1996) Sampling to differentiate between pulse and press perturbations *Environmental Monitoring and Assessment,* 42, 241-252.

Harding, J. S., E. F. Benfield, P.V. Bolstad, G.S. Helfman, E.B.J. Jones III (1998) Stream biodiversity: The ghost of land use past. *Proceedings of the National Academy of Sciences,* 95, 14843–14847.

Hughes, R. M. (2006) Landscape influences on stream habitats and biological assemblages. *American Fisheries Society symposium; 48* (ed A. F. Society).

IPSFCommission, I. P. S. F. (1966) Effects of log driving on the salmon and trout populations in the Stellako River., pp. 88. Vancouver.

James, N. C. (December 7, 1956) Letter to Public Utilities Commissioner Holtzel. (ed F. Commission). Portland.

Jepsen, D. B., Kevin Leader (2007) Abundance monitoring of juvenile salmonids in Oregon coastal and lower Columbia Streams (ed O. D. o. F. a. Wildlife). Corvallis.

Jones, K. (2007) Aquatic Inventories Project Habitat and Reach Data Coverages. (ed O. D. o. F. a. Wildlife). State of Oregon, Corvallis.

Kline, J. D. (2003) Characterizing Land Use Chang in Multidisciplinary Landscape-Level Analyses. *Agricultural and Resource Economics Review,* 32, 103-115.
Lichatowich, J. (1999) *Salmon without rivers : a history of the Pacific salmon crisis.* Island Press, Washington, D.C.
Ludington, S., Barry C. Moring, Robert J. Miller, Kathryn S. Flynn, James G. Evans, Paul A. Stone (2006) Preliminary integrated geologic map databases for the United States. (ed U. S. G. Service). United States Geological Service, Reston.
Morgan, H. (May 31, 1957) Letter to Fish Commission Director Hodges. (ed P. U. Commission).
Napolitano, M. B. (1998) Persistence of Historical Logging Impacts on Channel Form in Mainstem North Fork Caspar Creek. (eds U. S. D. o. Agriculture, F. Service & P. S. R. Station). Albany, CA
Nilsson, C. F. L., Bjorn Malmquist, Erik Tornlund, Niclas Hjerdt, James M. Helfield, Daniel Palm, Johan Ostergren, Roland Jasson, Eva Brannas, Hans Lundqvist (2005) Forecasting Environmental Responses to Restoration of Rivers Used as Log Floatways: An Interdisciplinary Challenge. *Ecosystems,* 8, 779-800.
Northcote, T. G., G.F. Hartman (2004) *Fishes and Forestry.* Blackwell Science, Ames, IA.
Oregon, S. o. (1924) Testimony Nehalem Driving and Boom Company. *Public Utilities Commission*. State of Oregon.
Sedell, J. R., Fred H. Everest, Frederick J. Swanson (1981a) Fish Habitat and Streamside Management: Past and Present. *Society of American Foresters. Convention*. SAF publication.
Sedell, J. R., Karen J. Luchessa (1981b) Using the Historical Record as an Aid to Salmonid Habitat Enhancement *Acquisition and utilization of aquatic habitat inventory information : proceedings of a symposium* (ed N. B. Armantrout). American Fisheries Society (?), Portland.
Sedell, J. R., W.S. Duval (1985) Influence of forest and rangeland management on anadromous fish habitat in western North America: water transportation and storage of logs. (ed F. S. U.S. Department of Agriculture, Pacific Northwest Research Station), pp. 68. Portland, OR.
Shotton, H. (1926) Letter to District Inspector A.P. Holloday.
Taylor, J. E. I. (1999) Burning the Candle at Both Ends: Historicizing Overfishing in Oregon's Nineteenth-Century Salmon Fisheries *Environmental History,* Vol. 4, No. 1 pp. 54-79.
Walker, G. W., McLeod, N.S. (1991) Geological Map of Oregon. United States Geological Survey.
Wendler, H. O., G. Deschamps (1955) Logging dams on coastal Washington streams. (ed W. S. D. o. Fisheries). Olympia.
Yount, J. D., Niemi, Gerald J. (1990) Recovery of Lotic Communities and Ecosystems from Disturbance-A Narrative Review of Case Studies. *Environmental Management,* 14, 547-569.