Freshwater Habitat and Salmon Recovery: Relating Land Use Actions to Fish Population Response

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Developing approaches for the recovery of freshwater habitat of Pacific salmon requires a method for evaluating potential population response to proposed suites of management actions. However, developing an approach that relates freshwater habitat conditions to population levels or survival rates of juvenile salmon is complicated by the high degree of spatial and temporal variability in productive capacity and the fact that habitat requirements vary by species and vary through time for a species. We are developing an approach which addresses spatial variation by describing habitat using coarse-scale attributes. Temporal variation in fish abundance is addressed by expressing reach-level populations relative to the total fish abundance in the watershed.

Relating Habitat Condition to Population Performance

The relationship between freshwater habitat condition and productivity of fish populations has traditionally been examined at very fine spatial scales (individual habitat units or short stream reaches) over short periods of time (one to five years). Much of this research has attempted to associate an environmental condition to a life-stage specific response by the fish, such as the effect of fine sediment on incubation survival (Everest et al. 1988) or average densities of juveniles during summer or winter rearing periods (Reeves et al. 1989). This type of research is important to understand the mechanisms by which various factors affect salmon populations and provides a basis for evaluating the potential impacts of land-use actions. However, extrapolating these site-specific and life-history-specific relationships to the watershed (10^1-10^3 km^2) or region ($\geq 10^4$ km^2) level has been difficult for a number of reasons, including the high degree of reach to reach variation in salmon production and the lack of detailed data across large regions.

We are aware of three basic approaches to the problem of "scaling-up". The first approach is to gather site-specific data across entire watersheds, apply site-specific relationships at all locations, and sum the results across the study area. For example, Beechie et al. (1994) and Pess et al. (1999) use habitat-specific rearing densities and average seasonal survivals to estimate coho salmon smolt production in watersheds of the Puget Sound region, as well as to evaluate the effects of different land uses on coho production. Both studies were able to extrapolate site-specific rearing densities to large watersheds by utilizing habitat unit data collected throughout the watershed. While this approach is effective, it generally has not been used to estimate productivity of salmon populations at larger spatial scales because detailed field data are not available across large areas.

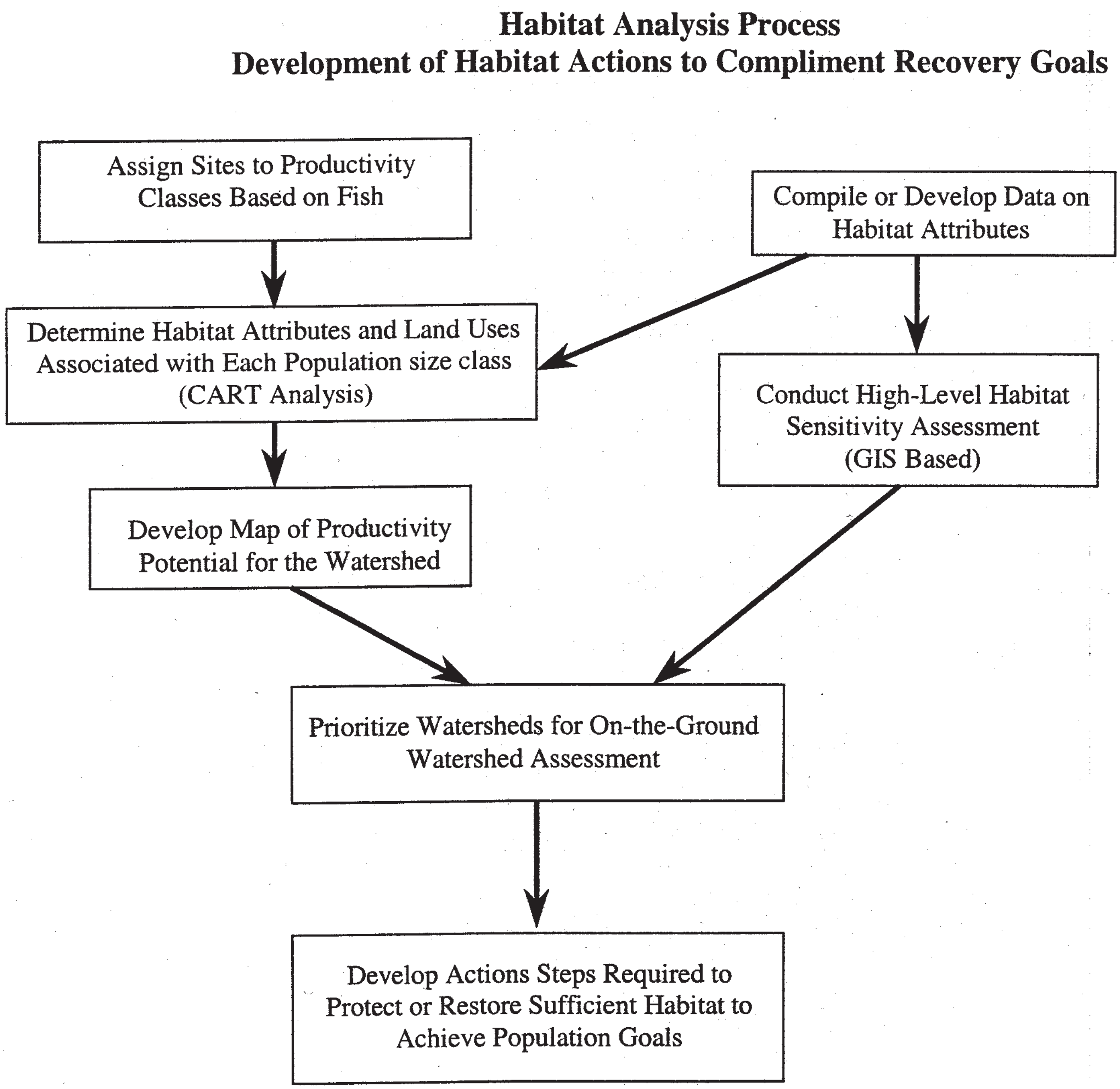
The second two approaches are classification approaches. Dozens of stream classification systems have been used in the past century to organize stream information, and classifications have been based on wide range of biota or physical features, and on single or multiple scales (Naiman et al. 1992). Approaches to creating a classification scheme are of two general forms: *a priori* classification, in which stream classes are developed based on known variables and observed relationships prior to evaluating how well they stratify the response variable, or *clustering*, in which data of unknown relationships are statistically analyzed to identify classes (Beechie 1990).

In one recent example of *a priori* classification, Lunetta et al. (1997) predicted reach-level habitat condition for salmonids across western Washington based only on channel slope (from the Washington DNR stream layer and USGS 30-m DEM) and riparian vegetation class (from Landsat TM). These two variables predict channel type (sensu Montgomery and Buffington 1997) with 75% accuracy overall. However, Lunetta et al. (1997) did not relate habitat condition to salmonid productivity. Predicted channel type can now be related to salmonid spawner densities based on subsequent reach-level research (Montgomery et al.1999). This approach shows promise, but runs the risk of missing other important variables that may influence salmonid population performance.

The clustering approach to classifying terrestrial and stream ecosystems at the region level has been in use for more than a decade, and its effectiveness is well documented (e.g., Bailey 1978, Larsen et al. 1986, Whittier et al. 1988). In this approach, stream variables such as substrate, water quality, and fish community composition are clustered to identify sub-regional patterns in response variables, and then to create a sub-region classification based on the patterns. In this approach it is possible to identify relationships among numerous variables. The main drawback of the approach is that it may be difficult to explain the physical or biological processes that are responsible for the relationships among disparate variables.

For our analysis, we have chosen the clustering approach to predicting salmonid abundance based on landscape variables. We use a range of regionally available data sets (e.g., geology, precipitation, vegetation) as indicators of the availability and condition of the habitat types a species requires to complete the freshwater phase of its life history. Some variables are indicators of natural processes controlling habitat condition and others are indicators of human impacts. Classes of habitat condition are derived by examining the spatial distribution of fish abundance in a watershed, segregating the sites into classes based on relative abundance of fish and identifying the habitat characteristics common to each population size class (Fig. 1). This approach addresses seasonal or life-history variations in habitat requirements in that it averages the variability over broad space and time scales. It also allows us to evaluate the relative importance of many different variables that may affect salmonid population performance in a single analysis.

Figure 1 – Components of the habitat analysis approach.



Developing Population Size Classes

Abundance of salmon varies greatly over time and space. Some of this variation may be attributed to the variable effects of weather and flow conditions on survival and fish production in the freshwater environment. However, some of the variation is attributable to factors impacting the fish during other periods of their life history, which affects the number of adults returning to spawn. As this variability is not a direct product of the condition of the freshwater habitat, it is difficult to account for in attempting to relate fish abundance to habitat condition.

Abundance of juvenile salmon also varies spatially. Strong relationships between fish abundance and habitat attributes have been developed at the scale of individual stream reaches (Bisson et al. 1982). For example, coho salmon have been shown to prefer pools to faster water habitats. Although this preference is expressed consistently, the actual density of coho salmon using pools may vary considerably among stream reaches (Fransen et al. 1993). Variability among watersheds is illustrated by the 540-fold variation in the production of stream-rearing salmon and trout reported in the scientific literature (Bisson and Bilby 1998). This variation among reaches or watersheds cannot be accounted for by differences in habitat condition as it has been traditionally defined.

We are attempting to address the variation in fish abundance by expressing local population levels relative to their contribution to total population for a watershed. Examination of time series of salmon escapement or redd counts in the Snohomish River (tributary to Puget Sound) and the Salmon River (tributary to the Snake River) reveal significant interannual variability in fish abundance (Fig. 2). However, these data indicate that specific subunits of watersheds (subwatersheds) consistently support large numbers of fish while others are used by very few (Fig. 3). The proportion of the total population using a subwatershed is very consistent from year to year regardless of escapement level (Fig. 4). Expressing subwatershed population levels as the proportion of the total numbers of spawners in the watershed produces a parameter not greatly influenced by interannual variations in total fish abundance.

Ideally, the classification process would use information on juvenile salmon abundance rather than counts of spawning fish or redds. However, long-term data on juvenile fish abundance collected at multiple locations are available for very few watersheds. Information on spawner abundance is generally available throughout the region and often includes periods of record extending for several decades or more. We feel that the relative abundance of adult fish at various locations in a watershed is indicative of the condition of freshwater habitat. As the fish from all subwatersheds within a watershed are subjected to comparable conditions in the migration corridor, estuary and ocean, consistent differences in population level among subwatersheds are most likely related to freshwater habitat conditions. We have segregated the subwatersheds for which fish population data are available into population size classes (high, medium, low) based on the relative contribution they make to the population for the watershed. An average population level and estimate of spatial and temporal variability is generated for each population size class by averaging spawner or redd counts across all sites within each class for all years of record (Fig. 5).

Figure 2 – Coho salmon escapement estimates for the Snohomish River basin from 1984 to 1998

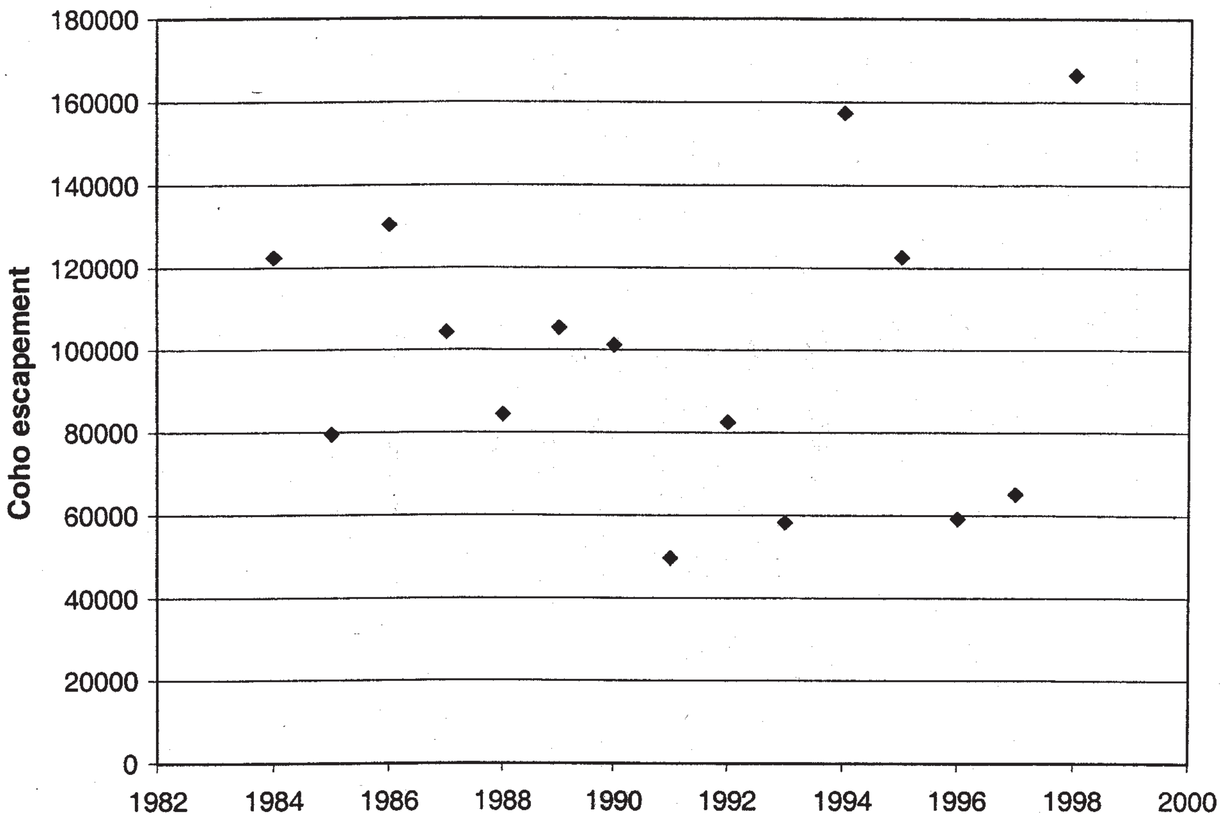


Figure 3a – Spatial distribution of spawning coho salmon in the Snohomish basin. Bars represent the percent of total coho salmon found in each subwatershed for which data are available.

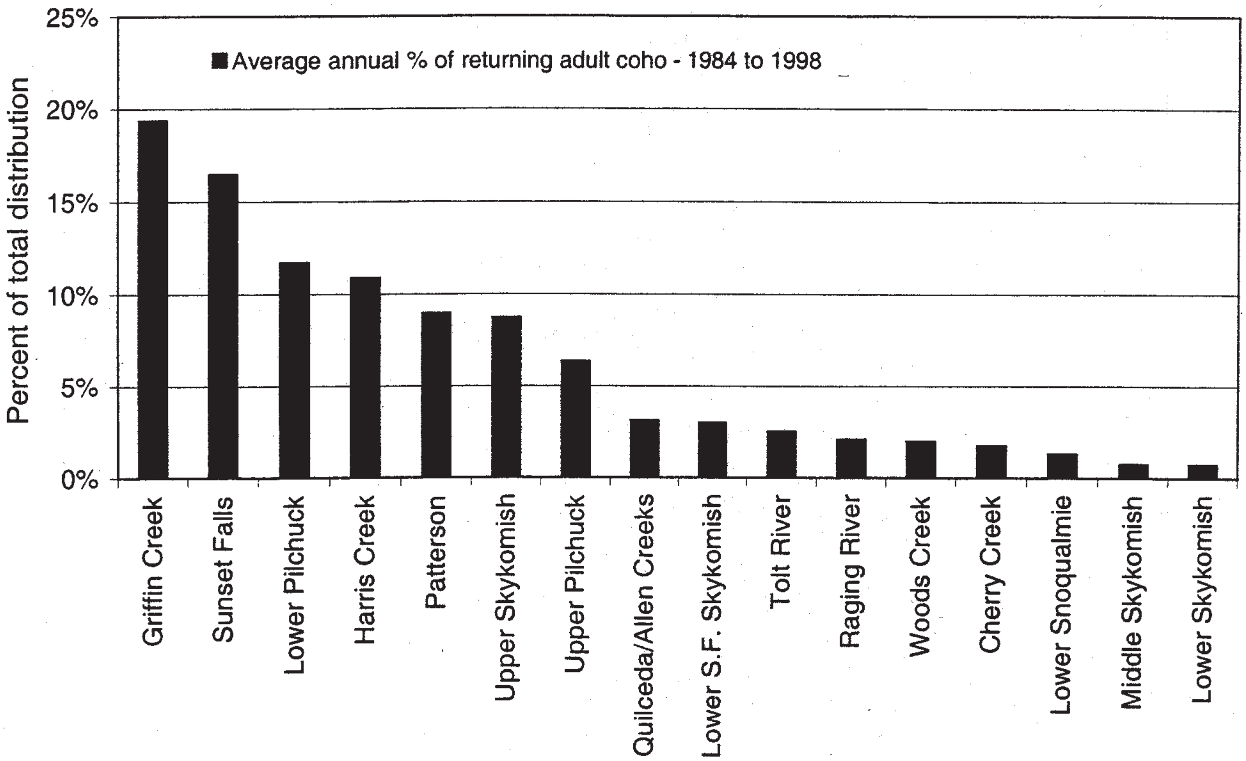


Figure 3b – Salmon River, Idaho Spring and Summer Chinook spatial distribution and abundance (1960 to 1973)

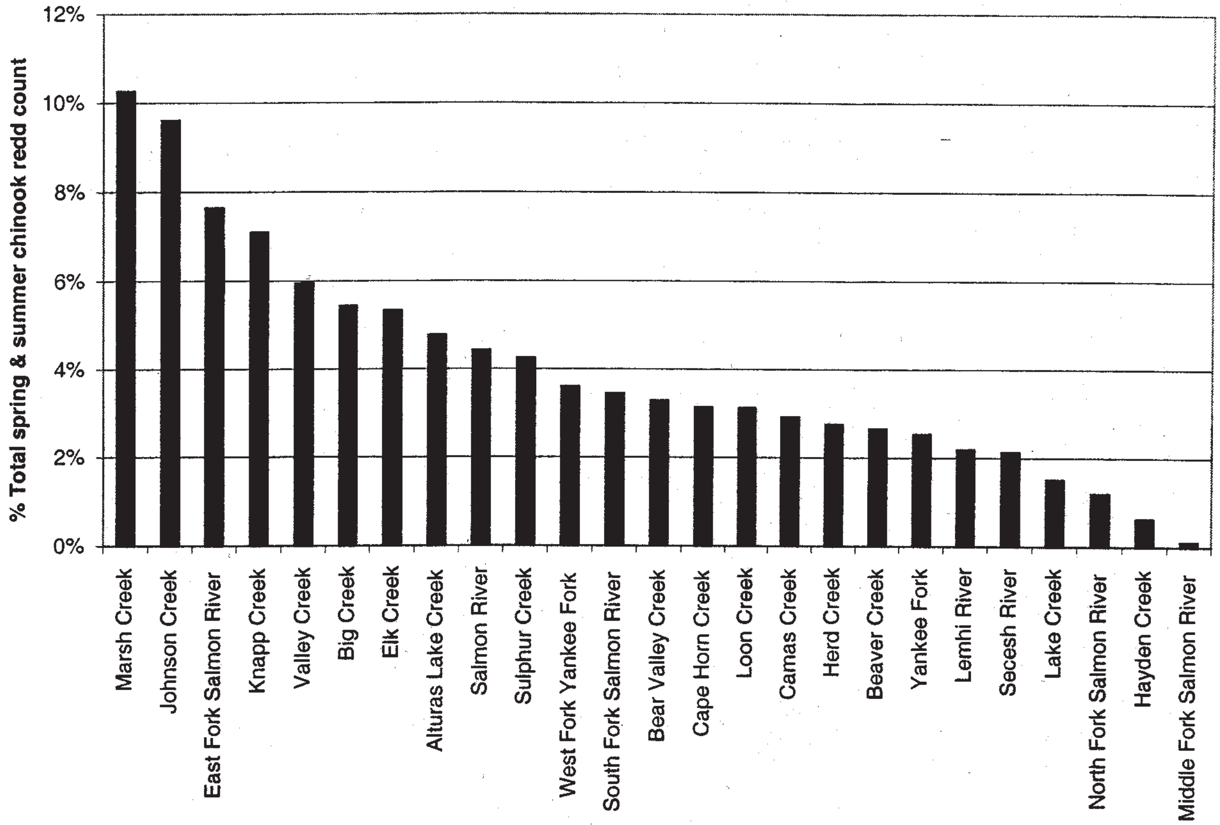


Figure 4 – Distribution of Snohomish coho salmon escapement abundance. Index reaches are grouped by the relative salmon abundance. Bars represent the proportion of the total number of spawning salmon counted within each group of index reaches for the year of highest and lowest salmon abundance.

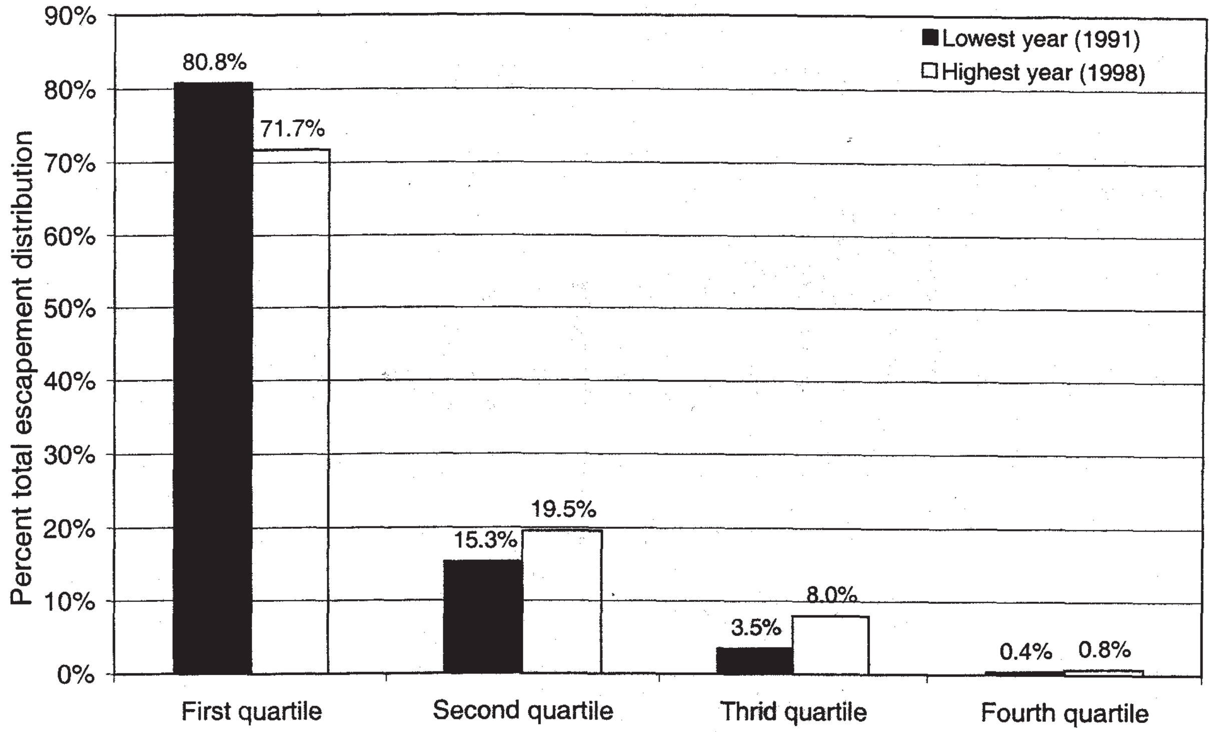
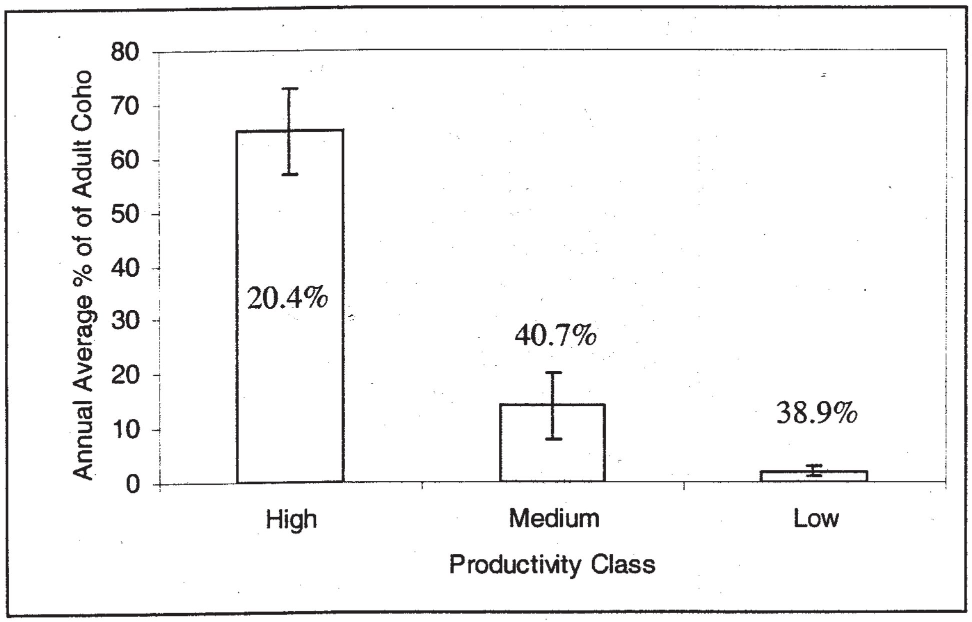


Figure 5 - Proportion of coho salmon spawners associated with each population size class for the Snohomish River watershed. Each bar represents the annual average proportion of coho salmon counted at the sites in that population size class. Data are from counts at 54 sites from 1984 through 1998. Error bars indicate ± one standard error. The values in or above each bar represent the proportion of the index sites that the bar represents. Thus, the *High* population size class supports, on average, 65% of the spawning salmon but includes only 20.4% of the index reaches.



Habitat Characterization

Habitat conditions are associated with salmon production by determining the features that are common to the subwatersheds in each population size class. This analysis is currently being conducted for the Salmon River and Snohomish watersheds. Much of the habitat information is derived from GIS coverages or other databases, although the extent and resolution of the data varies among watersheds. Parameters being examined include physical attributes of each subwatershed and the pattern and type of land use. Examples of physical habitat characteristics include geology, topography, channel and valley type distribution, hydrologic regime, riparian composition, and occurrence and extent of wetlands (Tables 1 & 2). Land use parameters include proportion of the area subjected to various types of human activity (e.g., forestry, agriculture, urban development), degree of channel or floodplain alteration and condition of the riparian vegetation (Tables 1 & 2). Reach and watershed scale data is either developed or gathered using existing GIS layers (Tables 3, 4a & 4b). Once the landscape characteristics are associated with salmon population size classes, sites for which no fish data are available can be assigned to population size classes based on their physical attributes and land use pattern (Figs. 6 & 7). Estimating productive potential for the entire watershed is accomplished by summing productivity across all the subwatersheds. This approach also enables prediction of population response to future alterations in habitat quality. The population response predictions can then be used in the risk-assessment models the NWFSC will use to examine salmon population performance through its entire life history.

Table 1 – Reach and watershed scale variables that can effect coho in the Snohomish River Basin

Species	Landscape v. land use	Reach scale	Watershed scale
Coho	*Landscape*	• Channel slope • Channel confinement • Riparian composition • Off-channel habitat	• Surficial geology • Extent of wetlands
	Land use	• Riparian alteration • Channel modification	• % forest, rural, agriculture, and urban • % impervious surface • % riparian alteration

Table 2 – Reach and watershed-scale variables that can effect spring and summer chinook in the Salmon River Basin

Species	Landscape v. land use	Reach scale	Watershed scale
Spring & Summer type Chinook	*Landscape*	• Summer & winter stream temperatures • Channel slope • Channel confinement • Channel sinuosity • Off-channel habitat	• Geology • Drainage area • Hillslope gradient • Extent of wetlands • Riparian composition • Precipitation • Temperature
	Human disturbance	• Riparian zone alteration • Channel modification	• % in forest, agriculture, and rangeland • Water withdrawals • Mine density • Change in upstream sediment supply due to land use activities

Table 3. Summary table of preliminary watershed-scale, landform, and land use data layers used in habitat analysis for the Snohomish River Basin, Washington.

Datalayer	Source	Category	Scale	Gridcell Size/Resolution	Description
Surficial Geology	Booth (1990)	- Vashon till - Advanced outwash - Recessional outwash - Alluvium	1:100K	30 m	Classification of geologic map units according to major surficial geology.
Land use Land cover	Puget Sound Regional Council Landsat thematic mapper (1992)	-forested - rural residential - agriculture - urban	1:100K	30 m	Classification of LANDSAT TM imagery into land cover categories.

Table 4a. Summary table of watershed-scale, landform datalayers used in habitat analysis for the Salmon River Basin, Idaho.

Datalayer	Source	Category	Scale	Gridcell Size/Resolution	Description
Hillslope	Intermountain Fire Sciences Lab, 90 m DEM, acquired from ICBEMP	- Flat (0 – 10%) - Gentle (11 – 30%) - Steep (31 – 50%)	Unknown	1,000 m	Slope classes coded to 6th Field HUCs
Major Lithology	USGS, acquired from ICBEMP	- Carbonate & Shale - Conglomerate - Granitic - Sedimentary - Surficial Deposits - Syncline - Volcanics	1:500K	200 m	Classification of geologic map units according to major lithology. Generalized to 7 classes from original 25
Vegetation	Redmond et al. (1997) and Homer (1998), and Landscape Dynamics Lab, University of Idaho, acquired from Idaho GAP Analysis Program	- Non-forested Riparian (graminoid or forb dominated, shrub dominated, mixed non-forest) - Forested Riparian (needleleaf dominated, broadleaf dominated, needle/broadleaf dominated, mixed [forest & non-forest])	1:100K	30 m	Classification of LANDSAT TM imagery into various vegetation and land cover categories. Original LANDSAT image ca. 1990?
Temperature	Peter Thornton, University of Montana, acquired from ICBEMP	Continuous, values ranged from –4 to +12°C	Unknown	2,000 m	Average yearly temperature for 1989, which was considered a "normal" year
Precipitation	Peter Thornton, University of Montana, acquired from ICBEMP	Continuous, values ranged from 135 to 2,498 mm	Unknown	2,000 m	Total annual precipitation for 1989, which was considered a "normal" year

Table 4b. Summary table of watershed-scale, land use datalayers used in habitat analysis for the Salmon River Basin, Idaho.

Datalayer	Source	Category	Scale	Gridcell Size/Resolution	Description
Land Use Land Cover (LULC)	USGS	- Agricultural (cropland, pasture, orchards, groves, vineyards, nurseries, confined feeding operations, other) - Rangeland (herbaceous, shrub & brush, mixed) - Forest Land (deciduous, evergreen, mixed)	1:250K	N/A	Land use and land cover generated using Anderson (1976) protocols
Mining Claim Density	US Bureau of Mines, acquired from ICBEMP	Continuous	1:500K	N/A	Mapped originally as mining claims per section (PLSS), 1994
Management Area Categories (MAC)	BLM and Forest Service, acquired from ICBEMP	Eight categories ranging from relatively undisturbed to "permanently altered" ecological conditions	1:24K to 1:1,000K	N/A	Classification of LANDSAT TM imagery into various vegetation and land cover categories. Original LANDSAT image ca. 1990?
Road Density	Intermountain Fire Sciences Lab, acquired from ICBEMP	Six categories: - None - Very Low - Low - Moderate - High - Extremely High	1:100K	1,000 m	Extrapolated from known road densities in other areas, predicted based on management region, lifeform, elevation, slope and UPS roads.
Diversions	USFS - Intermountain Research Station, acquired from ICBEMP	Points	1:100K	N/A	Diversions, screens, ladders, and pumps, supplemented by BPA, and Idaho Fish and Game data

Figure 6 – Snohomish coho population size classes by watershed

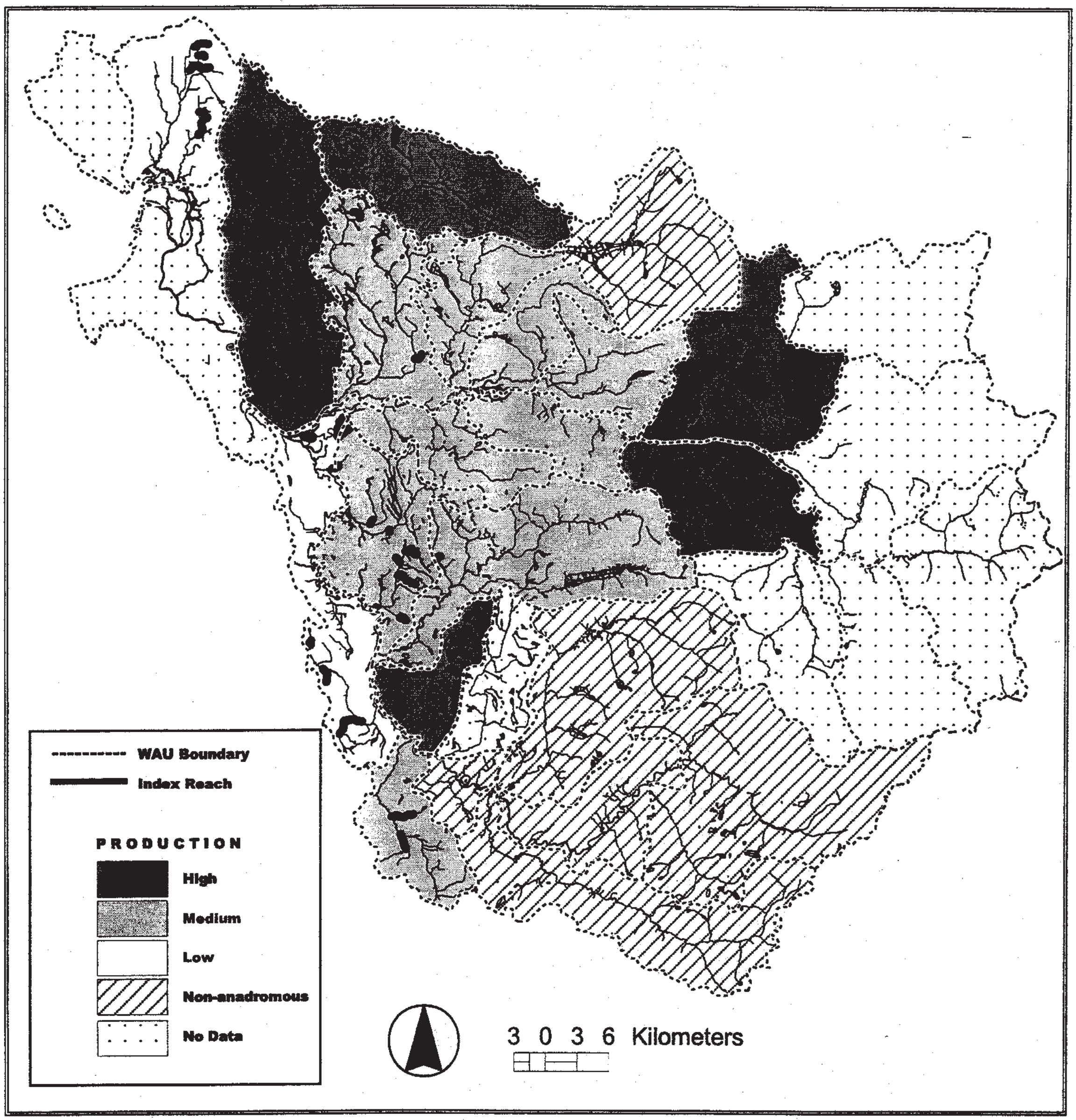
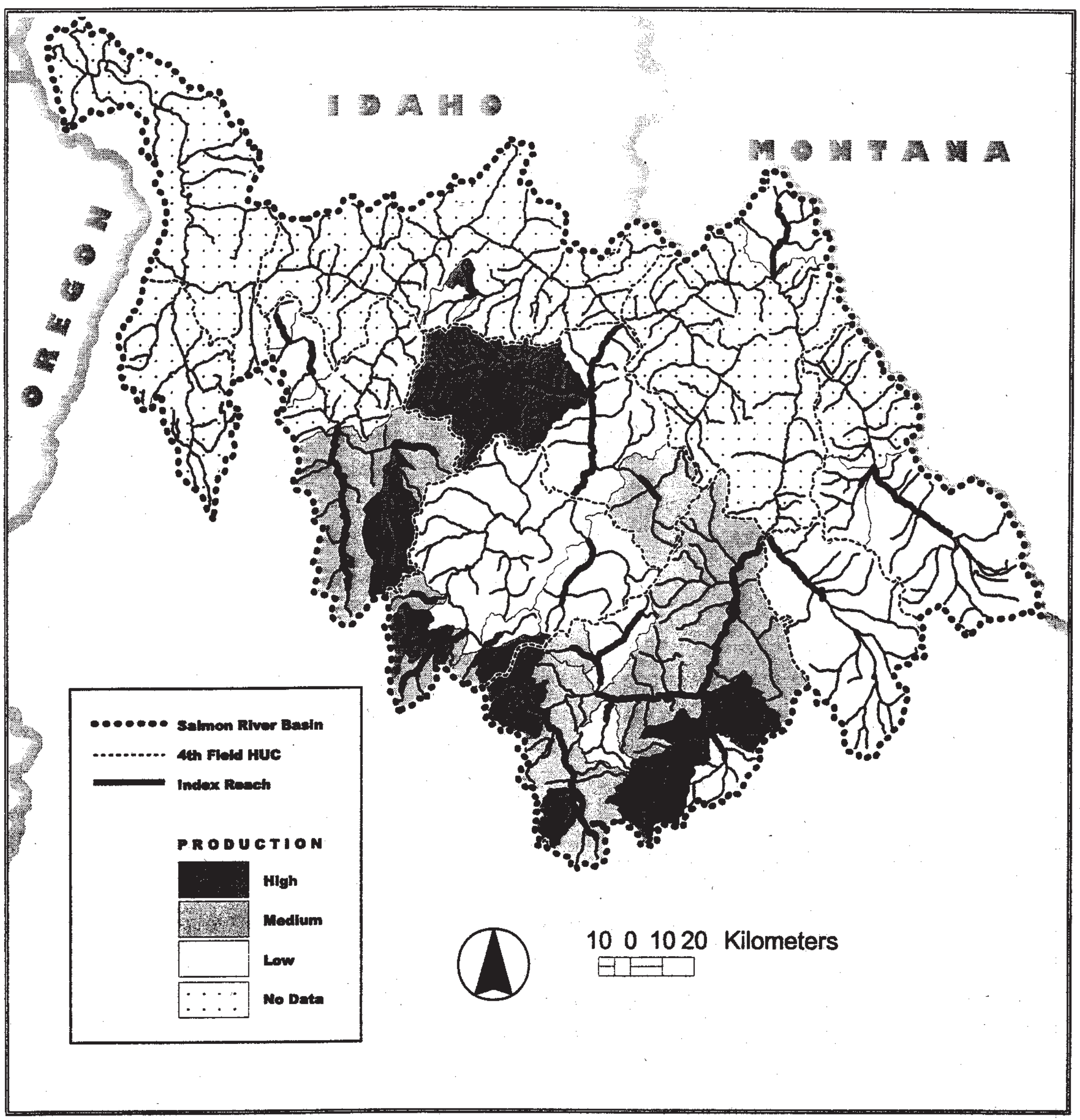


Figure 7 – Salmon River spring and summer chinook population size classes by HUC6 drainage influence area



Habitat Datalayers and Modifications

The Salmon River

We used index reach, redd density data and two general types of habitat datalayers for our analysis of Salmon River chinook salmon: landform and land use. These datalayers were derived from a variety of sources and represented a range of spatial scales (Table 4).

Redd count data from 1960 to 1973 for 23 index reaches supporting spring and summer chinook salmon were normalized to number of redds/year/kilometer of stream channel. Normalized salmon abundance (N_a)was calculated for each index reach using the following formula:

$$N_a = (IR_a - IR_A)/IR_A$$

where IR_a is the production for a given index reach (redds/km/yr), and IR_A is the mean annual production for all 23 index reaches for the corresponding year (redds/km/yr). Each of the 23 index reaches was then classified as low, medium, or high, based on the 33rd, 67th and 100th percentiles, respectively, for each year.

The locations of the index reaches were linked to USGS 1:100,000 scale DLG hydrographic datalayers, and the total length of all given index reaches was calculated at this scale. Much of the habitat data in the Salmon River watershed is compiled at the USGS 6th hydrologic unit code level (6th field HUCs). In order to create a 2D representation of salmon production and link it to the habitat datalayers, we identified all of the 6th field HUCs that drained into and/or contained a given index reach. This was defined as the HUC6 drainage influence area.

We overlayed the aforementioned 2D outlines of index reaches on each of the habitat datalayers use ESRI ARC/INFO. This GIS software kept track of the complex polygons (over 300,000 polygons) that we generated with over 11 separate overlays. Each polygon had a unique area, index reach label, and labels for each of the habitat datalayers' attributes.

We first calculated the total area for each habitat class category that fell within any index reach 6th field HUC influence area. For some datalayers, such as hillslope and major lithology, the sum of categories for any given HUC6 drainage influence area was always one. The categories in these datalayers were classified as covarying, so they were always analyzed simultaneously. In other cases, such as vegetation and land use/land class, the various categories did not sum to one, and they could be analyzed individually.

We used classification tree analysis in STATISTICA® to determine the influence of all habitat variables on index-reach salmon population size (dependent variable). Classification and regression tree (CART) analysis was first described by Breiman et al. (1984) and has been used extensively by scientists in such diverse fields as medicine to ecology. Rieman et al. (1997) used a similar approach for characterizing the habitat features most important for bull trout ecology in the Columbia River and Klamath River Basins, and Thurow et al. (1997) used classification trees to predict the distribution and status of various native salmonids in similar areas. Classification tree analysis examines all variables (predictors) one at a time (similar to forward selection regression), creates a split in the tree that divides dependent variable classes into two groups (nodes), each of which is more pure than the original, based on the Gini index (Breiman et al. 1984). The technique is powerful in that it can accommodate categorical and ordinal predictors; is free from distribution requirements and assumptions; facilitates statistical significance testing via cross validation of numerous variables (which accounts for nonfunctional relationships between the dependent variable and predictors); and the results are easily interpreted.

The parameters in STATISTICA for growing our classification trees were as follows: CART style exhaustive search for univariate splits; FACT style direct stopping (0.02); seed value of 11; Gini measure goodness of fit; estimated prior probabilities; and equal misclassification cost.

The Snohomish River

We used index reach escapement data and two general types (surficial geology and land cover) of habitat datalayers for our analysis of Snohomish coho salmon. Escapement data from 1984 to 1998 for 54 index reaches supporting coho salmon were normalized to number of adult coho/kilometer of stream channel. Mean salmon abundance was calculated for each index reach. The locations of each index reach were linked to a Washington Department of Natural Resources (WADNR) 1:24,000 scale DLG hydrographic datalayer. We overlaid surficial geology and land cover data layers with the index reaches using ESRI ARC/INFO.

Preliminary Results

Salmon River Spring-Summer Chinook Salmon

We are currently in the process of conducting our CART analysis for the Salmon River, but we have some preliminary results that are promising. The CART analysis identifies landform variables as key distinguishing variables more frequently than those related to land use, with the exception of water temperature. The lack of apparent influence of land use variables is probably a function of spatial scale, general accuracy of the data layers, correlation between landform and land use variables, and the degree to which land use variables are extrapolated from other variables. The CART analysis suggests that HUC6 drainage influence areas with shrub or meadow dominated riparian area greater than about 2.6% of the total area, support the highest levels of spring/summer chinook production. Other significant landform variables are proportions of the three hillslope classes, and distributions of sedimentary, and carbonate and shale lithology.

Snohomish River Coho Salmon

Surficial geology (Fig. 8), land-use (Fig. 9) and the combination of these two factors (Fig. 10) influenced abundance of spawning coho salmon. Average density of coho was 3 to 16 times greater in areas underlain by Vashon Till (800 coho/km) than all other geologic types. Recessional outwash and alluvium-dominated index reaches have support comparable fish abundance (275 coho/km and 225 coho/km), while advanced outwash reaches have the lowest returns (50 coho/km).

Forest-dominated index reaches support 1.75 to 13 times more spawning salmon (325 coho/km) than all other land-use categories. Returning coho returns in rural-residential areas (200 coho/km) is most similar to forest dominated index reaches. Index reaches in agricultural lands (110 coho/km) were 2 times less than rural areas but 4 times greater than urban reaches, which have the lowest returns of all the land-use categories (25 coho/km).

Combining surficial geology and land-use provides an indication of the relative sensitivity of different geologic types to land use. Advanced outwash and alluvium reaches exhibit the greatest sensitivity to land-use, while recessional outwash reaches have less variation by land-use category. Coho salmon abundance in reaches flowing through advanced outwash in rural areas is 14 times that in urban reaches on the same geology. Alluvium dominated, forested reaches have average coho returns that are 4 to 8 times greater than rural and agriculture areas with the same surficial geology. Recessional outwash reaches display the least amount of variation between land-use categories (1 to 4 times). Index reaches in Vashon Till are not included in figure 10 because only one land-use is associated with this geology.

Figure 8 - Snohomish River returning adult coho by surficial geology (1984 to 1998)

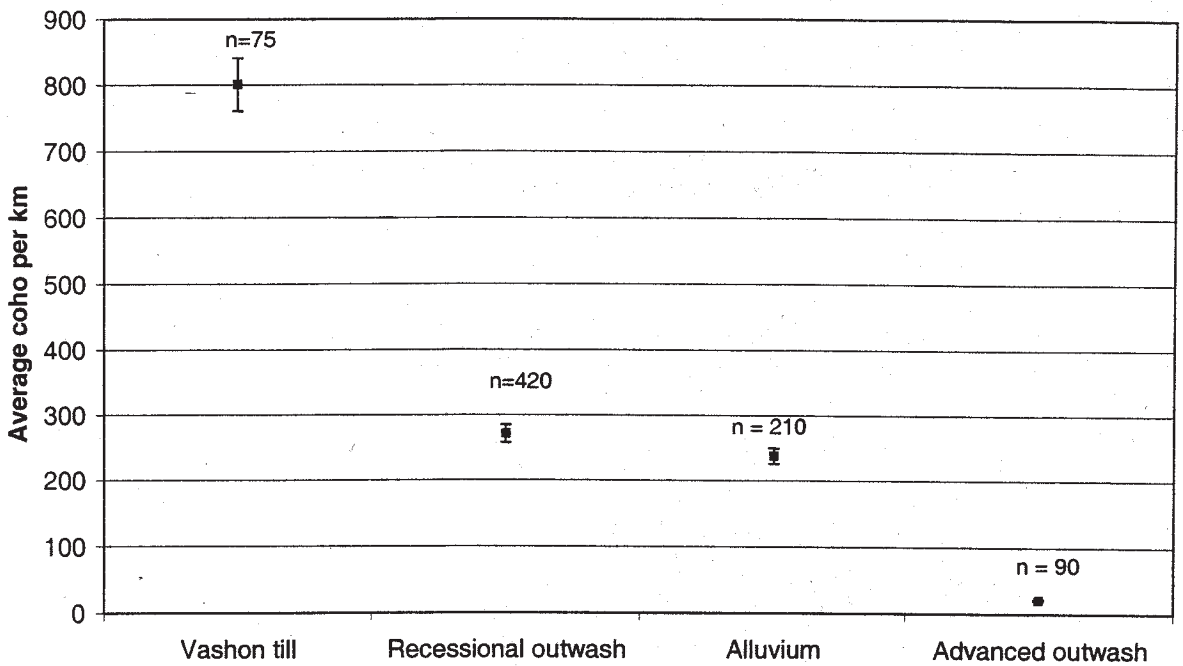


Figure 9 - Snohomish River returning adult coho by land cover (1984 to 1998)

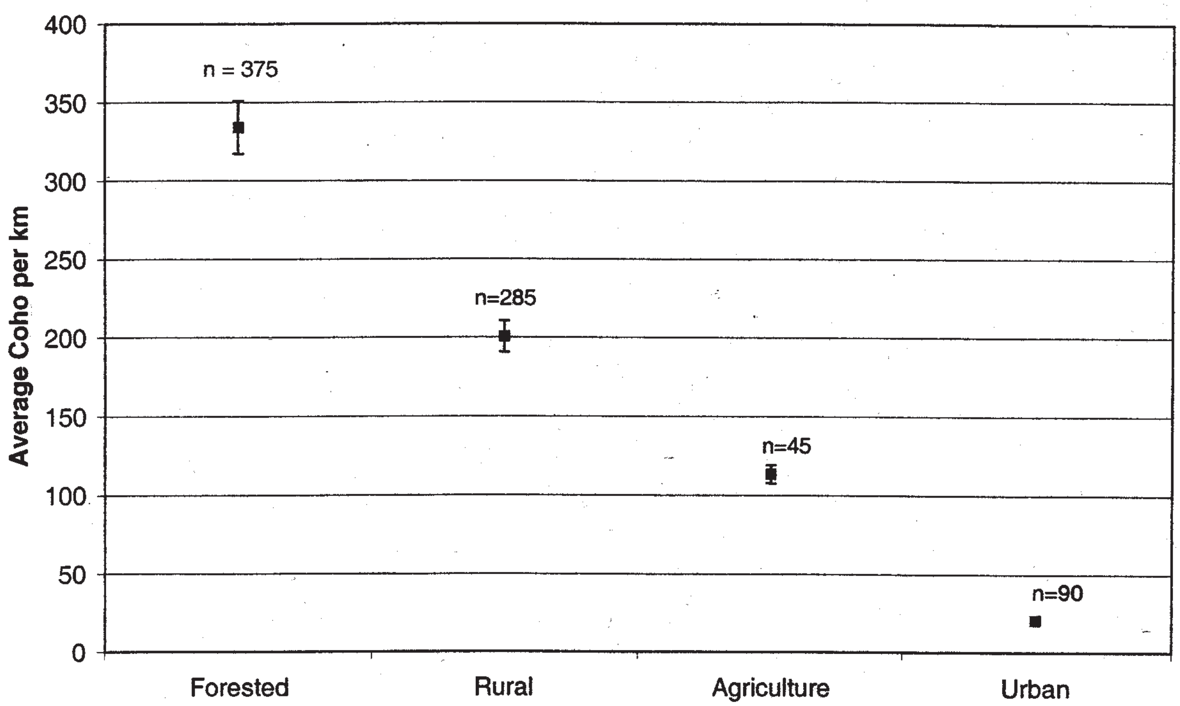
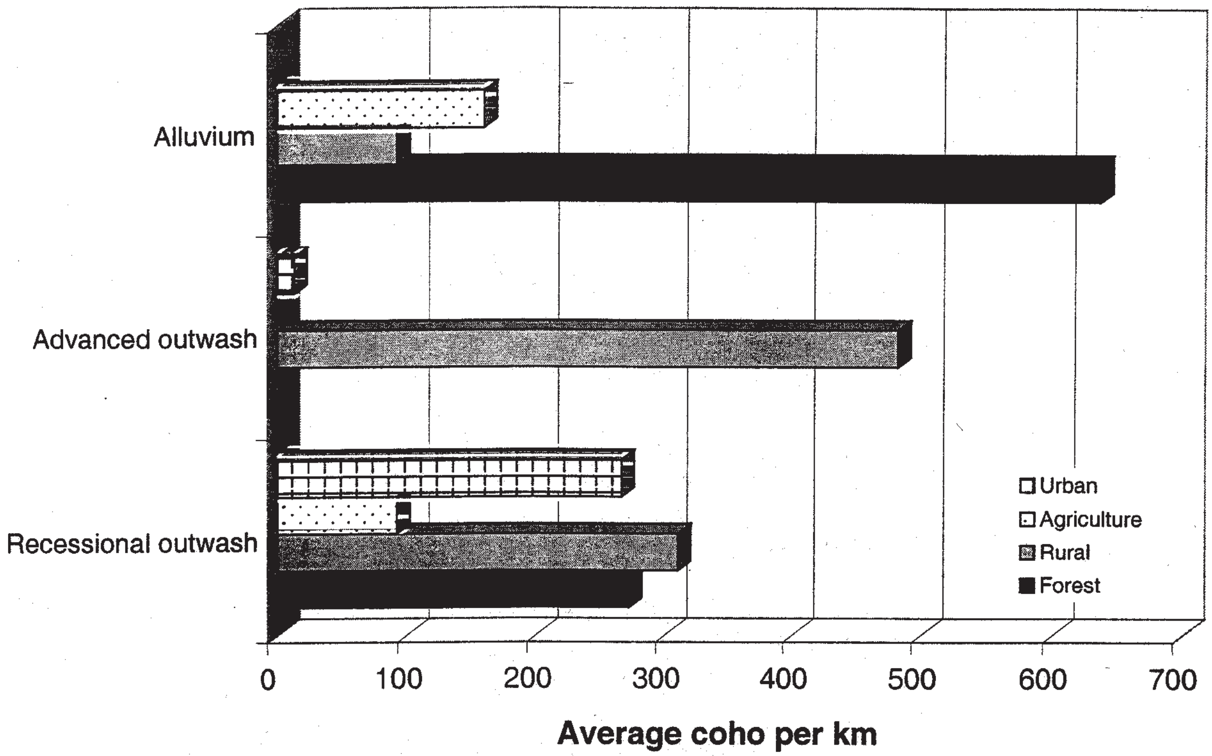


Figure 10 – Snohomish River average returning adult coho by geology and land-use – 1984 to 1998



Evaluating the Effects of Land Use Actions on Habitat Condition

Many human actions have the potential to impact habitat quality. The effect of these actions on salmon populations depends upon the type and extent of the proposed action, the sensitivity of the subwatershed to that activity and the relative contribution the subwatershed makes to overall watershed production. A great deal of research over the last thirty years has been directed at better understanding the response of aquatic ecosystems to various human impacts. As with research on habitat–population relationships, much of this work has been conducted at relatively fine spatial and temporal scales. However, over the last decade a number of procedures have been developed that examine the cumulative impacts of human activities on the condition of aquatic systems. These processes are generally referred to as watershed assessments or watershed analyses. The advent of GIS technology and spatially referenced data bases has greatly enhanced our ability to conduct assessments of habitat condition and sensitivity to management actions at large spatial scales.

Generally, watershed assessment approaches acknowledge that the condition of habitat in streams and rivers is largely a product of interactions with the surrounding terrestrial ecosystem. Water, sediment, biological materials (e.g., wood, leaf litter) and nutrients are provided by these terrestrial-aquatic interactions. Thus, predicting the response of stream habitat to a human action is often best accomplished by examining the effect this action will have on the delivery of these products to the stream. For example, road construction on unstable slopes may dramatically increase sediment delivery to a channel, altering channel characteristics in the affected subwatershed. Removal of riparian vegetation will change the rate of input and type of wood and other organic material delivered to the channel altering both channel form and trophic dynamics of the stream. Understanding how these delivery processes are affected by management activities and the likely impact alteration of these processes will have on the habitat parameters that have been associated with population response provides a straightforward procedure for associating human activities with population response.

Predicting changes in subwatershed-level habitat conditions due to site-specific land management actions requires knowledge of the relative sensitivity of that location to the proposed action. In some subwatersheds, certain activities may be compatible with the maintenance of high quality habitat but the same actions might significantly degrade habitat in another location. Watershed assessments generally include procedures for identifying locations prone to mass wasting and surface erosion. Some assessments also include protocols for the evaluation of the sensitivity of riparian areas and susceptibility to hydrologic alterations, although these methods tend to be less well developed than those for sediment production. Continued improvement in these assessment methods will improve our ability to predict changes in habitat condition and assess population response.

Recently GIS-based tools for providing a coarse-scale assessment of the spatial distribution of watershed sensitivity have been developed. For example, the Skagit Watershed Council developed an approach to estimate changes in sediment supply due to land use by extrapolating from sediment budgets in representative sub-watersheds of the Skagit basin. Based on Paulson (1997), they assigned sediment supply rates under forested conditions to four geology classes and to the alpine zone (termed the "natural" rate of sediment supply), and then assigned a multiplier to each vegetation cover class based on the sediment supply rate for immature forest (Table 5). Sediment supply rate in any sub-watershed without a sediment budget can then be estimated by averaging the sediment supply rates from all the geology-vegetation polygons, where the sediment supply rate in each polygon is the natural rate multiplied by the land use factor. This method accurately predicted sediment supply class (either similar to the "natural" background rate, or significantly higher than the background rate) in seven of the ten sub-watersheds where sediment budgets had been constructed. This type of preliminary assessment of relative subwatershed sensitivity, when coupled with the distribution of potential salmon production can be used to prioritize subwatersheds for more detailed watershed assessment.

Table 5. Average sediment supply rates and vegetation factors used in estimating current sediment supply and changes from natural sediment supply for each WAU in the Skagit River basin.

	Geology class				
	All rock types/alpine	Alluvium	Surficial deposits	Low-grade metamorphic	High-grade metamorphic
Natural sediment supply rate ($m^3/km^2/yr$)	409[a]	0[b]	33[c]	130[d]	53[e]
Land use factor for early-seral, mid-seral and late-seral.	NA	1	1	1	1
Land use factor for other forest (clear-cut to hardwood).	NA	1	3[f]	4[f]	6[f]
Land use factor for water and non-forest.	NA	0	0	0	0
Land use factor for alpine areas, rock outcrops, glaciers.	1	NA	NA	NA	NA

a. Average sediment supply rate from granitic rocks in alpine areas, New Zealand. Region has annual precipitation similar to that of the upper Skagit basin, and granitic rocks are prevalent in the upper Skagit basin.
b. Alluvial areas are predominantly floodplains. No mass wasting occurs.
c. Sediment supply rate for forest >20 years old in a sub-basin dominated by glacial sediments (Paulson 1997).
d. Sediment supply rate for forest >20 years old in 3 sub-basins dominated by phyllite and sandstone (Paulson 1997)
e. Sediment supply rate for forest >20 years old in sub-basins dominated by granitic and high grade metamorphic rocks (Paulson 1997).
f. Relative increase in mass wasting rate where forests are less than 20 years old (Paulson 1997).

Application of the Habitat Assessment Products

The ability to relate human activities to changes in habitat condition and population response of salmon provides a powerful tool for salmon protection and recovery. This approach to habitat assessment provides a basis for evaluating regional land use plans and habitat conservation plans, prioritizing habitat restoration actions and evaluating specific land use actions.

Evaluation of Proposed HCPs, Conservation Plans etc.

Understanding the spatial distribution of salmon production in a watershed provides a means of prioritizing areas for protection or restoration based on their relative contribution to system productivity (Fig. 11). For example, future land use activities with a high potential to impact salmon habitat could be directed away from those subwatersheds that have a high productive potential. This approach will enable subwatersheds where productive potential is currently impaired by past human actions to be identified. Restoration activities could be prioritized to first address those impaired subwatersheds with the appropriate underlying physical attributes to support high levels of production. These areas represent locations where restoration activities are likely to have the greatest impact on salmon productivity.

This application can be illustrated with two examples for Snohomish River coho salmon, one evaluating response to restoration the other the consequences of habitat degradation (Fig. 12). As indicated above, coho production in the Snohomish basin is concentrated in areas with an alluvial surficial geology and forested land cover. A small tributary in the basin, Cherry Creek drains an alluvial area that has been impacted by diking, drainage and removal of forest cover. The average abundance of spawning coho salmon in Cherry Creek over the last 15 years was 2279 fish/year, placing this site in the moderate population size class. The underlying physical attributes of the Cherry Creek subwatershed suggest that it could support high levels of coho salmon if the factors currently impairing production are corrected. Average abundance of spawning coho salmon in highly productive subwatersheds in the Snohomish basin is 575 fish/km/yr. Restoring Cherry Creek to conditions that existed prior to habitat modification would increase abundance of spawning fish to 9200 fish/yr., increasing total coho production of the Snohomish basin by 7.3%. Degradation of the Griffin Creek subwatershed, currently a highly productive site, to moderate productivity would lead to a decrease in the abundance of spawning fish from 18,763 coho/yr. to 4300 coho/yr. This decrease corresponds to a 15.3% decline in total coho production for the entire Snohomish basin.

Relationship to Recovery Goals/Relationship to Other Components of the CRI Model

This method also allows habitat characteristics to be directly related to recovery goals for salmon. Recovery goals are likely to be expressed as minimum population levels established at the ESU and watershed level. Associating subwatershed habitat condition with population levels enables the current productive capacity for freshwater habitat in a watershed to be estimated. Assessing the potential effect alterations in subwatershed habitat condition have on productivity of the watershed as a whole provides a method of developing alternatives for achieving the quantity and quality of freshwater habitat conditions required to achieve the recovery population goal for the watershed.

The CRI model incorporates the habitat assessment tool described above with an evaluation of the cumulative impact of all factors influencing salmon population performance. Thus, the influence of changes in productive potential for freshwater habitats resulting from land-use actions can be evaluated in terms of effect on overall population performance in light of the hatchery, harvest, hydropower or other factors influencing that population.

Figure 11 – Land use evaluation flowchart

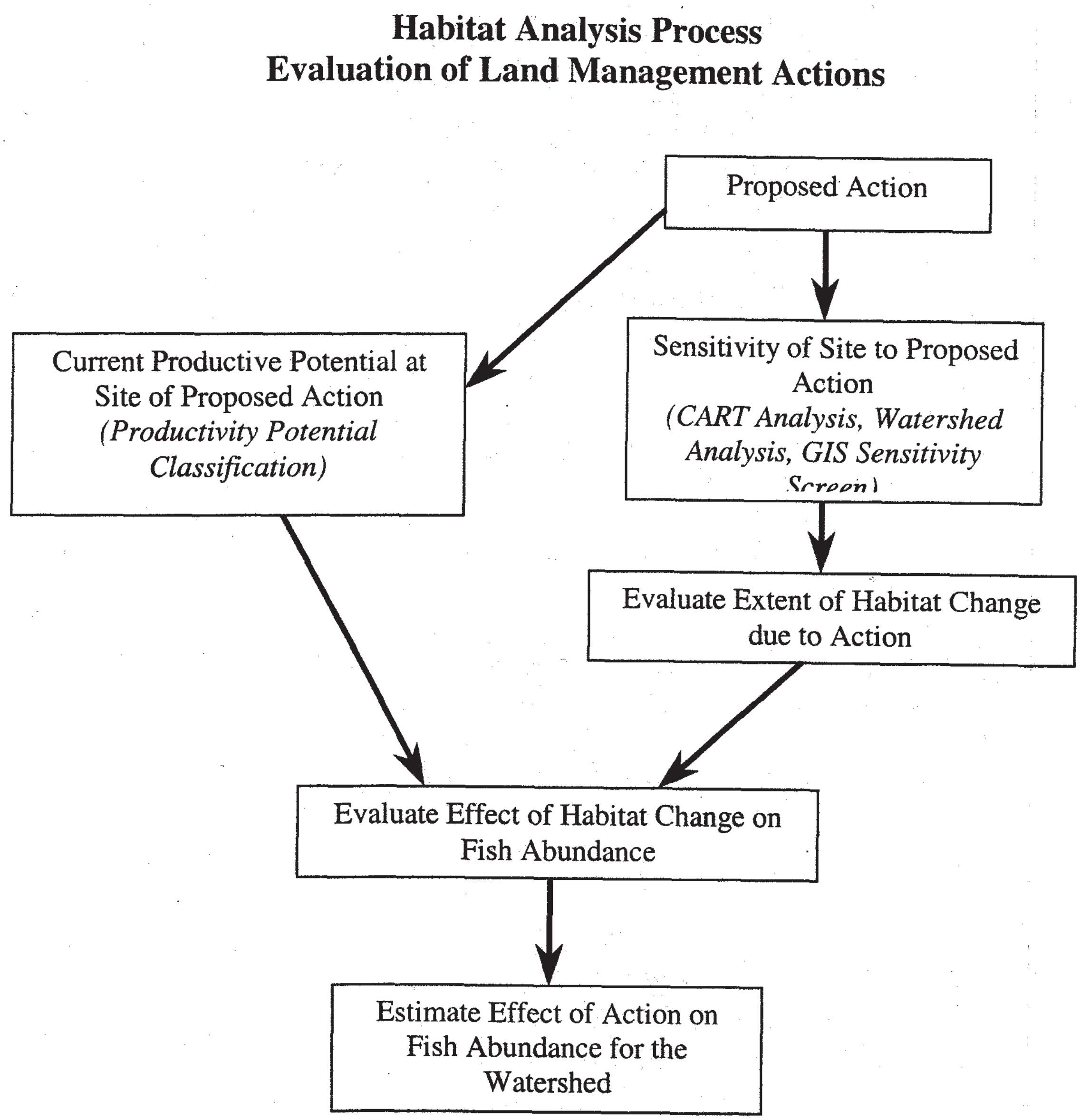


Figure 12 - An example of application of the habitat-population relationship to evaluate effect of habitat changes on coho salmon population in the Snohomish River. Values in the table below represent average density of spawning coho salmon at index reaches in each population size class. Example 1 evaluates the effect of restoring Cherry Creek, a tributary currently impacted by agricultural practices. Example 2 evaluates the degradation of habitat in Griffin Creek from its current highly productive state to a medium level of productivity.

Population size class	Average Coho Spawner Density (fish/km/yr)
High	575
Medium	215
Low	146

Restoration of Cherry Creek (medium productivity to high productivity)

Accessible Stream Length -- 16 km
Current Coho Use – 2279 fish/yr (actual value for the subwatershed)
After Restoration – 9200 fish/yr (575 fish/km x 16 km)
Change in Snohomish River Coho Production: +7.3%

Degradation of Griffin Creek (high productivity to medium productivity)

Accessible Stream Length -- 20 km
Current Coho Use – 18,763 fish/yr (actual value for the subwatershed)
After Degradation – 4300 fish/yr (215 fish/km x 20 km)
Change in Snohomish River Coho Production: –15.3%

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