Project ID: 35016

Title: A Pilot Study to Test Links Between Land Use / Land Cover Tier 1 Monitoring Data and Tier 2 and 3 Monitoring Data

Section 9 of 10. Project description

a. Abstract

This proposed research will test the use of land use / land cover (LULC) geospatial data in the Willamette River subbasin as a Tier 1 monitoring data base, which will be linked to Tier 2 data in the Willamette River floodplain, anadromous fish distribution areas and riparian zones and then statistically correlated with field-sampled Tier 3 data. After modification of protocols already developed by the Pacific Northwest Ecosystem Research Consortium (PNW-ERC) to create these LULC datalayers are completed, they will be transferred and applied to either the John Day or Wenatchee subbasin.

The pilot test will be conducted in the Willamette subbasin to take advantage of previous investments by the PNW-ERC in data and sampling protocol development. These investments include complete LULC data for 1850 and 1990 to be used as referents in tracking change in contemporary LULC, as well as spatial information on major river floodplain and stream habitat change (vegetation, revetments, land value, human occupancy, channel configuration). Algorithms for tracking change constitute an important component of the transferable lessons of the proposed effort.

This project will directly address action items 180 and 181, and will couple with other status monitoring programs. Specifically, this project will work in conjunction with other probabilistically based sampling programs such as EPA EMAP Tier II. This project links time series LULC data to field data to strengthen correlative and causative understandings of change in riparian and aquatic resources.

The primary focus of this integrated analysis is on the human-dominated portion of the landscape where historic LULC analyses show anthropogenic change has been greatest. Contemporary projections for human population growth in the West generally and the Columbia Basin specifically indicate this pressure for change will continue. We emphasize how to evaluate the effects of ecosystem characteristics in lowlands and uplands on aquatic life at Tier 1, 2 and 3 levels, with special attention to salmonids.

Expected results include 1) documentation of primary Tier 3 (local habitat) relationships using field measurements for 4 response variables (riparian vegetation composition, large wood abundance within 120 m of rivers and streams, total fish richness and relative fish abundance); 2) analysis of ecosystem changes over time at subbasin (Tier 1) and intermediate (Tier 2) scales using hydrogeomorphic, anadromous fish distribution, and riparian areas of influence on fish communities; 3) accuracy assessment of LULC characterization of status and change over time; and 4) transferring the lessons learned from the Willamette subbasin pilot test at Tier 1 level to the John Day or Wenatchee River subbasin.

b. Technical and/or scientific background

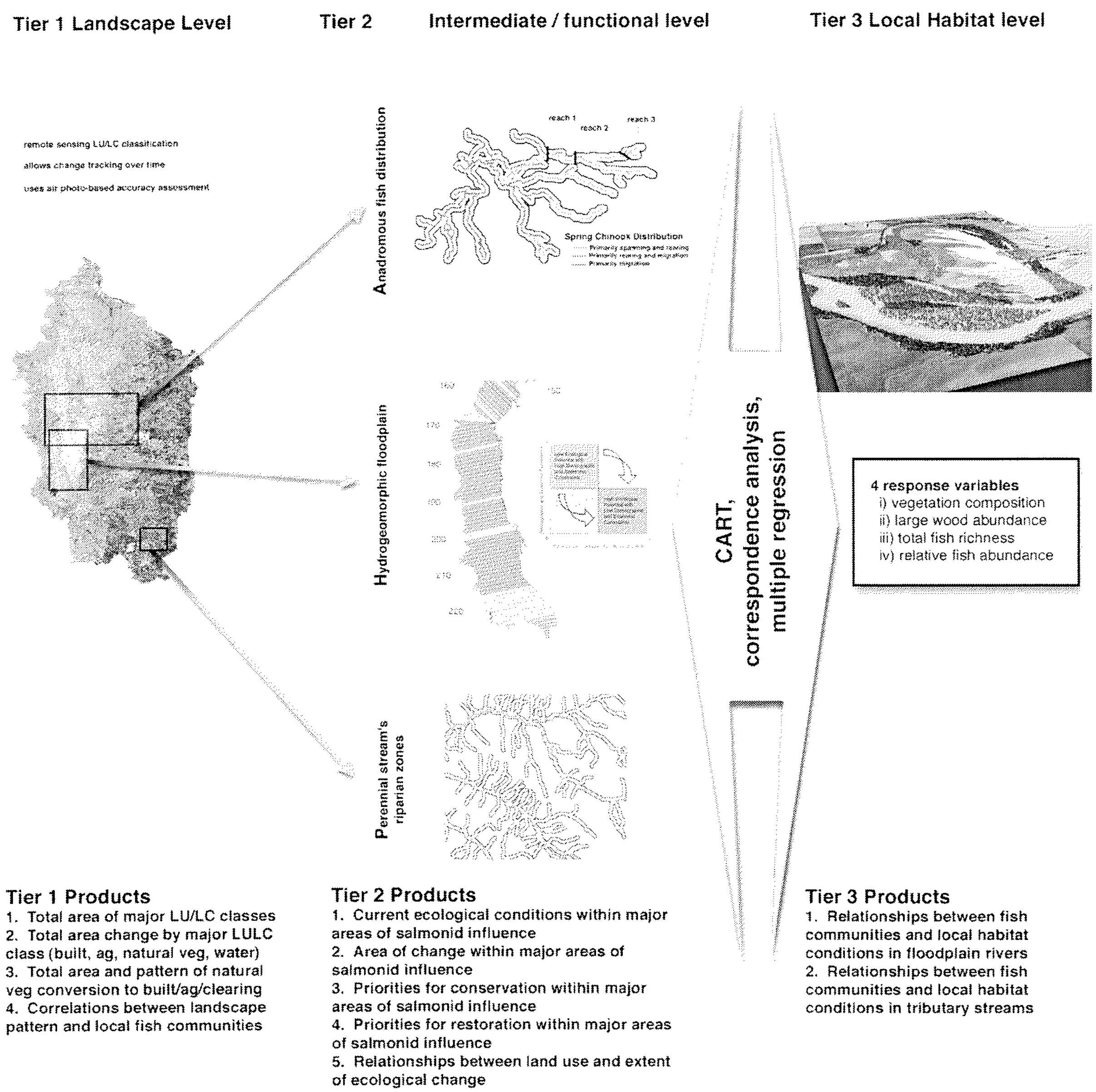
Floodplains and riparian forests are some of the most dynamic zones of any landscape, and they contain some of the highest levels of biological diversity and habitat complexity. Complex patterns in riverine systems emerge because of the interdependence of biophysical and human processes, non-linearity in factors that shape process and pattern, and the unique behavior of linear patchwork mosaics bounded and arrayed within river networks [5,15,34]. These areas also are highly valued for their access to water, transportation potential, food and fiber production, recreation, and beauty.[21] Historically, towns and cities along rivers have encroached on this zone and then attempted to create stable streambanks in areas that are, by nature, dynamic. This inherent contradiction is the basis for management of floodplains and riparian forests worldwide. The pressures on ecosystem processes from growing human populations, especially in and proximate to riparian lands, appears unlikely to subside within the next century. The number of people in the United States grew 13% between 1990 and 2000 [39] and is expected to increase another 50% by 2050.[18] These percentages are even higher for many rapidly developing areas in the western United States, most of which are concentrated near large rivers due to the history of human settlement patterns. Integrated regional assessment of the status and trends of biophysical and socio-economic patterns in rivers and floodplains improves our understanding and provides greater potential for long-term persistence of river restoration efforts and increased likelihood of ecological effectiveness.

Such assessments depend on, first, valid classifications of terrestrial and aquatic ecosystem status and trends, and second on conceptual frameworks for geographic prioritization of site-level restoration efforts that are consistent with the biophysical and human dynamics of the systems being managed. Land use and other human activities have extensively modified rivers and their floodplains in the past century. In responding to these modifications, many conservation and restoration efforts are based on opportunities (e.g., willing land owners, public lands and short-term funding sources) and are treated as add-ons to other river modification projects. These projects often lack a broader strategic framework based on both the ecological resources of the river *and* future pressures to develop land along the river. As a result, attempts to modify rivers or "restore" river systems often fall short of their goals. In some cases these attempts unintentionally cause detrimental changes to the ecosystem by not considering the larger river network and its biophysical/social interactions. Restoration efforts based on short-term opportunities are not undesirable. However, their success can be increased by application of a strategic conceptual framework based on activity within the river corridor. Ecologically-designed restoration efforts commonly are based on vegetation patterns,[39] hydrology,[12] geomorphic processes,[40] or floodplain dynamics.[48] These approaches tend to focus on the biological or physical components of rivers but rarely consider the human activities that shape the potential for ecological recovery and create future pressures to modify the river ecosystem. Patterns of riparian vegetation, human population densities and structural development, as well as economic values and productivity of the land along rivers, create critical constraints on the locations and outcomes of restoration.

Research Framework

LULC patterns of critical riverine and riparian components and human land uses at the Tier 1 landscape level create a context for efficiently tracking status and trends over time and space. Data sources, accuracy assessments, LULC classification, spatial data evaluative strategies and LULC change tracking protocols will be applied at the landscape level to project the trajectory of change for the subbasin. Spatial and temporal contexts produced from this analysis will then be employed in three different spatial constructs for organizing Tier 2 environmental data. Tier 3 data will consist of four field sampled response variables. Relationships between Tier 3 data and Tier 2 environmental characteristics will be determined through CART, correspondence analysis and multiple regression. Figure 1 summarizes the research framework.

Fig. 1 A graphical summary of the conceptual framework and products of the proposed research



Tier 1: Land Use and Land Cover as a classification scheme for implementing the approach at the Subbasin Level

A growing body of reports on the state of the environment in the US and other nations paint a compelling picture of the need to better track environmental change. [42,44] Two recent reports, one on the State of Oregon's Environment [22,42] and one by the Independent Multidisciplinary Science Team of the Oregon Plan for Salmon and Watersheds[22], called explicitly for regular, recurring use of LULC data to track environmental change. Information sets having adequate spatial and classificatory detail and length of record in time to complete such a task are few and in most locations, literally, far between. The expense, complexity and challenge of gathering and updating on-the-ground information for large areas with so many important environmental processes has simply been too great. Yet we now find ourselves at a point where the absence of such information constrains our ability to answer important questions, questions such as "is this critical ecological process functioning within historic ranges of variability?"... or ..."is this resource improving or getting worse over time?"...or... "what is the status of key environmental attributes that effect species of concern?." Without answers to such questions, ecological values will most often lose to those for which markets, laws, local controls and culture provide measures in comparable currencies of value through systems of interaction and accountability. [20]The advent of satellite and other sources of information about the earth's surface has significantly improved the ability to track environmental change over time, yet several criteria must be met by information sources purported to be up to this challenge. They must:

- be readily available over broad spatial extents,
- be affordable to acquire, classify, verify and update,
- be sensitive to change in the characteristics of interest, and
- provide full extent coverage over sustained periods of time at acceptable cost.

LULC data form the foundation of the Tier 1 status and change tracking approach we propose, and this approach relies principally, although not solely, on remotely sensed land cover data. Remotely-sensed land use and land cover (LULC) data have been available since 1972. Once properly processed and ground checked, they can be used to map the landscape in a cost effective manner with known degrees of certainty. [6;7;8;28;33;41]

Satellite Classification Methodology

Satellite remote sensing data are to be used in this project for Tier 1 mapping at the subbasin level. This includes both land cover and cover change characterizations (the latter in the Willamette River Basin--WRB--only). Land cover mapping protocols for this project were established in our earlier project (PNW-ERC) within the WRB. However, we will take advantage of new techniques and datasets to evaluate potential improvements to the cover maps.

Land Cover Mapping

In the WRB project a multiseasonal Landsat Thematic Mapper (TM) data set consisting of five image dates from a single year was used to characterize agricultural and related land cover in the basin (Oetter et al. 2001). Image registration was accomplished using an automated ground control point selection program (Kennedy and Cohen in press). Radiometric normalization was performed using a semiautomated approach based on the identification of no-change pixels in forest, urban, and water classes using a technique known as Ridge Regression (developed by Kennedy and Cohen, as referred to by Song et al. 2001). "Reference" data were developed using existing data sets, including low-level 35-mm color slide photographs, 1:24,000 color airphotos, and ancillary GIS coverages. Preliminary examination of the data structure included plotting of training set temporal trajectories in spectral space with reference to existing crop calendars. A subsequent stratified, unsupervised classification algorithm, in combination with a geoclimatic rule set and regression analysis, was used to label mapped cells. A map of 20 land cover classes was developed. Classes included agricultural crops and orchards, valley forest and natural cover types, and urban building densities. An accuracy assessment indicated a final map error of only 26%.

For the forested, upland portion of WRB mapping protocols were established by Cohen et al. (2001). In that study, we modeled forest vegetation attributes as continuous variables across western Oregon using a multi-image mosaic of TM data. Four specific attributes were modeled using regression analysis: percent green vegetation cover, percent conifer cover, conifer crown diameter, and conifer stand age. Reference data for the cover and diameter attributes were derived from airphotos, and existing agency polygon databases were used for stand age. We developed and applied a new method for regional mapping called applied radiometric normalization. The method involved development of a set of models for a centrally located "source" scene which were then extended to "destination" scenes (neighboring scenes in the TM mosaic). The overall map accuracy for 7 forest classes was over 80%. Use of airphotos and existing digital databases in combination with applied radiometric normalization translated into a cost-effective procedure for regional mapping with TM data. Modeling forest attributes as continuous variables enabled creation of a flexible forest cover information base, containing important fundamental building blocks for a variety of related classification schemes.

The final land cover map for the WRB (ca. 1900) was developed by integrating the two maps described above (i.e., the agricultural valley and the upland forest). This integrated map was then augmented by Hulse et al. with land use information and used to model present and future landscapes for the basin. [21]

These same basic mapping procedures will be applied to 2004 Landsat Enhanced Thematic Mapper Plus (ETM+) data collected over the WRB and 2006 ETM+ data collected over either the John Day or Wenatchee River subbasins. In addition, we will test an approach that incorporates MODIS (Moderate Resolution Imaging Spectrometer) data (Justice et al. 1998) and uses a new modeling strategy based on Gradient Nearest Neighbor (GNN) method of Ohmann and Gregory (in press). This method has already been developed and applied over most of the Coast Range ecosystem of Oregon. GNN is a method of predictive vegetation mapping that integrates vegetation measurements from field plots and other reference data, mapped environmental data, and satellite imagery. The method applies direct gradient analysis and nearest-neighbor imputation to ascribe detailed ground attributes of vegetation and related land cover classes to each pixel in a digital map. In past and current research Ohmann and Gregory (in press) demonstrated that at the regional level, mapped predictions closely represented the range of variability present in the plot data for a variety of measures of forest composition and structure, and landscape proportions of vegetation types closely matched sample-based estimates. At the site level, mapped predictions maintained the covariance structure among multiple response variables. Prediction accuracy for tree species occurrence and several measures of vegetation structure and composition was similar to or better than achieved with other methods (Ohmann and Gregory in press). Because the vegetation information mapped by GNN was retained at the most detailed level (the basic field measurements), the data could be post-classified to create maps of any vegetation attribute that was available for the plots (e.g., tree species, down wood).

Using GNN, the first requirement is a forest versus non-forest stratification. To accomplish this, a variety of existing datasets will be used, including an existing stratification already developed for the WRB, Landsat imagery, and land-use and related census data. This stratification will be checked for accuracy and improved as necessary using additional criteria.

To map forest cover attributes we will use GNN to derive tree lists for each pixel, as was successfully accomplished for the Oregon Coastal Region in an earlier study. Mapping the occurrence of tree species in each pixel should facilitate subsequent derivation of accurate forest type classes that are more generalized and ecologically relevant. In Oregon, the mapping of species was largely dependent on the relationship between species distributions and averaged climate. In this study, we propose to increase the information content of climate data over our prior GNN work through three means. First, we will take advantage of newly-available climate data that provides daily estimates of weather (currently 18 years of data, 1980 – 1997), gridded at 1km resolution (Thornton et al. 1997, Thornton et al. 2000; www.forestry.umt.edu/ntsg/), to investigate whether indices of climate variability may improve species predictions. Second, we will explore the potential of linking the variability in climate data to variability in satellite imagery for the same periods, through such simple measures as inferred date of greenup, duration of greenness period, and maximum greenness by year. This latter approach may allow us to better discriminate species groups by their responses to variable climate, a topic we suspect from prior GNN analyses (and from Ohmann and Spies 1998) may be useful. We will use the growing archive of near-daily MODIS data at the 500m and 250m pixel scale, to track vegetative response across seasons. While these satellite data are at a relatively coarse spatial resolution, the GNN mapping itself will be based on ETM+ data and will be done at the grain size of those data given that fine-grained land management prescriptions are also a major signal controlling species distributions.

Successional stage of forest vegetation is largely a structural phenomenon. As such, seasonal spectral information greatly enhances the ability to accurately map structural attributes in that variations in sun angle enhance the spectral differences among structural stages. Lefsky et al. (2001) demonstrated this in western Oregon by comparing single-date versus multi-seasonal Landsat data to estimate a variety of forest structure variables. An approach to be used in this study is to include three growing-season dates of ETM+ and again incorporate seasonal MODIS data within the GNN method to map forest successional stage.

For the non-forest classes GNN will be used in combination with reference data collected for that purpose from field visits and existing datasets. As demonstrated by Oetter et al. (2001), seasonal image data were critical for mapping agricultural crops and related non-forest vegetation in the WRB. Here, MODIS data should provide a substantial benefit over Landsat data alone and GNN should be a superior method for integrating various datasets.

Combining these new datasets and techniques with our established protocols should significantly increase the quality and utility of the land cover maps. Moreover, these techniques should enable establishment of state-of-the-art Tier 1 monitoring capabilities.

Characterizing Land Cover Change

The minimum level of change detection needed in this study is a comparison of land cover maps derived from 1990 and 2004 for the WRB. This technique, known commonly as post-classification change detection involves spatially overlaying the two maps and developing a land cover transition image, and was popularized within ecological circles by Hall et al. (1991). Although change detection done in this way is simple and straightforward, it is prone to generating change maps having greater errors than those techniques that evaluate spectral change over time directly, such as multi-date image differencing (Muchnoney and Haack 1994). We propose an alternate method for use in meeting our needs most efficiently and accurately. Given the need for an accurate current map of 2004 land cover, and a large volume of data to process, we will use the 1992 map and work forward in time evaluating spectral change between 1992 and 2004. For the change classes we are expecting to map, we will identify multispectral difference thresholds (or spectral change vectors, after Lambin and Strahler 1994) that represent each change class. For areas identified in this way as changed, we will use the images from the 2004 date to classify the land cover that is present at that date. For areas that have not changed, we will maintain the label from the 1992 cover map. This approach was tested in the Greater Yellowstone Ecosystem (Wright et al. in review) and in western Oregon (Lefsky et al. in preparation). In both cases, the new land cover maps were equally accurate to those developed independent of the earlier map and the change information was significantly more accurate than that of the post-classification change method. Errors in the change maps will be assessed with independent reference data.

These remotely-sensed images of landscape patterns can also be correlated with ground-level changes to critical ecological processes and updated with data at finer space and time grains as these become available. Scientific studies have established linkages between LULC change and important resources such as fish and wildlife habitat, urban stormwater runoff, soil productivity, forest condition, air quality and biological diversity. [5; 25; 33; 35] However, to adequately represent human-dominated portions of the land, land cover data must be augmented to provide the necessary information about culturally-driven landscape change. [12] Any representational model of land and water conditions is subject to constraints, i.e. it is necessarily an abstraction. An information set which is adequate to characterizing both biophysical and social factors must represent both land cover and land use, but it must do so at a grain of detail fine enough to capture key features and processes too small or frequent for LANDSAT Thematic Mapper sensors alone to detect. This is especially true for those characteristics that pertain specifically to the intended human *use* of land, in addition to the *cover* types detectable and classifiable through conventional remote sensing techniques. [28]

To meet the land use characterization needs of the proposed LULC classification, we will draw on eight principal geospatial data sources in addition to satellite data, all of which meet the criteria outlined above. They are:

- County assessor taxlot parcel data to characterize land value, urban residential density and status of structures as residences in rural environments
- USGS 7 1/2 minute topo quads to locate rural structures
- State Dept. of Transportation data on primary and secondary roads
- USDA Forest Service and USDI Bureau of Land Management data for tertiary roads on federally managed lands
- US EPA's River Reach file, modified for the Pacific Northwest by the PNW-ERC
- USDC FEMA flood plain and floodway mapping
- US Bureau of the Census population data
- 1850 General Land Office and US Army Corps of Engineer historic river maps

Need for time series LULC data to conduct change tracking at the Tier 1 level

Current vegetation type and distribution for the Willamette basin and major tributaries will be identified from transformation of satellite spectral information. Dr. Warren Cohen of the LTER Program has worked with NASA, EPA and NSF to develop algorithms based on vegetation reference stands in the region and will direct this component of the research. Developed images have a grain size or resolution of 25 m. This pixel size will provide characterizations of the riverine vegetation by plant type (e.g., agricultural crop type, deciduous, mixed, coniferous forest) and age class where applicable (e.g., 0-20 yr, 20-80 yr, 80-200 yr, and > 200 yr). We have data for

1972, 1976, 1980, 1984, 1988, and 1990. We propose to produce comparable data and classifications for the Year 2004. Transformation of the data and analysis of land use and cover patterns will allow us to identify changes in landscape condition over the last 30 years using the three Tier 2 constructs shown in Figure 1 and described below. Use of both aerial photography and ground-level data will allow us to calibrate the sources of remotely sensed information. We will supplement image comparisons with field validation of major vegetation, land use and habitat types as listed above. A network of LULC validation sites will be established along the length of the valley, and existing reference plots established by Oregon State University and EPA's EMAP Program will be incorporated into the database. [41] Data and analyses from this network will provide a benchmark for future analyses of ecosystem change and inform the efforts necessary to implement similar networks in other subbasins.

Tier 1 Products

The expected results include a defined set of LULC classes for use in mapping baseline land use / land cover conditions in the WRB in 1990, 2004, and at 3-4 year intervals thereafter; the algorithms for classifying raw satellite data into the relevant LULC classes and the resulting LULC classification for the Wenatchee or John Day subbasin; and a set of statistically validated 1990-2004 change tracking results for the WRB quantifying:

1. Total area of major LULC classes
2. Total area change by major LULC class (built, ag, natural veg, water)
3. Total area and pattern of woody vegetation conversion to built/ag/clearing
4. Correlations between landscape pattern and local fish communities

Tier 2: Comparing and contrasting three approaches for assessing relationships between environmental characteristics and salmonid trends

One of the most compelling conclusions of our recent work with the PNW-ERC was that, regardless of landscape type (i.e. urban, rural, agricultural, forested, lowland, upland, etc.) or the nature of assumptions about what will drive landscape change in the coming 50 years (e.g.,more development oriented, more conservation oriented, or status quo) the LULC characteristic that was most strongly correlated with predicted overall stream condition and aquatic life response was the percent of agriculture and development within 120 m of the stream or river. [2] The inverse of this, the longitudinal extent of contiguous woody vegetation within 120 m of the stream or river, thus plays a key role in our proposed work at the Tier 2 level.

We propose to apply three different spatial constructs—a hydrogeomorphically-based area of influence on salmonids in large rivers, an area of influence based on distributions of anadromous salmonids, and an area of influence on salmonids based on 120-m riparian areas along all perennial streams—to determine which is better correlated with field measured (Tier 3) evidence of salmonid and total fish trends. While the duration of this project will prevent us from producing long term (> 5 yr.) evidence of these correlations, the nature of this effort as a pilot is to demonstrate the efficacy of the overall approach so that it can be adapted to other locations and sustained through time to provide a longer record, being further refined and tailored to local conditions in the process of adaptation.

In the three Tier 2 constructs presented below, we focus attention on those portions of the subbasin that evidence indicates matter most to anadromous salmonids, the historic floodplain and land areas within 120 m of rivers and streams (both total riparian areas and those associated with the range of anadromous salmonids). While there are important differences in the three constructs, they share some important characteristics. One of these is that the territories they define may serve as 'spatial containers' for varying types of spatial data. This Tier 2 component of the proposed effort compares and contrasts differences in strength of correlations obtained between one spatial container's LULC data and Tier 3 response variables vs. the strength of correlations between the other spatial container's LULC data and the same Tier 3 response variables.

<u>Area of salmonid influence based on hydrogeomorphic floodplain function</u>

In this component of the Tier 2 analysis, the floodplain provides the most constant and quantifiable spatial framework for comparing physical, biological, demographic, and economic characteristics of the river corridor. [1; 14; 19] Channel position, forests, and land use may change, but the floodplain, i.e., the area historically inundated by floods, is relatively constant. Here, we employ a spatial framework for floodplain assessment by mapping 1-km "slices" of the Willamette River floodplain at right angles to the floodplain's center axis (Fig. 2). Within each of 228 1-km slices, numbered 0 (zero) starting at the confluence of the Willamette and Columbia Rivers and ending with 227 at the confluence of the Middle and Coast Forks of the Willamette, we measure historic and contemporary characteristics of channel complexity, floodplain forests, human systems, and economic patterns. The longitudinal display of these features creates a linear illustration of the characteristics of the Willamette River and allows consistent and simultaneous analysis of a floodplain river and the human systems along its course. Additionally, it creates a spatial context based on the natural processes that shape river channels and create their floodplains.

We then use this spatial framework for each slice to compare the presence and amount of various LULC classes (built, agriculture, native and natural vegetation, water) with Tier 3 response variables using CART, correspondence analysis and multiple regression.

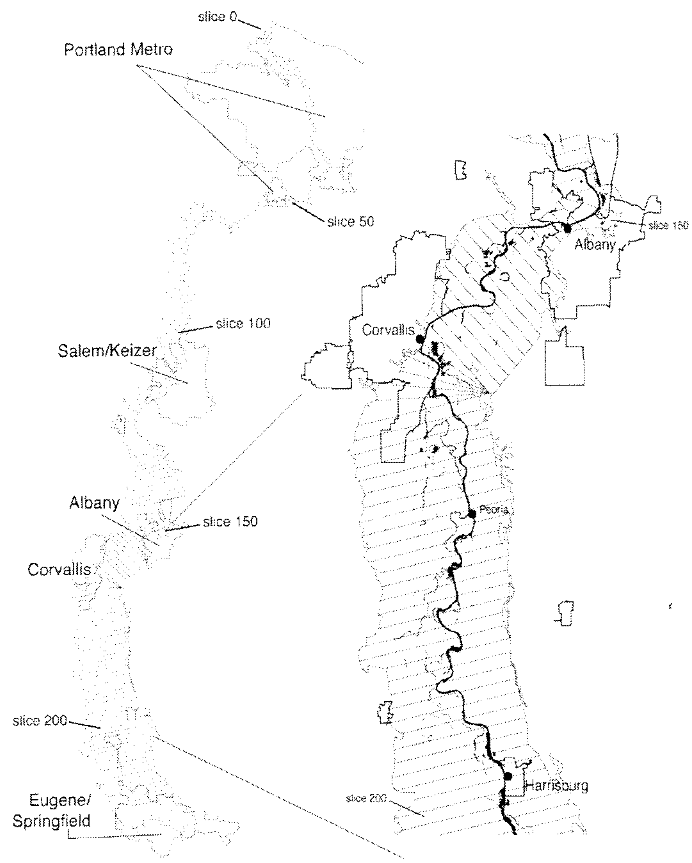


Fig. 2 - *Spatial framework for prioritizing locations for river restoration using historical floodplain and 1 km 'slices' perpendicular to floodplain axis.*

Area of salmonid influence based on riparian areas along tributary streams

In this component of the Tier 2 analysis, we evaluate ecological conditions and change within the riparian areas (120-m on each bank) along all perennial streams within the WRB. [1,14;19] For riparian areas, we will analyze ecological conditions based on LULC maps within 120 m of the stream and divide the stream network for the basin into reaches that are generally 500-200 m in length. This allows us to characterize the LULC conditions for a specific reach, multiple reaches, a riparian network for a subbasin, or the full riparian network. Within each reach, we quantify characteristics of riparian vegetation (based on Tier 1 land cover maps), channel slope, road systems, and major land use types for 1850, 1990, and 2004. The longitudinal display of these features creates a network illustration of all riparian areas and allows consistent and simultaneous analysis of the ecological and human systems along the riparian network.

We then use this spatial framework for each reach to compare the presence and amount of various LULC classes (built, agriculture, native and natural vegetation, water) with Tier 3 response variables using CART, correspondence analysis and multiple regression.

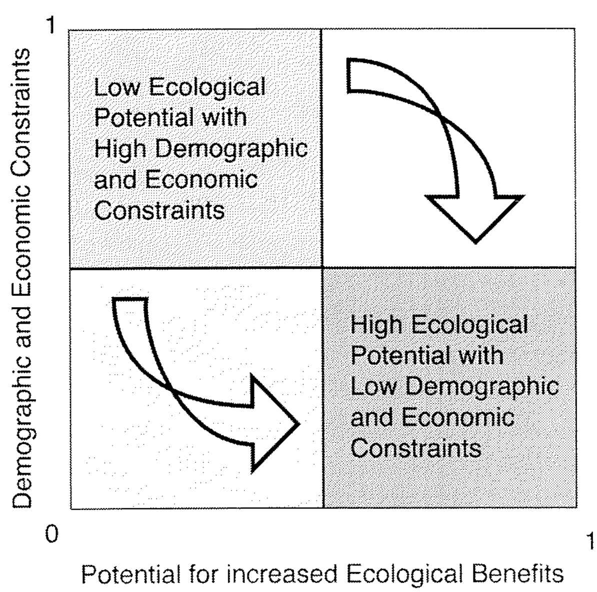
Area of salmonid influence based on anadromous fish distribution

Following similar logic, we then employ a spatial construct of more direct biological origins, the land area within 120 m of streams and rivers used by steelhead and spring chinook for a) primarily spawning and rearing, b) primarily rearing and migration, and c) primarily migration. The same LULC classes (built, agriculture, native and natural vegetation, water) will then be tested within this territory for strength of correlation with Tier 3 response variables using CART, correspondence analysis and multiple regression.

Geographic prioritization for river conservation and restoration at Tier 2 levels

The primary focus of this integrated analysis of biophysical and socio-economic potential for restoration is to 1) spatially identify ecological, demographic, and economic potential for riparian restoration and 2) identify changes in patterns, policies or practices that influence the future likelihood of restoration. In this approach, patterns of critical riverine ecosystem components and major human population centers and land uses create a spatial context at Tier 2 levels for locating conservation and restoration efforts (Fig. 1).[12] In addition to testing strengths of correlations, we also propose to compare and contrast the hydrogeomorphic floodplain and riparian zone constructs as spatial containers for geographic prioritization. This approach assumes that potential for increased ecological function of various candidate Tier 2 river reaches and Tier 3 focal areas is related to the difference between current patterns and historical conditions in 1) river channel complexity and hydrology and 2) floodplain vegetation. Constraints and incentives for conservation and restoration created by human systems are determined by 3) the patterns of human populations and structural development of the floodplain and 4) the economic values and productivity of the land within the floodplain. We classify the floodplain along the Willamette River using these four major typologies, and thereby providing a "proof of concept" quantitative basis for identifying areas with both high potential for increased ecological benefit and low socioeconomic obstacles to conservation or restoration.

Fig. 3 - *Conceptual framework for prioritizing conservation and restoration locations*



High conservation and restoration potential

The lower right quadrant of Figure 3 represents areas with high potential for ecological recovery and low constraint from human settlement and land value. These lands should have the greatest potential for future ecosystem recovery. Such areas are better suited for conservation and restoration because their ecological values could increase more than other areas. The efforts put forth and costs absorbed by communities to prevent channel change and flooding are often higher here than elsewhere. Economic constraints and demographic pressures are frequently lower. Ecological recovery is likely to be greater on these lands, while social pressures to reverse restoration are likely to be lower.

Potential for policy change and incentives

The upper right and lower left quadrants of Figure 3 depict those areas that combine either high potential for increased ecological value with high demographic and economic constraints or low potential for increased ecological value with few constraints. Lands in these categories are mixes of positive and negative features. In these areas, decision makers can focus on alternative policies or practices that might move a site into the lower right quadrant. Policy changes and incentives tend to modify demographic and economic constraints rather than changing the potential for ecological benefits. Examples would be changes in lending rules or interest rates, federal farm assistance requirements, or converting through purchase, private to public lands. Other possibilities would be use of land zoning restrictions or taxation policies that would have minimal economic consequences but major ecological benefits.

Low conservation and restoration potential

Areas that combine low potential for increased ecological response with high demographic and economic costs are likely to be poor choices for restoration. These areas fall in the upper left quadrant of Figure 3. These sites provide little ecological benefit, are located in areas where pressures for future modification are high, and investments in restoration may be costlier than other areas because of property values. In contrast to lands described above, these areas are more suited for intensive use because their conversion will achieve less ecological response per unit of investment.

Before rejecting lands in the low restoration potential category, however, the following questions should be asked. First, are critical habitats or at risk species present? If so, restoration outcomes may warrant heroic efforts even in the face of large socioeconomic obstacles. Second, do these lands present opportunities to learn about the values of and approaches for conservation and ecological restoration? Particularly in urban areas, these sites are where people live and work. As we pass these habitats every day and use them for recreation, such landscapes provide a tangible link between people and the natural processes upon which we depend.

Geomorphic, floodplain vegetation, demographic and economic characteristics

Channels, floodplains, and hydrology create the physical setting for the development of the ecological properties of a river system. The primary role of these physical processes is recognized in fundamental ecological ideas, such as the river continuum concept [38a] and the flood pulse concept.[14]

Restoration is a process of change, and channel features prone to frequent change (e.g., river tributary junctions, multiple channel reaches) have greater potential for rapid restoration. On the other hand, when people attempt to stabilize these dynamic reaches, enormous investments are required by agencies and local communities to confine channels. Historical patterns of river channels offer useful contexts for determining potential responses to restoration in the future.

Diversity and extent of floodplain forests are closely linked to channel structure and dynamics of flooding. River reaches with high geomorphic complexity and frequent channel changes are characterized by high vegetative species diversity of riparian patches and related diversity within those stands. Tributary junctions and multiple channel reaches exhibit complex mosaics of riparian forests, and single channel reaches contain simpler patterns of floodplain vegetation. The stability of the single channel reaches can support older forests because the vegetation is not exposed to the effects of floods as frequently as more complex channel reaches.

Patterns of recent and current human land use create a context for considering potential future ecosystem patterns and locations for restoration efforts. Efforts to limit the impacts of development along the major rivers in the region have intensified as measures to limit development in floodplains and minimize impervious surface area are being applied in rapidly urbanizing lands.[2] Major urban development in river floodplains is largely irreversible over the near future, while agricultural and forest lands offer much greater potential for restorative change.

Economic production influences landowner decisions about the use of lands along rivers. Prices of goods and services derived from riparian lands provide an indication of the likelihood of landowner participation in restoration efforts. Regulatory processes also influence landowners' decisions, and the longevity of governmental policies may be sources of uncertainty for land owners. Patterns of land productivity strongly influence the feasibility of conservation and restoration and must be evaluated along with patterns of river modification and ecological condition.

Conservation and Restoration Prioritization process

Although land acquisition and regulation are powerful tools, there will never be enough money, political support, or willing sellers to protect ecosystem values in landscapes dominated by private ownership. Regardless of the strengths and weaknesses of classification schema, the pace of human-caused landscape change often leads to situations where the need for restoration outstrips the resources available to restore lost ecological functions. [5a] Conservation and restoration of ecologically significant patterns and processes in places where human population density and land use intensity are high may require reversal of long standing investments in land form and water course alteration. If ecological restoration and the benefits of built environments are in opposition – gain in one necessarily causing loss of the other – then the conceptual model described previously expresses the nature of the prioritization task: at the Tier 3 river network extent find those Tier 2 reaches where two conditions exist, investment in constructed conditions is low and the potential for increased ecological benefit is high. If potential ecological gain is high but the existing structural investment is as well, then future net gain is interpreted as small, as is the likelihood of community acceptance of large scale conservation or restoration projects. While we illustrate here this particular conception of restoration priorities, it is important to note that there are other equally valid sets of priorities. We argue that the key issue is that decision-making processes used to geographically prioritize conservation and restoration locations (and the classification and monitoring schema on which these processes are based) must be consistent with *both* the biophysical and human dynamics of the systems being managed. Otherwise these gains in ecosystem restoration will not endure, no matter how sophisticated their classifications or laudable their goals.

Figures 4 and 5 show two examples of how to make the proposed conceptual approach quantitative and spatially explicit.[11] Beginning with river kilometer zero at the confluence of the Willamette with the Columbia River, we illustrate the use of the hydrogeomorphic spatial construct explained previously to quantify key factors affecting both opportunities and constraints for restoration. These two approaches are not mutually exclusive, but may be used in concert by individuals or groups interested in choosing among available options for restoring riverine and floodplain ecosystems.

Again, note that either of these approaches may be applied with restoration priorities other than those we illustrate, given the necessary data for the relevant factors.

One approach for prioritizing locations of restoration actions is graphical inspection of multiple factors of a river network. Applying this approach does not require access to sophisticated tools or computationally-intensive techniques, and thus it could be employed by any group with access to the kinds of graphs shown. Potential users of this approach might be newly-formed watershed councils or lay person monitoring efforts seeking to localize their efforts in the places best suited to their aims. In Figure 4, a single value is recorded for each factor for each river slice and the resulting single-factor linear graphs are stacked atop one another so that you may read the values for both opportunities and constraints for a chosen slice by visually scanning up or down the figure. In this graphical inspection approach, constraints on restoration are low where two factors, 1990 population density and 1990 number of structures per slice, are low. Conversely, ecological opportunity for restoration efforts to succeed is expressed in terms of change since pre-EuroAmerican settlement in channel complexity and in area of floodplain forest. This approach assumes that restoration potential is high where there has been a large loss of these factors since settlement. Thus these slices have the biophysical potential to recover what has been lost by employing natural processes as a restoration aid.

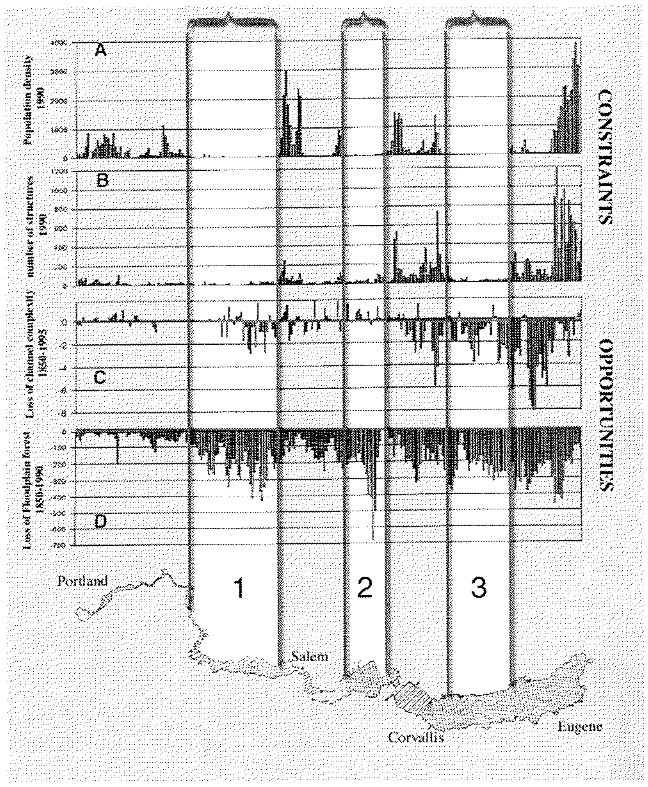


Fig. 4 - *Graphical example of river reaches with coincident low constraint and high opportunity to restore channel complexity and native floodplain forest.*

Highlighted vertical bands labeled 1 through 3 (outlined in blue in Figure 4) indicate reaches of the river where *both* desired conditions exist: constraint measures are low and opportunity measures are high. This example puts constraint in the controlling position (i.e., only look for opportunities where you know constraints are low) and shows the degree to which opportunity, as represented in Figure 4 by just two indicators, may also be available in these zones. This graphical inspection approach is a simple way to use the longitudinal pattern data previously described to prioritize river reaches for restoration.

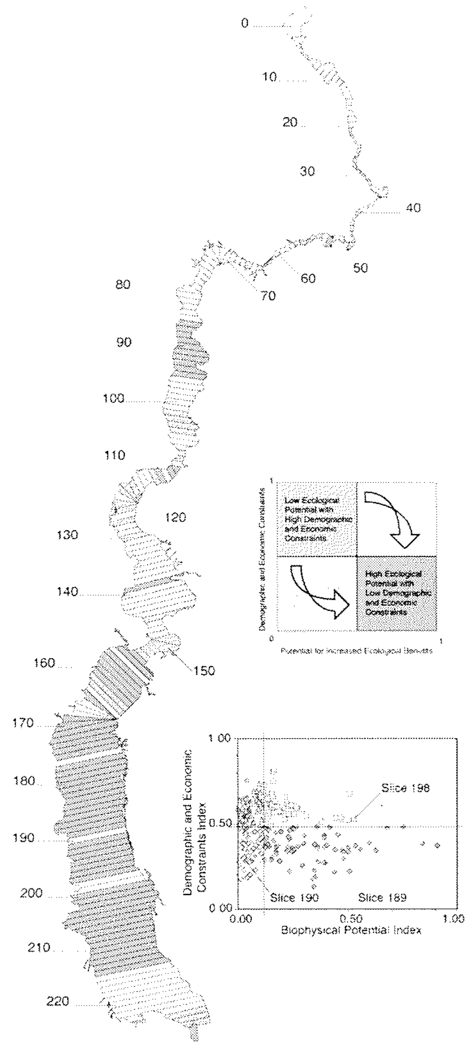


Fig. 5 - *Illustration of possible restoration priorities using the purposes of 1) increase channel complexity, 2) increase area of floodplain forest, 3) increase non-structural flood storage. Other purposes may alter priority locations.*

A more quantitatively and functionally detailed example of how data on longitudinal patterns can be used to identify areas with relatively high restoration potential is illustrated in Figure 5. Potential users of this more complex approach include resource managers, professional planners and staff advising elected officials charged with natural resource conservation and development decision making. In the example, restoration objectives are to increase channel complexity, floodplain forest area and non-structural flood storage. The potential ecological benefits of restoration are represented by three biophysical factors and the social constraints are represented by five different demographic and economic factors.

Human factors and hypothetical relative weightings (constraints)

1. 1990 pop. density / slice	0.11
2. 1990 bldg. density / slice	0.11
3. 1990 road density / slice	0.22
4. 1990 area of private land / slice	0.22
5. 1990 percent of slice worth more than $6200 / hectare.	0.34

Biophysical factors and hypothetical relative weightings (opportunities)

1. change in length of forest / slice 1850-1990	0.4
2. change in length of channel / slice 1850-1995	0.4
3. percent of channel length in revetment 1995	0.2

These factors, and their weightings are then used to quantitatively rank each slice using two independent indices describing a) social constraints and b) biophysical opportunities. The former consists of five components - population, structure, road, private land ownership, and higher price taxlot areal densities within each slice. Biophysical opportunities are then described by three components - change in length of river bank woody vegetation, change in length of channel complexity, and percent of bank revetted per slice.

Each component is assigned a number between 0 and 1, using a linear relationship between the minimum value (or, in the case of forest change and channel length change, a threshold) and the maximum value. Then, a weighted sum of these normalized components is computed to form each composite index. A restoration potential value is then defined for each slice using these two indices, and the median value of each index is used to divide the space into quadrants. Each slice falls into a single quadrant (Fig. 5).

The color-coded map and scatter plot of slices in Figure 5 shows the priority locations that emerge from these restoration purposes and their corresponding factors and weightings. Note the contiguous green slices, especially where such slices are adjacent to pale orange slices (e.g., slices 188, 189 and 190). These are locations where high potential for increased ecological benefit (green) occurs next to places that are already functioning relatively well ecologically and have less likelihood of future pressure for development (pale orange).

Conservation and Restoration Prioritization Process for Riparian Areas

The same process will be applied to the 120-m riparian areas along all perennial streams based on the available measures of biophysical conditions and human activity and value. Reaches will be ranked and prioritized in a system that is similar to the prioritization for floodplain reaches. This analysis will create a prioritization for riparian areas throughout the WRB and all major subbasins.

Relationship between Land Cover Change and Land Use

Maps of land cover change within 1) all riparian areas, 2) range of anadromous salmonids, and 3) large river floodplains will be evaluated to determine the relationships between land cover change and human land uses for the different areas of influence. We will analyze the databases for land condition and land use within the three areas of influence using both correspondence analysis and multiple regression. We anticipate that change will be greatest in the halos around high density areas of human populations. These lands are subject to urban sprawl and rural residential development and thus are subject to the most rapid change under current conditions and development forces.

Tier 2 products

The expected results include 1) an analysis of a defined set of LULC classes for 1850, 1990, 2004, and at 3-4 year intervals thereafter for a) all riparian areas along perennial streams, b) riparian areas within the distribution range for anadromous salmonids in the WRB, and c) the Willamette River floodplain; 2) an analysis of priorities for conservation based on existing LULC conditions for the three areas of influence on salmonids, and 3) an analysis of priorities for restoration based on change in LULC conditions between 1850-2004 and 1990-2004 for the three areas of influence on salmonids, and 4) an analysis of correlations between ecological change and major land use categories within the three major areas of influence on salmonids:

1. Current ecological conditions within major areas of salmonid influence
2. Area of change within major areas of salmonid influence
3. Priorities for conservation within major areas of salmonid influence
4. Priorities for restoration within major areas of salmonid influence
5. Relationships between land use and extent of ecological change

Tier 3 - Field Studies

Physical heterogeneity and productivity are critical determinants of biological diversity [50;51]. We hypothesize that floodplain forests strongly influence patterns of biodiversity in riverine systems [28,38]. In smaller streams in the major tributaries, riparian vegetation and floodplain presence will strongly influence fish communities.

Three major biophysical reach types in large rivers influence ecosystem structure and function-single channel reaches, multiple channel reaches, and tributary junctions. Tributary junction environments are one of the most diverse areas within the river network because of their array of depths, velocities, and channel edges. They also encompass species associated with different habitats in the main channel and adjoining tributary system. Side channels and sloughs in complex channels also provide a wide array of physical habitats and may serve as off-channel, low-velocity refuges during floods. River reaches with simple physical structure are characterized by lower potential diversity, low rates of geomorphic change through time, and less diverse food resources. These simple reaches are typical of less frequently changing riverine environments. Where these include uniform riparian vegetation without complex vertical or horizontal structure, we expect to find fewer species of riparian plants and fish. Riparian forest patterns are shaped by successional processes on the mosaic of surfaces created in these unique reach types, and the consequences for forest community composition, age, canopy structure, patch size, and distribution influence the food resources and physical habitats of aquatic ecosystems. Major land use types-urban, rural residential, agriculture, forestry, transportation systems- impose predictable structure and rates of ecological change on longitudinal patterns of channels and riparian vegetation. Each of these land use types and corresponding institutional behaviors are characterized by distinct spatial patterns of resources, timing of riparian alteration, duration of effects, and magnitude of impacts on vegetation, channel, and flow. Conversion of native riparian forests will simplify habitat and food resources, leading to lower abundance and richness of aquatic communities.

Our research in Cascade Mountain streams and development of fish abundance models demonstrated that the presence of floodplains along smaller streams also was a major determinant of fish communities. [11;3;4] Abundances of fish were significantly correlated to riparian forest conditions, but models only predicted 22% of the variance in abundance based on local conditions. In the model of salmonids abundance by D'Angelo et al., our models accounted for more than 55% of the variance in salmonids abundance if floodplain conditions were included.

Empirical relationships between human land use and ecological measures of complexity will be determined from field studies of a floodplain river and its major tributaries. We have identified trajectories of change in floodplain geomorphology and riparian forests for the Willamette River and lower tributaries from 1850 to the present and we have projected future changes through 2050. Composition, richness, evenness, distribution, and abundance of riparian plant and fish communities will be measured in high priority river reaches. This research will complement similar measurements used under a National Science Foundation grant to sample representative habitats of the Willamette River floodplain, but this project will focus on reaches identified in the conservation and restoration prioritization process. Aquatic and riparian habitats will be measured in river reaches that exhibit different patterns of 1) riparian floodplain forest, 2) human land use in the upstream basin, and 3) geomorphic channel type. Field studies will focus on major tributaries to the mainstem Willamette River and sections of the mainstem floodplain. Based on prior EPA research, sampling of selected reaches has demonstrated significant linkages between intact riparian forests and richness of fish communities and accumulations of large wood (Fig. 6).

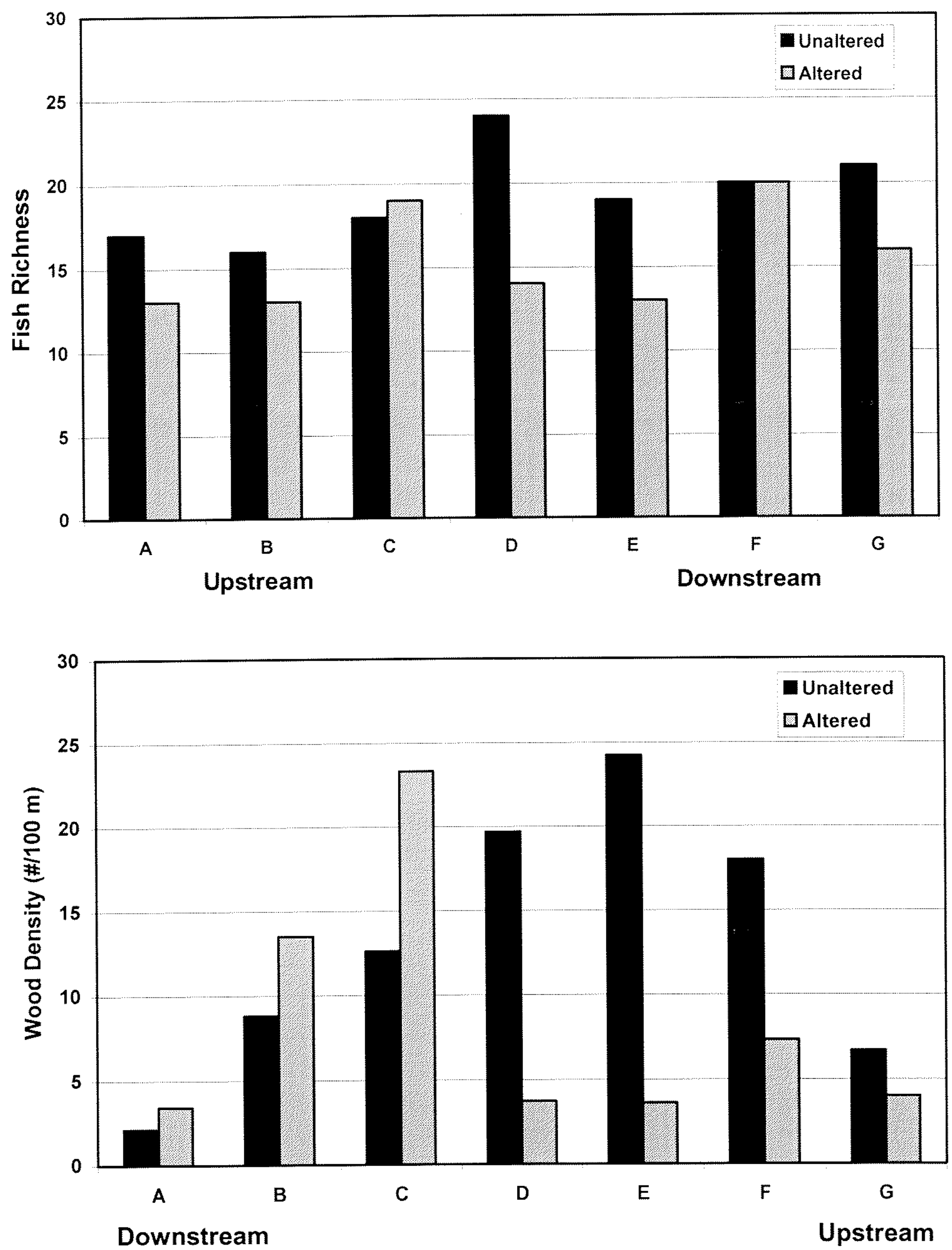


Fig. 6. *Differences in richness of fish communities and standing stocks of large wood in seven paired reaches of the Willamette River with intact floodplain forests and converted floodplains.*

Floodplain Plant Communities: The fundamental properties of riparian plant communities used to quantify complexity are 1) composition, 2) richness, 3) evenness, and 4) connectivity. Floodplain riparian plant communities will be sampled based on a stratified random selection of patch types as determined from satellite images and air photos. Within representative patch types for the major reaches, vegetation patch structure will be measured from satellite classifications and air photos. Patches will be subsampled in the field to determine composition of the plant communities. Sampling intensity will vary with the size and spatial heterogeneity of the patch type. Within each patch, overstory composition and structure will be quantified in terms of canopy cover, stem density, and diameter distribution by species. Canopy-height diversity will be calculated within each plot. Cover of herbaceous and woody species and numbers and heights of vegetation layers will be recorded to characterize the vertical structure of the vegetation. Fish assemblages: Fundamental properties of riverine fish communities will be used to quantify complexity: 1) richness, 2) evenness, 3) abundance, and 4) percent exotic species. In addition, external tumors, lesions, and abnormalities will be determined to measure stressors related to human activities. Fish communities will be sampled in the same reaches used to characterize the riparian vegetation. All sites will be sampled over a reach length of 1 km and the tributary junctions or side channels will be located in the middle of the 1-km reach. Fish assemblages will be sampled for species richness using a combination of collecting methods (boat electroshocking, beach seines, electroshocking microhabitats). Sampling duration and effort will be standardized so that relative abundances can be calculated for measures of evenness and H', realizing that gear selectivity and differential species and life history vulnerability to capture will affect estimates. Fish sampling will record frequency and types of abnormalities and relate these patterns to land use practices and point source discharges within the floodplain. In addition, relative composition of native and exotic fish species in different reach types and habitats will be determined as an additional measure of human impact and habitat alteration. Habitat characteristics (large wood, depth, velocity, substrate, and water chemistry) will be measured.

In years 3 and 4, a random stratified sampling program will be established to augment existing databases on habitat conditions and fish abundances. Habitat and fish populations will be sampled in these reaches using standard EMAP protocols. Estimates of fish populations from rapid approaches for electroshocking will be validated using both mark recapture methods and multiple pass removal methods of fish population assessment. Our research recently has shown that the population estimators are sensitive to habitat complexity and traditional approaches (multiple pass removal) and rapid protocols (single pass removal) must be calibrated with mark-recapture methods and general linear modeling. Study reaches will be selected from the ranges of anadromous salmonids so that both resident and anadromous salmonids will be included in the field measurement of fish populations. We will evaluate relationships between local fish abundance and land cover and human influence in upstream riparian areas and the entire basin upstream of a local reach. These data on relationships between fish abundance and local habitat conditions will then be used to project potential fish abundances along all perennial streams and streams within the range of anadromous salmonids.

Tier 3 products

1. Relationships between fish communities and local habitat conditions in floodplain rivers
2. Relationships between fish communities and local habitat conditions in tributary streams

Significance of research contributions

The central effort of this proposal is to 1) employ patterns of land cover and land use at a Tier 1 level to track status and trends over space and time; 2) use the spatial and temporal context produced from this analysis to test three spatial constructs for organizing Tier 2 attribute data, 3) statistically determine the strength of relationship between LULC data in each Tier 2 construct with 4 field-sampled Tier 3 response variables, and 4) transfer the Tier 1 classification approach and change-tracking lessons learned to either the John Day or Wenatchee subbasin.

The significant contributions of this research are:
• Pilot testing an operational and transferable approach for integrating monitoring and evaluation at Tier1, 2, and 3 levels;
• Refining Tier 1 LULC classification and change tracking approaches;
• Quantifying strength of correlations between hydrogeomorphic, anadromous fish distribution and riparian zone constructs and Tier 3 response variables.

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c. Rationale and significance to Regional Programs

This proposed work directly addresses calls for the development of broadscale salmonid population and habitat monitoring programs in the NWPPC's Fish and Wildlife Program (NWPPC 2000), CBFWA's Program Summaries for the Mainstem/Systemwide Province (Jordan et al. 2002), Federal Caucus Basinwide Salmon Recovery Strategy (Federal Caucus 2000,) and the NMFS Biological Opinion on the Operation and Maintenance of the Federal Columbia River Power System (NMFS 2000). Of particular relevance are the requests for proposals to help meet BPA's obligations under the NMFS FCRPS Biological Opinion for a monitoring program for listed anadromous salmonids in the Columbia River basin (statusmonitorrpa180.pdf, FutureNeeds.pdf, GapAnalysis.pdf).

According to Jordan et al. (2002) Tier 1 Ecosystem Status Monitoring will address two general questions: what is the distribution of adult salmonid fishes, and what is the ecosystem status for Columbia River Basin (CRB) fish populations. This proposed research will directly address the latter general question. Specifically, a landscape scale characterization of land use and land cover, stream and road networks, and land ownership in various Columbia River basin subbasins will be the targeted endpoint. When completed, this project and its methodologies can be applied to all other subbasins in the Columbia River basin as necessary.

In addition, RPAs 9, 180, 181, 198, of the FCRPS Biological Opinion directly address the responsibilities of the Action Agencies and other regional entities for the development of system-wide fish and habitat status monitoring. In addition to information needed to address these population level questions for ESA listed populations, the Action Agencies and the region will require information to assess progress toward performance standards for the hydro corridor and for tributary, mainstem, and estuary habitat conditions. This proposed LU/LC classification scheme will meet much of the aforementioned information needs by giving planners and scientists alike powerful tools for assessing the condition of and predicting future of habitat conditions vital to ESA listred species. Furthermore, the geospatial datalayers that will be generated will easily be supported by and integrated into a regional data management system that facilitate the collection, analysis and dissemination of the monitoring data.

d. Relationships to other projects

The proposed work builds on recently completed land use / land cover (LU/LC) data development in the Willamette River subbasin, and extends those lessons to other subbasins in the Columbia River basin. Specifically, it links time series LU/LC data to field data to strengthen correlative and causative understandings of change in riparian and aquatic resources.

e. Project history (for ongoing projects)

(Replace this text with your response in paragraph form)

f. Proposal objectives, tasks and methods (See Technical Background)

1) Create a LU/LC ca. 2000 coverage for the Willamette Basin using refinements to the approach used in the PNW-ERC that created LU/LC ca. 1990. This would be the information base for Tier 1 monitoring.

2) Update, extend and refine monitoring on the ground/river in floodplain of Willamette River, anadromous fish distributions, and riparian areas for perennial streams for population and habitat status for key fish species.

3) Monitor floodplain variables at higher spatial and temporal resolution on the ground/river to quantify effects of select set of floodplain and riparian restoration projects in Willamette floodplain and riparian areas of tributary streams.

4) Use lessons learned from Willamette subbasin work to prepare Tier 1 LU/LC data for either John Day or Wenatchee basin.

g. Facilities and equipment

A computing workstation ($15,000) is requested for the data development team in Year 1 and Year 4. The grad student positions will require a work station for data development support starting in Year 1. In addition, LU/LC data synthesis and applications to large spatial databases will require development of code and applications for supercomputing, necessitating additional computer support late in Year 3 or early in Year 4. Each of the three laboratories (OSU data management and field research, UO GIS laboratory, and USFS remote sensing laboratory) will require funds each year ($5,000 per laboratory in Years 2-5) for computer hardware, software, and storage media (Note: storage requirements for the large array of spatial databases, web-based assessable databases, primary data are large).

Supplies and services budgets average $13,000. This includes costs of field supplies for two crews, computer supplies, photocopying, phones, mailing, meetings, and routine operating costs. In addition, supplies and services includes operating costs, engine repair, and fuel for boats. Our recent research on the Willamette required $1,500 per month for gasoline and boat supplies and $2,500 per year for boat, engine, and shocker repair. Field costs account for approximately $10,000 of the projected annual costs for supplies and services.

h. References

References for technical background included with text

Reference (include web address if available online)	Submitted w/form (y/n)
http://oregonstate.edu/dept/pnw-erc/	N

Reference (include web address if available online)	Submitted w/form (y/n)
Federal Caucus, 2000. Conservation of Columbia Basin Fish: Final Basinwide Salmon Recovery Strategy. Vol. 1 & 2. http://www.salmonrecovery.gov/strategy_documents.shtml	N
Jordan, C.E. and 15 co-authors 2002. Mainstem/Systemwide Province Stock Status Program Summary. Guidelines for Conducting Population and Environmental Status Monitoring. February 22, 2002. Prepared for the Northwest Power Planning Council. http://www.cbfwa.org/files/province/systemwide/subsum/020515StockStatus.pdf	N
National Marine Fisheries Service (NMFS). 2000. Federal Columbia River Power System Biological Opinion: Reinitiation of Consultation on Operation of the Federal Columbia River Power System, Including the Juvenile Fish Transportation Program, and 19 Bureau of Reclamation Projects in the Columbia Basin. NMFS-NWR, Seattle, WA.	N
Northwest Power Planning Council. 2000. 2000 Columbia River Basin Fish and Wildlife Program, a multi-species approach for decision-making, November 30, 2000, Council document 2000-19. Portland, Oregon. http://www.nwcouncil.org/library/2000/2000-19/index.htm	N

Section 10 of 10. Key personnel

Project Duties: (Principal investigator/research coordinator)

Education:
- Ph.D., Fisheries Science, University of Washington, Seattle, WA, 1999.
- M.S., Fisheries Science, University of Washington, Seattle, WA, 1991.
- B.S., Zoology, University of Wisconsin, Madison, WI., 1986.

Employer: National Marine Fisheries Service, Northwest Fisheries Science Center, Environmental Conservation Division, Watershed Program.

Position: Statistician (Biology), NMFS employee since 1999.

Present assignment: I am responsible for designing and participating in research in two areas: the relationship between various fish populations and their terrestrial/estuarine habitat; and the interaction between non-indigenous species and estuarine food webs and ecosystems. I use a landscape scale approach for most of my research, but I am also interested in the effect of climate, spatio-temporal scaling, and various anthropogenic influences.

Previous research/expertise: I am a spatial ecologist, but I have extensive experience in basic ecology, ethology, neurobiochemistry, and biology. My doctoral research focused on the spatio-temporal dynamics of the invasion of a non-indigenous aquatic plant in Pacific Northwest estuaries. For my master's research, I examined the impact of industrial noise on the estuarine ecology of juvenile Pacific salmon. I have published my research in the peer reviewed literature and I am frequently invited to present at scientific symposia. In addition, I have given numerous guest lectures at the University of Washington, on topics ranging from spatial ecology to GIS technology.

Relevant Publications:

Feist, B.E., E.A. Steel, G.R. Pess, and R.E. Bilby,. What is the correct scale for habitat analyses aimed at prioritizing restoration efforts for salmon? Animal Conservation. In Review.

Feist, B.E., and E.O. Box. 2002. Vegetation and Ecosystem Mapping. In: Encyclopedia of Science and Technology. McGraw-Hill publishers, New York, NY (invited). In Press.

Levin, P.S., S. Achord, **B.E. Feist**, and R.W. Zabel. 2002. Non-indigenous brook trout and the demise of Pacific salmon: a forgotten threat? Proceedings of the Royal Society of London - Biology. In Press.

Pess, G.R., D.R. Montgomery, R.E. Bilby, E.A. Steel, **B.E. Feist**, and H.M. Greenberg. 2002. Correlation of landscape characteristics and land use on coho salmon (*Oncorhynchus kisutch*) abundance, Snohomish River, Washington State, USA. Canadian Journal of Aquatic and Fisheries Science. 59:613-623.

Feist, B.E., and C. A. Simenstad. 2000. Expansion rates and recruitment frequency of exotic smooth cordgrass, *Spartina alterniflora* (Loisel), colonizing unvegetated littoral flats in Willapa Bay, Washington. Estuaries. 23(2):267-274.

Simenstad, C.A., and **B.E. Feist**. 1996. Restoration potential of diked estuarine wetlands: Inferring fate and the recovery rate of historically-breached sites. EPA 910/R-96-005. 115 p.

Christopher E. Jordan, Ph.D.
Mathematical Biology and Systems Monitoring, Program Manager
NMFS Northwest Fisheries Science Center
2725 Montlake Blvd. E.
Seattle, WA 98112

Education:

University of Washington	Ph.D.	1994	Zoology
University of Chicago	B.A.	1985	Biology, with honors

Positions Held:

Program Manager	NOAA/NMFS/NWFSC, Seattle,	2002 - present
Operations Research Analyst	NOAA/NMFS/NWFSC, Seattle	1999 - 2002
Research Assistant Professor	Washington State Univ., Pullman	1999 - present
Assistant Professor	University of Colorado, Boulder	1995 - 1999
Research Associate	University of Chicago, Chicago	1994 - 1995
Research/Teaching Assistant	University of Washington, Seattle	1987 - 1994

Mathematical and Biological Publications:

Jordan, C.E. 1992. A model of rapid starting intermediate Reynolds number swimming: Undulatory locomotion in the chaetognath Sagitta elegans. *J. exp. Biol.* **163**, 119-137.

Daniel, T.L., C.E. Jordan, and D. Grunbaum. 1992. Hydromechanics of animal locomotion. In: *Mechanics and Energetics of Animal Locomotion, Advances in Comparative and Environmental Physiology, Vol. 11.*, pp. 17-49. ed. R.McN. Alexander. Springer Verlag, Berlin.

Jordan, C.E. 1996. Coupling internal and external mechanics to predict swimming behavior: a general approach? *Amer. Zool.*, **36**(6):710-722.

Steinberg, E.K. and C.E. Jordan. 1997. Using genetics to learn about the ecology of threatened species: the allure and the illusion of measuring genetic structure in natural populations. In: Conservation Biology. eds, P. Fiedler and P. Kareiva. Chapman Hall, New York.

Katz, S.L. and C.E. Jordan. 1997. A case for building integrated models of aquatic locomotion that couple internal and external forces. In: Proceedings of the 10th International Symposium on Unmanned Untethered Submersible Technology: Bioengineering. AUSI, Durham, NH.

Jordan, C.E. 1998. Scale effects in the kinematics and dynamics of swimming leeches. (**76**(10):1869-1877, Can. J. Zool.)

McClure, M. M., Sanderson, B. L., Holmes, E. E. & Jordan, C. E., (2001). A large-scale, multi-species risk assessment: Anadromous salmon in the Columbia River Basin. Ecol. Apps. In Review

Philip R., C.E. Jordan, M.C. Liermann, and A.E. Steel. (2002) Monitoring design: important considerations for developing monitoring of aquatic restoration. In review

ABBREVIATED CURRICULUM VITA

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Education
1981 B.S.L.A. Colorado State University, College of Forestry and Natural Resources. Ft. Collins, Colorado
1984 M.L.A. (Distinction) Harvard University Graduate School of Design. Cambridge, Massachusetts

Honors
1985 Fulbright Scholar
1989 Young Researcher Award of Distinction, Council of Educators in Landscape Architecture
1994 President's Service Award, American Society of Landscape Architects

Employment

1999-present	Professor, University of Oregon
1995-2000	Department Head, Dept. of Landscape Architecture, University of Oregon
1990-1999	Associate Professor, University of Oregon
1985-1990	Assistant Professor, University of Oregon
1984-1985	Visiting Assistant Professor, Universita' di Firenze, Florence, Italy

Selected Recent Professional Service
Science Advisor - Grand Canyon Research and Monitoring Center, 2001-present
Consortium on Biodiversity and Land Use, 2001-present
State of The Environment Report Science Panel, State of Oregon 1998-2000.

Selected Recent Publications
D. HULSE, S. GREGORY, J. BAKER. (EDS). (2002) Willamette River Planning Basin Atlas: Trajectories of environmental and ecological change. (2nd edition), Oregon State University Press, Corvallis, Oregon 97333. 180 p.

D. HULSE and S.V. GREGORY (2001) Alternative Futures as an integrative framework for riparian restoration of large rivers, chapter 9 in Applying Ecological Principles to Land Management, V.H. Dale and R. Haeuber (eds.). Springer-Verlag, New York. Pp. 194-212. ISBN 0-387-95099-0.

D. HULSE and R. RIBE (2000) Land conversion and the production of wealth. Ecological Applications. 10(3). Pp. 679-682.

D. HULSE, J. EILERS, K, FREEMARK, D. WHITE, C.HUMMON (2000) Planning alternative future landscapes in Oregon: evaluating effects on water quality and biodiversity., Landscape Journal 19(2): 1-19.

GREGORY, S.V., D.W. HULSE, D.H. LANDERS, E. WHITELAW (1998) Integration of biophysical and socio-economic patterns in riparian restoration of large rivers, in Hydrology in a Changing Environment, H. Wheater and C. Kirby (eds.), vol. I, Theme 2 Ecological and hydrological interactions, D. Gilvear editor, John Wiley and Sons, Chicester. pp. 231-247.

R. RIBE, R. MORGANTI, D. HULSE, R. SHULL (1998) A management driven investigation of landscape patterns of northern spotted owl nesting territories in the high Cascades of Oregon. Journal of Landscape Ecology. 13: pp. 1-13.

D. HULSE, L. GOORJIAN, D. RICHEY, M. FLAXMAN, C. HUMMON, D. WHITE, K. FREEMARK, J. EILERS, J. BERNERT, K. VACHE, J. KAYTES and D. DIETHELM (1997) Possible Futures for the Muddy Creek Watershed, Benton County, Oregon. Institute For A Sustainable Environment., University of Oregon., Eugene, Oregon 97403. 90 pp.

K. FREEMARK, C. HUMMON, D. WHITE and D. HULSE (1996) Modeling risks to biodiversity in past, present and future landscapes., Technical Report No. 268, Canadian Wildlife Service, Headquarters, Environment Canada, Ottawa K1A 0H3. 60 pp.

Recent Research Support and Collaborators

- National Science Foundation Biocomplexity Program., "Interactions of riparian pattern, policy and biocomplexity in coupled human/riverine systems"., Oregon State University and the University of Oregon., 2001 - 2005. $560,000.
- U.S. Environmental Protection Agency., "Pacific Northwest Ecosystem Research Consortium"., A multi-university consortium consisting of Oregon State University, the University of Oregon, and the University of Washington. 1995 - 2001. $1.84 million.
- National Science Foundation/U.S. Environmental Protection Agency – NCERQA., "Ecological, Demographic and Economic Evaluation of Opportunities and Constraints for Riparian Restoration". 1997 - 2001. $373,000.
- National Science Foundation/U.S. Environmental Protection Agency – NCERQA., "Establishing correlations between upland forest management practices and the economic consequences of stream turbidity in municipal supply watersheds". 1997 – 2001. $320,000.

Research Collaborators of the past five years

Stan Gregory, Dixon Landers, Ed Whitelaw, Kathy Freemark, Joe Eilers, Denis White, John Bolte, Steve Polasky, Warren Cohen, Gordon Grant, Rick Edwards, Joan Baker, John Van Sickle, Court Smith

Graduate Student Thesis Advisees of the past five years

David Richey, Susan Payne, Maureen Raad, Hilary Dearborn, Lisa Goorjian, Kate Kirsh

Own Graduate Advisors

Carl Steinitz, Laurie Olin, John Stilgoe

CURRICULUM VITA

STANLEY V. GREGORY
Department of Fisheries & Wildlife
Oregon State University
Corvallis, OR 97331

I. Educational Background

B.S. 1971. Zoology. University of Tennessee
M.S. 1974. Fisheries. Oregon State University
Ph.D. 1980. Fisheries. Oregon State University

II. Professional Experience

1993 - present	Professor. Fisheries and Wildlife, Oregon State University
1986 - 1993	Associate Professor. Fisheries and Wildlife, OSU
1981 - 1986	Assistant Professor, Research. Fisheries and Wildlife, OSU
1977 - 1981	Leader of Field Research Station - Corvallis. Columbia National Fishery Research Laboratory, U.S. Fish and Wildlife Service

III. Interdisciplinary Studies

Dr. Gregory has been involved in the development of interdisciplinary ecological studies at Oregon State for two decades. He has participated in the International Biological Program and is a co-principal investigator of the Long-Term Ecological Research Program at the H.J. Andrews Experimental Forest. Dr. Gregory has directed the stream research program informally known as the Stream Team since 1986. This interdisciplinary research program has been recognized for its contributions in teaching and research by the College of Agricultural Sciences, the College of Forestry, and the U.S. Forest Service.

IV. Selected Publications

Hulse, D., and S.V. Gregory. 2001. Alternative futures as an integrative framework for riparian restoration of large rivers. In: V.H. Dale and R. Haeuber (eds.). Applying Ecological Principles to Land Management. Springer-Verlag, New York.

Hulse, D., S.V. Gregory, and J. Baker. 2002. Willamette Basin Atlas: Trajectories of environmental and ecological change. Oregon State University Press, Corvallis, Oregon.

Gregory, S.V. 1996. Riparian management in the 21st century. Pages 69-83. In: J. Franklin (ed.). Forestry for the Twenty-First Century. Island Press, Washington, D.C.

Gregory, S.V., and P.A. Bisson. 1996. Degradation and loss of anadromous salmonid habitat in the Pacific Northwest. P. 277-314. In: D. Stouder and R.J. Naiman (eds.). Pacific Salmon and their Ecosystems: Status and Future Options. Springer-Verlag.

Gregory, S.V., F.J. Swanson, A. McKee, K,W. Cummins. 1991. Ecosystem perspectives of riparian zones. BioScience 41:540-551.

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EDUCATION

Ph.D., 1989, Colorado State University, Forest Science (Remote Sensing & Wildland Fire)
M.S., 1984, University of Maine, Forest Science (Remote Sensing)
B.S., 1978, Northern Arizona University, Forest Science (Forest Management)

RELEVANT WORK EXPERIENCE

1989-Present. Research Forester/Ecologist and Director of the Laboratory for Applications of Remote Sensing in Ecology, PNW Research Station, USDA Forest Service, Corvallis, OR. I conduct research in remote sensing and related geographic and ecological sciences. My primary focus is translation of remote sensing data into useful ecological information, with significant activity in analysis and modeling of vegetation structure and composition across multiple biome types. My research involves spatially-explicit modeling of ecological processes with significant attention to scaling from fine to coarse grain. I am Assistant Professor (courtesy) in three departments at Oregon State University (Forest Science, Geosciences, and Computer Science), where I intermittently teach a graduate level remote sensing and landscape ecology course, advise graduate students as both major and minor professor, serve on interdepartmental committees, and give guest lectures and seminars.

SELECTED REFEREED JOURNAL ARTICLES AND BOOK CHAPTERS (60 total)

Cohen, W.B., T.A. Spies, and G.A. Bradshaw. 1990. Semivariograms of digital imagery for analysis of conifer canopy structure, *Remote Sensing of Environment*, 34:167-178.

Cohen, W.B., P.N. Omi, and M.R. Kaufmann. 1990. Heating-related water transport to intact lodgepole pine branches. *Forest Science* 36:246-254.

Cohen, W.B. 1991. Chaparral vegetation reflectance and its potential utility for assessment of fire hazard, *Photogrammetric Engineering and Remote Sensing*, 57:203-207.

Cohen, W.B. 1991. Response of vegetation indices to changes in three measures of leaf water stress, *Photogrammetric Engineering and Remote Sensing*, 57:195-202.

Cohen, W.B. and T.A. Spies. 1992. Estimating structural attributes of Douglas-fir/western hemlock forest stands from Landsat and SPOT imagery, *Remote Sensing of Environment,* 41:1-17.

Cohen, W.B., T.A. Spies, and M. Fiorella. 1995. Estimating the age and structure of forests in a multi-ownership landscape of western Oregon, USA, *International Journal of Remote Sensing*, 16:721-746.

Cohen, W.B., M.E. Harmon, D.O. Wallin, and M. Fiorella. 1996. Two recent decades of carbon flux from forests of the Pacific Northwest, USA: preliminary estimates, *BioScience* 46:836-844.

Cohen, W. B., M. Fiorella, J. Gray, E. Helmer, and K. Anderson. 1998. An efficient and accurate method for mapping forest clearcuts in the Pacific Northwest using Landsat imagery, *Photogrammetric Engineering & Remote Sensing* 64:293-300.

Turner, D.P., **W.B. Cohen**, R.E. Kennedy, K.S. Fassnacht, and J.M. Briggs. 1999. Relationships between leaf area index and Landsat TM spectral vegetation indices across three temperate zone sites, *Remote Sensing of Environment* 70:52-68.

Milne, B.T. and **W.B. Cohen**. 1999. Multiscale assessment of binary and continuous landcover variables for MODIS validation, mapping, and modeling applications, *Remote Sensing of Environment*

Lefsky, M.A., **W.B. Cohen**, S.A. Acker, G.G. Parker, T.A. Spies, and D. Harding. 1999. Lidar remote sensing of the canopy structure and biophysical of Douglas-fir western forest, *Remote Sensing of Environment* 70:339-361.

Turner, D.P., **W.B. Cohen**, and R.E. Kennedy. 2000. Alternative spatial resolutions and estimation of carbon flux over a managed forest landscape in western Oregon, *Landscape Ecology* 15:441-452.

Oetter, D.E., **W.B. Cohen**, M. Berterretche, T.K. Maiersperger, and R.E. Kennedy. 2001. Land cover mapping in an agricultural setting using multiseasonal Thematic Mapper data, *Remote Sensing of Environment* 76:139-155.

Cohen, W.B., T.K. Maiersperger, T.A. Spies, and D.R. Oetter. 2001. Modeling forest cover attributes as continuous variables in a regional context with Thematic Mapper data, *International Journal of Remote Sensing* 22:2279-2310.

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Cohen, W.B., T.A. Spies, R.J. Alig, D.R. Oetter, T.K. Maiersperger, and M. Fiorella. 2002. Characterizing 23 years (1972-1995) of stand replacement disturbance in western Oregon forests with Landsat imagery, *Ecosystems* 5:122-137.

Langford, B.T., T.G. Dietterich, and **W.B. Cohen**. In press. Examples of significant sensitivity of a landscape pattern metric to errors in land-cover classification, *Remote Sensing of Environment.*

Lefsky, M.A., **W.B. Cohen**, D.J. Harding, G.G. Parker, S.A. Acker, and S.T. Gower. In press. Lidar remote sensing of aboveground biomass in three biomes, *Global Ecology and Biogeography*.

Hudak, A.T., M.A. Lefsky, and **W.B. Cohen**. In press. Integration of lidar and Landsat ETM+ data for estimating and mapping forest canopy height, *Remote Sensing of Environment.*

Kennedy, R.E. and **W.B. Cohen**. In press. Automated designation of tie-points for multiple-image coregistration, *International Journal of Remote Sensing*.