

PROFILE

Landscape-Level Ecological Regions: Linking State-Level Ecoregion Frameworks with Stream Habitat Classifications

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ABSTRACT / Regionalization is a form of spatial classification, where boundaries are drawn around areas that are relatively homogeneous in landscape characteristics. The process of delineating ecological regions, or ecoregions,

includes the analysis of ecosystem structure. To date, ecoregions have been developed at national and state scales for research and resource management. Stream classification is another method to order the variability of aquatic habitats that spans spatial scales from microhabitat to valley segment. In this study, landscape-level ecoregions are developed for the upper Grande Ronde River basin in northeastern Oregon, 3000 sq km in area. The ecoregion framework presented here is proposed to bridge the gap between stream habitat and state-level ecoregion classifications. Classification at this scale is meant to address issues of management at local scales: to aid in sampling design, in extrapolation of the results of site-specific studies, and in the development of best management practices that are more predictive of ecosystem response than current methods.

It is only human to take the complexity of the natural environment, incomprehensible in its variety, and try to make it ordered and simple. Classification is one human attempt to create order out of apparent chaos. Through classification, objects are divided into groups according to similarities, relationships, or hierarchies (Warren 1979, Platts 1980). Working within a tested classification system, researchers can generalize, extrapolate, and predict with greater confidence.

Ecological regionalization is a form of spatial classification. It is the process by which boundaries are drawn around relatively homogeneous areas at a specific scale or level of detail. The delineation of ecoregions includes the analysis of ecosystem structure. Ecoregional boundaries indicate where significant changes are occurring in landscape characteristics. The changes may be either gradual or abrupt, but, because the process of regionalization creates discrete areas out of a continuum, the resulting region boundaries are approximations. Ecore-

gions are models of reality; their boundaries represent a transition area of varying width.

Ecoregional schemes developed in the United States and Canada either focus on the terrestrial aspects of ecosystems (Krajina 1965, Wiken 1986) or attempt to integrate terrestrial and aquatic systems (Lotspeich and Platts 1982, Bailey 1983, Omernik 1987). The rationale for a terrestrial/aquatic integration is that streams are a reflection of the watersheds that they drain. The climate, geology, and soil of an area determine the substrate, seasonal discharge, channel morphology, and chemical properties of the waterbody. The vegetation type and its extent also influence water quantity as well as its temperature and clarity.

Stream classification is an attempt to organize the variability of aquatic habitats at a more site-specific level, i.e., at spatial scales from stream microhabitats to geomorphic valley types. The grouping of basins into ecoregions having similar geology, topography, soil, and vegetation allows a comparison of streams of similar size across a relatively homogeneous area.

The purpose of our study was to extend Omernik's ecoregion framework to another more detailed level in the classification hierarchy—the landscape-level ecoregion. Regions at this scale capture the variability missed

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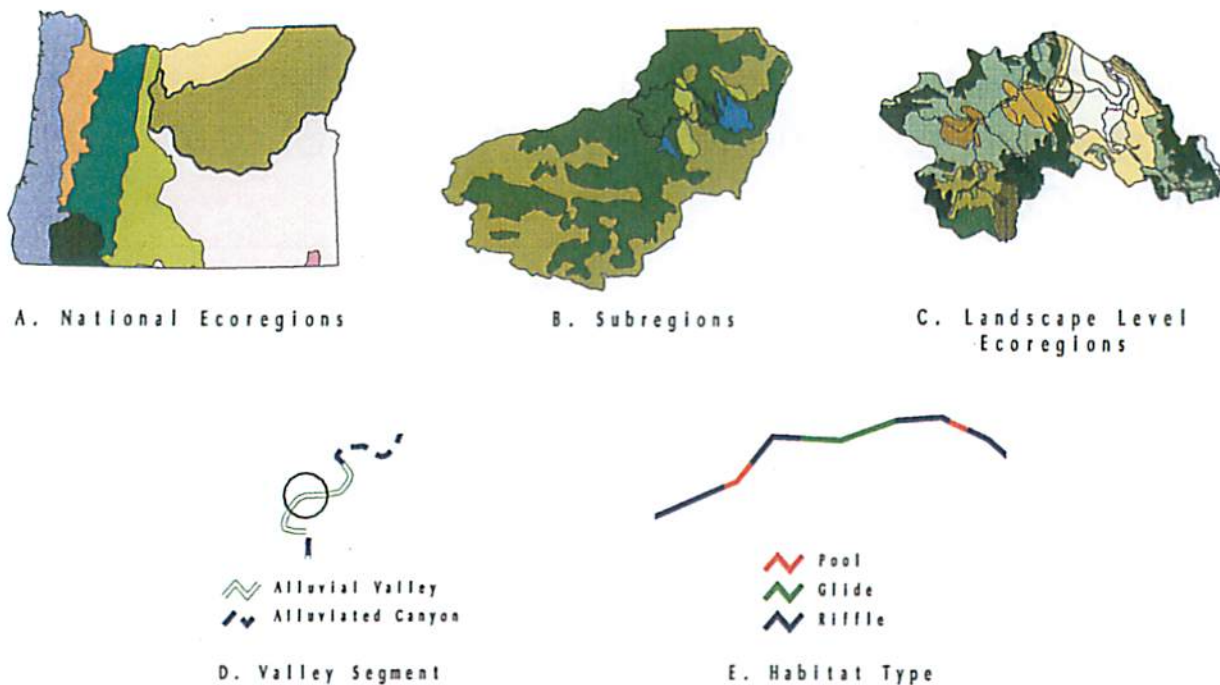


Figure 1. Hierarchical levels of ecoregions and stream classifications.

at the coarser detail of state-level subregions (Figure 1c). They encompass the territory of more local management decisions, i.e., a river basin or national forest. The landscape-level ecoregions provide the ecosystem context at a scale within which individual streams may be characterized using stream habitat classifications. This project in the upper Grande Ronde River watershed of northeast Oregon was a pilot to test the methodology to develop regions at the new scale.

Linking Two Classifications Systems

Ecoregion Framework

Omernik's ecoregion framework spans a five-tier hierarchy. Levels I and II, recently revised in cooperation with environmental agencies in Canada and Mexico, illustrate continental-scale macroregions (Omernik 1995a). The US Environmental Protection Agency (EPA), in cooperation with various state agencies, initially used Omernik's national ecoregion framework, level III, to assess the quality of aquatic resources and to set biocriteria for water quality (Omernik 1987). However, as planning for biocriteria evolved, researchers realized that for state-level management regional differences were better explained by reducing variability even

more, that is, by further subdividing ecoregions into subregions (level IV).

Subregionalization has been done at a 1:250,000 scale for the states of Colorado (Gallant and others 1989), Florida (Griffith and others 1994a), Iowa (Griffith and others 1994b), Oregon (Clarke and others 1991, Thiele and others 1992, Thiele and Omernik 1993), and parts of Alabama and Mississippi (Alabama Department of Environmental Mangement 1995).

In 1990 the Ecoregions Subcommittee of the Science Advisory Board, a public advisory group providing scientific information and advice to EPA, reviewed the ecoregion concept. They found it "a defensible classification technique for large areas . . . that is superior to the classification methods that are currently used by most environmental managers" (US Environmental Protection Agency 1991). The subcommittee recommended that the hierarchical subdivision of ecoregions be taken to even higher resolution, to that of local management decisions, which would encourage the incorporation of large quantities of existing site-specific research data into the ecoregion framework. This pilot project was undertaken, with these recommendations in mind, to test whether ecoregions at the landscape-level would be feasible over large areas, both in terms of cost and time expenditure.

Stream Classification

Stream biologists, working up in scale from an individual stream reach, have problems simply defining the boundaries of their sphere of interest. The sample area may include a square meter of riffle, a pool-riffle sequence, a reach, a segment, or an entire drainage. Scale changes cause problems in selecting comparable sampling sites or in extrapolating information from a particular pool or riffle to a watershed or other geographical area (Minshall 1988). Water resource managers then face the wider problem of applying the results of these site-specific studies to broader-scale resource planning and management.

A variety of stream habitat classifications have been developed to respond to these issues. Many of these classifications place stream habitat features in a geomorphic context, recognizing that processes operating at broad scales over time affect stream ecosystem structure and function. Lithology and channel geomorphology shape biological community structure (both instream and riparian) by influencing habitat structure, water quantity and chemistry, and the transport and availability of nutrients (Brussock and others 1985, Gregory and others 1991, Frissell and others 1986). Platts (1974) recognized this terrestrial/aquatic connection when he classified streams in Idaho using channel characteristics and bank conditions as well as geomorphic types. He and Lotspeich expanded this idea to a general framework by proposing a classification system based on parts of several frameworks in existence at the time (Lotspeich and Platts 1982). Frissell and others (1986) developed a hierarchical framework that included five scales of stream habitat systems from microhabitat to watershed; their intent was to place the stream habitat in its geographical context and to eventually connect the stream classification to a broad-scale, biogeoclimatic land classification system as suggested by Warren (1979). White Horse Associates (1992), a consulting firm, used seven hierarchical levels to classify riverine/riparian habitats of the Five Mile Creek basin in the Umatilla National Forest, Oregon. They also perceived the need to place the classification in a multiscale context, doing so by connecting a detailed stream habitat classification with a hybrid regional framework patterned after Wertz and Arnold's (1972) controlling factor scheme at midscale levels and Omernik's (1987) national scale ecoregion at the coarsest scale.

Linking Ecoregion and Stream Classification

Landscape-level ecoregions are developed at a resolution fine enough to eliminate much of the variability still present in state-level ecoregions. One could continue in

this vein and attempt to subdivide the terrestrial landscape at an even finer scale. However, we suspect that regions at finer scales than landscape-level would require detailed data that are not readily available over broad areas. There is also a point of diminishing returns where small homogeneous areas become part of the noisy tapestry of individual phenomena. An alternative approach at finer scales is to mesh the multivariate classification system, i.e., ecoregions, with a thematic classification, such as vegetation associations or stream classifications.

In this project, landscape-level regions link Omernik's ecoregional framework to detailed stream classifications (Frissell and others 1986, Cupp 1988, White Horse Associates 1992, Montgomery and Buffington 1993, Rosgen 1994). For example, the stream classification system developed by Frissell and others (1986), and its derivative, developed by Cupp (1988), were designed to mesh with a land classification system at the valley segment level of their hierarchy (Figure 1). Valley segments identify stream variability within ecoregions through differences in valley bottom and side-slope geomorphological characteristics (Cupp 1988) (Figure 1d). However, at the time that these stream classifications were developed, an ecoregional framework did not exist to span the full range of scales from national level to local level.

Landscape-level ecoregions fill the gap that existed between stream habitat classification and state-level subcoregions; they merge with stream habitat classifications at the valley segment level (Figure 1c and 1d) and provide the geographic context for stream classification. Stream channel differences in gradient, constraint, and substrate may be identified within ecoregion areas of relatively homogeneous landscape characteristics.

The combination of a land classification with a stream habitat classification gives a predictive capacity to management decisions, through the assumption that a subpopulation of streams within a relatively homogeneous region will respond similarly to a specific type of management. Stream ecologists can compare natural variability, reference conditions, impact gradients, and restoration potential across groups of similar streams identified within an ecoregion at a chosen scale.

Development of Landscape-Level Ecoregions

The Study Area

Our project was an outgrowth of an historical study done by the US Forest Service, Pacific Northwest Research Station, on the upper Grande Ronde River and other Pacific Northwest rivers. Habitat conditions re-

ported on these rivers from 1935–1941 were compared with current, resurveyed conditions to estimate the loss of anadromous fish habitat (McIntosh and others 1994). In recent decades, fish stocks have been reduced to a small fraction of their former numbers (Williams and others 1989, Nehlsen and others 1991, Frissell 1993). We developed the landscape-level ecoregions to attempt to recreate the extent and character of the landscape drained by the upper Grande Ronde River and its tributaries. With this information, land managers can guide restoration efforts with an estimate of presettlement reference conditions. We define reference condition as the character of the river basin before logging, grazing, agriculture, and mining degraded the terrestrial, riparian, and aquatic habitats.

The upper Grande Ronde River basin lies in the northern Blue Mountains of northeastern Oregon between 45° and 46°N latitude, 117°45' and 119°45'W longitude. This area is at the southern edge of the Columbia Plateau, which was submerged during the Miocene epoch, between 17 and 6 million years ago, by massive basalt flows (Baldwin 1976, Baker and others 1991). Since then, the region has undergone vertical faulting and uplift as the Blue Mountains developed. The climate of the region is continental and temperate with hot, dry summers and cold winters; precipitation accumulates between 33 and 80 cm annually (13–32 in.), with upper elevations receiving greater amounts, much of it as snow (Barrash and others 1980).

The study area included the headwaters of the Grande Ronde River and its tributaries as well as the watershed of Catherine Creek to the southeast. The upper elevations of both watersheds are managed by the US Forest Service. Both streams flow from elevations of 2000 m (6600 ft) down to the broad agricultural Grande Ronde valley near La Grande, Oregon. The total watershed area is approximately 3000 sq km (1150 sq mi) measured upstream from the vicinity of Imbler, Oregon (Figure 2).

Materials

The map layers used for the regionalization of the Upper Grande Ronde River basin were soil, historic and present-day vegetation, geology, and topography. Draft maps at 1:250,000 scale from a new series of soils maps (STATSGO) were acquired from the US Soil Conservation Service (SCS, recently renamed Natural Resources Conservation Service). These were supplemented by existing county-level 1:24,000 scale soil maps and text (USDA 1985) and a preliminary Wallowa–Whitman National Forest Soil Survey. A present-day vegetation map of Oregon funded by the US Fish and Wildlife Service was also available in preliminary draft form from the

Idaho Department of Water Resources (Kagan and Caicco 1992). Historic forest type maps (Andrews and Cowlin 1936, USDA 1957); a national-scale, potential natural vegetation map (Kuchler 1970); and literature about the vegetation communities of the Blue Mountains (Johnson and Clausnitzer 1992, Hall 1973, Franklin and Dyrness 1973) completed the vegetation information. A 1:500,000 scale geology map (Walker and McCleod 1991) of the state of Oregon, two local 1:250,000 scale maps (Walker 1973, 1979), and two reports on local geology (Hampton and Brown 1964, Barrash and others 1980) comprised the geology data. Aerial photographs of the upper Grande Ronde basin and the Catherine Creek area from 1937, 1956–1957, 1970, and 1984 provided an historical cross-reference to land cover changes. Finally, US Geological Survey (USGS) topographic maps, at 1:250,000 and 1:100,000, were indispensable to interpret land surface form, drainage patterns, contour intervals, gradient, aspect, and elevation. The ecoregion boundaries were delineated using the topographic maps as base maps at both 1:250,000 and 1:100,000 scales, but the 1:100,000 scale maps were used for the final digitized regions.

Methods

The size, complexity, and variability of land management units preclude the creation of ecoregions inductively by extrapolation of available site-specific information. Available data are generally project-specific, not spatially distributed, and collected with nonstandardized sampling methods. Extrapolation of site-specific information is not possible until it is determined that the site is representative of a group of sites. By using a “top-down” approach to develop ecoregions, the process is reversed. Available landscape data provides a continuous fabric of information to illustrate landscape patterns. Once relatively homogeneous areas are identified, knowledge gained from specific projects may be organized within them.

Ecological regions are developed through the integration of multiple data sources, such as climate, geology, vegetation, soil, and topography. Because they are constructed through the use of many data sources, ecoregions do not have a specific theme, and thus have the potential for general application. Although ecoregions may not explain the response of any single ecological element, such as a particular species distribution, they do represent an area of integrated ecosystem potential.

Ecoregional mapping methods differ in the ways that the multiple component variables are applied at various scales. In one method, the controlling factor method, the region delineated is an interpretation of the result of particular ecological processes operating at each level

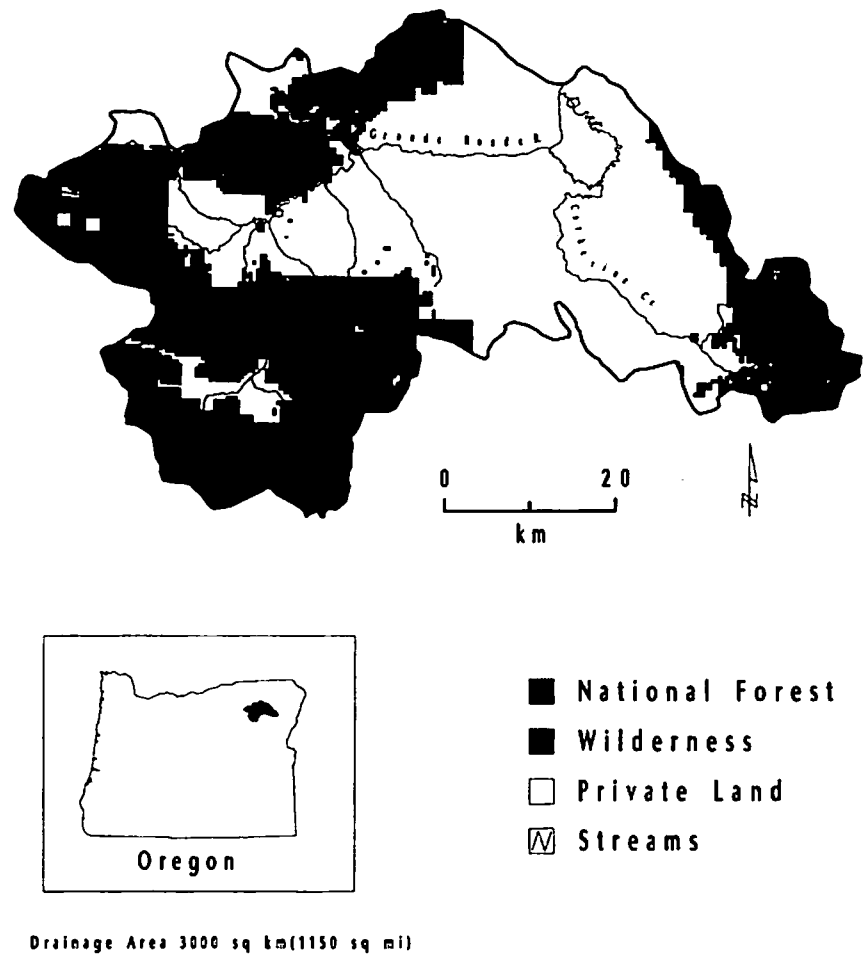


Figure 2. Location of the study watershed.

of resolution (Wertz and Arnold 1972, Bailey 1983). A single controlling factor, e.g., climate or climax vegetation, guides the search for homogeneous areas at each level of the hierarchy. The alternate method of regionalization, the multivariate method, detects the pattern of the influence of ecological process on a full array of landscape characteristics at each scale or level of resolution (Wiken 1986, Omernik 1987).

Bailey's ecoregional framework (1983) employs climate as the dominant controlling factor at the coarser scales. Changes in climate at these scales readily identify differences in ecosystems. Climate may be a major force in shaping ecosystems; however, accurate climate information is scarce at any scale. Weather station location is biased toward developed areas, and weather data are too sparse for precise mapping (Lotspeich and Platts 1982). In the absence of climate information, potential vegetation and soil information must then be employed as surrogates for climate to differentiate ecosystems.

There are those who would argue that climate is not the controlling factor that influences all other factors,

but is in itself controlled by feedback mechanisms from the biosphere. For example, daily maximum and minimum temperatures are controlled by gaseous emissions and by transpired water vapor. A substantial fraction of inland rainfall is the result of vegetative rather than oceanic evapotranspiration and can be considered recycled rain (Hayden 1996). The atmosphere has been created in large part by such feedback and is maintained by a continual flux of gases from the biosphere (Love-lock 1979).

In various classifications patterned after Wertz and Arnold's Land Systems Inventory of 1972 (Lotspeich and Platts 1982, White Horse Associates 1992), geology is the primary controlling factor at the second coarsest level of the hierarchy. Depending upon how the controlling factor system is applied within a particular scale, the selected controlling factor, geology in this case, may not identify differences among ecosystem types. There is a danger that the focus on geology at one level in the hierarchy could produce a single theme map for that scale rather than an integrated ecoregion map.

On the other hand, geology is certainly important to ecoregion delineation. In areas such as the Coast Range of Oregon, it can be the dominant factor among climate, soil, vegetation, or physiography in making ecoregional boundary decisions (Thiele and others 1992). Elsewhere, for example in Iowa, geological considerations are minor; surficial deposits and soil factors tend to dominate among the collection of landscape characteristics (Griffith and others 1994b).

The approach used in this study, the multivariate method, integrates all available landscape information at all levels of the hierarchy. Thus, the boundary decisions may differ from one side of a region to another depending upon the shifting dominance of the various landscape characteristics, e.g., vegetation, soil, topography, or geology. The rationale here is that important information may be missed at any scale if one does not consider the full range of landscape characteristics. For example, on the lee side of a mountain range, the upper foothill boundary may be determined by a drop in precipitation, the rain shadow effect, and a change in vegetation. At the lower foothill boundary, where the foothills meet the valley floor, physiographic and soil criteria tend to dominate.

The mapwork is completed by drawing the lines directly onto 1:100,000 scale topographic maps for digitization, correcting for topography where appropriate, to produce a precise line. Map analysis is only one aspect of this approach, however. An extensive literature review adds an understanding of regional-level ecosystem processes to guide line placement. In addition, collaboration with regional experts from state and federal agencies and academia has the dual benefit of introducing field experience into the process, plus allowing input from those who might use the final product. Finally, it is up to the geographer to integrate the disparate information from the map analysis, the literature review, and the experience of regional experts to create the final map. The product is not the result of the mechanical overlay of maps; the computerized geographic information system is a tool to aid in analysis and final graphic display of the regions. It does not have a role in making line decisions except to allow viewing of landscape data at a common scale. No computer can yet match the myriad critical judgements that are made based on research and experience. Expert judgement is a major factor in producing these maps. Any map is an interpretation or model of reality; it may not be appropriate to subject the result to a laboratory-style criterion of reproducibility. Interestingly, however, we have found that biogeographers trained in the multivariate system independently produce regional boundaries that are remarkably similar. Further discussions of the ecoregion

methodology used in this project may be found in Omerik (1987, 1995b), Gallant and others (1989), and Clarke and others (1991).

In the final analysis, the two methods of ecoregion delineation are really more similar than different. They have the common objective of creating a model of the potential capability of a system, assuming little or no human impact. Both use a measure of expert judgement. The landscape data sources employed by the two methods are the same. The controlling factor scheme uses multiple variables as surrogates when controlling factor data are incomplete. The major difference is that the controlling factor system applies rules a priori to compartmentalize the application of knowledge and experience of ecological process, while the practitioner of the multivariate system ranges across the entire spectrum of available information to decide which landscape characteristics dominate in line placement.

Boundary Decisions

Eighteen landscape-level ecoregions have been delineated for the upper Grande Ronde basin (Figure 3). Boundaries mark changes occurring in the physical characteristics of adjacent ecosystems. Work at each level of resolution requires decisions about the level of detail that is appropriate to the major issues and management needs of the area. However, the complete group of ecoregions may not be useful in every situation. Depending upon the objectives of a particular project, managers can aggregate regions as needed. For example, distinctions between basaltic, granitic, or tuffaceous substrates may be important to projects concerned with fish habitat, water yield, or streambank erosion. Researchers involved with terrestrial wildlife habitat, on the other hand, may choose to aggregate the geologic areas and concentrate instead on the elevational or aspect conditions of the mesic, xeric, and subalpine forest areas.

Boundary decisions begin with obvious breaks between distinctive heterogeneous areas. For example, the boundary between the Colluvial Slope and the Lacustrine Deposits regions was a clear demarcation between distinctive areas. The geology, topography, and soil type lines were nearly coincident at the valley floor. Other regional boundaries, not so readily apparent, had an underlying rationale that was the result of integrating written information with spatial patterns.

Boundary decisions in areas with high human impacts pose particular problems in the classification process. Ecological regions are developed on the basis of potential capability, i.e., a model of a presettlement condition provides a yardstick against which present-

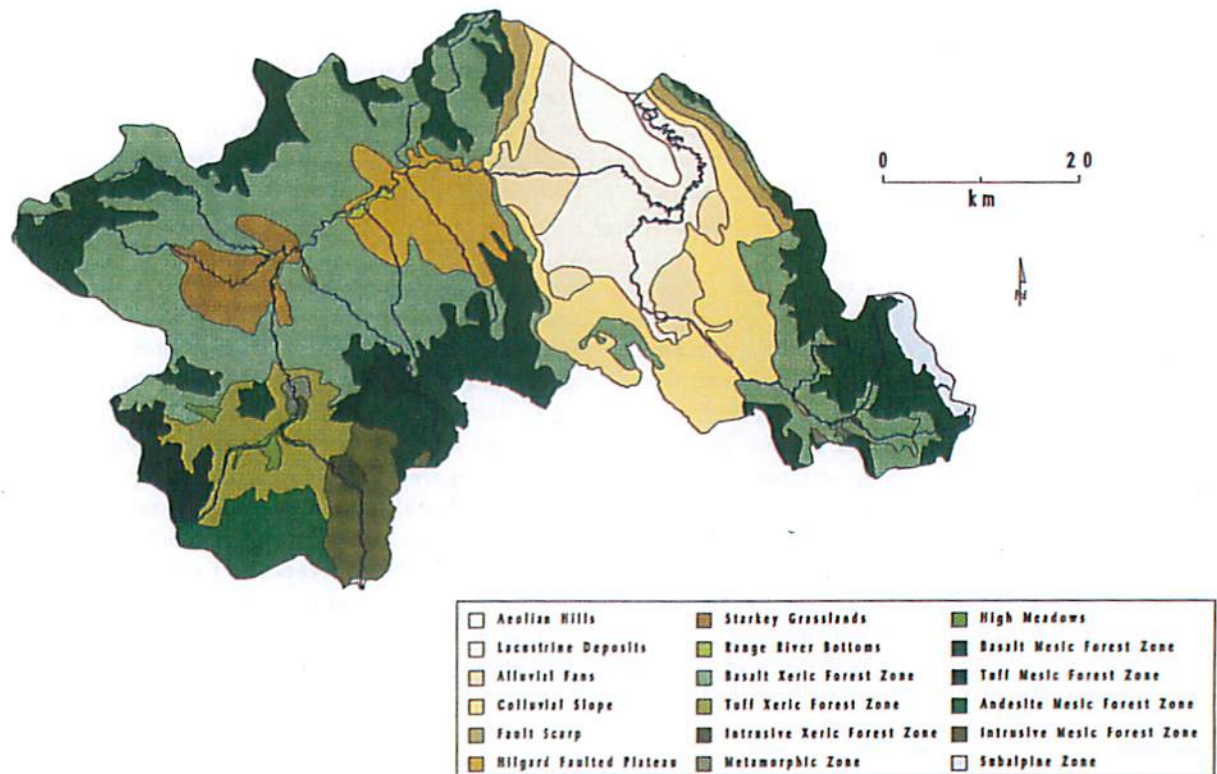


Figure 3. Landscape-level regions of the Upper Grande Ronde River basin.

day condition is measured. The preimpact regional description provides a model for restoration efforts even if heavy human use precludes returning to a pristine condition (Hughes and others 1990). In areas of extensive agriculture or resource extraction, particularly when early maps are not available, it is necessary to trace the history of development.

Timber cutting, fire suppression, and land clearing for grazing cattle have occurred in the Grande Ronde basin since the mid-19th century (Robbins and Wolf 1994). These activities have blurred the boundaries between forest types. Selective cutting and later clear-cutting of ponderosa pine (*Pinus ponderosa*), with accompanying soil disturbance and fire suppression, allowed the advance of Douglas fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), and Englemann spruce (*Picea engelmannii*) beyond their normal range into lower elevation, drier sites (Skovlin 1991). Thickets of second growth Douglas fir, larch (*Larix occidentalis*), lodgepole pine (*Pinus contorta* Dougl. ex Loud.), and grand fir create a different forest community than the one mapped by the National Forest Service in 1936 (Andrews and Cowlin 1936). The altered forest spans an area between the former higher elevation forest of grand fir and lodgepole pine and the open ponderosa pine forest at

lower elevations (Hall 1973, Franklin and Dyrness 1973). Insect pests devastated fir thickets throughout the 1980s (Skovlin 1991). Salvage logging will most likely change the forest character yet again. These changes in the character of the forest made the boundary between the original upper elevation, mesic forest zones and the xeric forest difficult to determine. The boundary had to be reconstructed from early forest type maps, vegetation texts, soil, elevation, precipitation and aspect information. As a result, the boundary not only marks a transition zone, but it is an expression of an historical situation that no longer exists. With the historical model as a guide, policy makers and land managers can plan affordable restoration efforts that measure incremental improvement toward the ultimate goal, even though that goal, the presettlement condition, may never be reached.

Evaluation and Applications

Evaluating the Regional Model

An ecoregional classification should be tested to show that it has ecological significance (Rowe and Sheard 1981, Bailey 1984, Larsen and others 1986). However,

expectations for classification schemes may vary among reviewers and users. Ecoregion boundaries may be regarded by some as hypotheses that are either true or false, or they may be seen as tools, to be judged by their ability to accomplish particular tasks. As a hypothesis, the regional framework ought to have some measure of representational accuracy; as a tool it ought to have utility (Warren 1979). Any evaluation of a regional model should incorporate both elements.

To test the representational accuracy of a regional classification system, researchers require spatially distributed data, such as fish distributions, physical habitat, or water-quality information. Unfortunately, available information of this nature is often limited and spotty in its distribution for any particular region. The ideal situation is to design a sampling program to collect sufficient spatially distributed data.

Careful site selection tailored to the scale of the regions, plus a complete analysis of biotic, physical habitat, and water-quality data provide a more robust evaluation and illuminate relationships at varying scales. The redundancy and overlap found in a full range of analyses lend corroborating evidence to any regional patterns in the data. In the evaluation studies of Omernik's national ecoregion framework (level III) in Oregon, Ohio, and Arkansas, results from fish faunal distributions were combined with additional analyses of abiotic factors, such as physical habitat and water quality (Larsen and others 1986, Rohm and others 1987, Whittier and others 1988). Time and budget constraints often preclude such a complete, customized evaluation of a regional model; however, if available data must be used to evaluate a regional framework, limitations should be recognized from the outset.

Regions at a subregional scale (level IV) have been tested once in a watershed in western Oregon, where fish species assemblages corresponded well with subregion lines separating the mountain, foothill, and valley portions of the watershed (Omernik and Griffith 1991). There was not sufficient funding for this project to evaluate the landscape-level ecoregions. However, a companion project to this pilot produced landscape-level regions for seven additional contiguous watersheds in northeast Oregon and southeast Washington state with an evaluation of the regions for fish habitat using stream habitat information (Clarke and Bryce, in review).

The ultimate test of a regional classification is in its application and usefulness (Warren 1979, Omernik 1995b). The pertinent questions then are: have the objectives for the classification been met? Does the ecoregion classification lead to a better understanding of the system? explain and order the natural variability? provide a framework for sampling and management?

allow the extrapolation of site specific information? lend a measure of predictability of ecosystem response to land use practices (Warren 1979, Gallant and others 1989, Clarke and others 1991)? The opinions of those who try to use the framework in the field are an important evaluation source of information. Unrealistic ecosystem boundaries will not survive the test of implementation.

Applications

The development of ecoregion classifications is timely considering the general movement toward ecosystem management within federal land management agencies. Following President Clinton's April 1993 Forest Conference, various federal agencies proposed initiatives to address problems in the Pacific Northwest with endangered species, remnant old-growth forests, poor forest health, and declining anadromous fish runs. The interagency Forest Ecosystem Management Assessment Team (FEMAT) report (Thomas and Raphael 1993) lists four components of an aquatic conservation strategy: the establishment of *riparian reserves* and *watershed refugia*, and *watershed analysis* as a foundation for *watershed restoration*. The Eastside Forest Ecosystem Health Assessment and the Eastside Scientific Panel are addressing similar forest problems in eastern Washington, Oregon, Idaho, Montana, and northern California (Everett and others 1993, Henjum and others 1994). The political pressures of these national initiatives initiated a demand for spatial frameworks to help plan research and recovery efforts (Bailey and others 1994).

Ecoregion classification at the subregional and landscape levels will contribute to watershed analysis by identifying groups of watersheds similar enough to respond to management and restoration efforts in a more predictable fashion. In addition, sets of stream reference sites identified in each region, representing the natural condition, provide a model for stream restoration.

The development of landscape-level ecoregions is continuing with two research projects funded by federal agencies charged with maintaining anadromous fish runs within the Columbia River drainage in the Pacific Northwest. The Bonneville Power Administration (BPA) is required by law to restore fish runs to a predetermined level to compensate for losses incurred at dams on the Columbia River. The BPA has sponsored landscape-level regionalization of a number of watersheds in northeastern Oregon and southeastern Washington (Clarke and Bryce, in review). Ecoregions will help determine expected habitat conditions. The National Marine Fisheries Service (NMFS) is also funding research to evaluate landscape-level ecoregion boundaries using existing fish habitat survey data for the entire drainage of the Grande Ronde River and four other river basins in Oregon

and Washington for which landscape-level regions have been completed.

Conclusions

Ecological regionalization is a form of spatial classification where boundaries are drawn around areas with similar landscape characteristics. Ecoregions are created from the top down to relate landscape pattern to ecosystem structure. Stream classification, on the other hand, is done rather inductively, moving from the particular to the general. Stream physical habitat elements at various scales are cataloged and fit into the geomorphic structure of the surrounding valley types. Stream and ecoregion classification were on a generally convergent pathway, but a gap existed between valley segment classifications and state-level ecological subregions. The object of this study was to bridge the gap between the two frameworks by extending Omernik's ecoregion methodology to landscape-level applications, to a scale of more localized land management decisions.

Adapting the ecoregional classification to a higher resolution is a new exercise. As ecoregions are developed at finer detail, they may be applied to new uses. The predominant use for ecological regions at the state level (level IV) is to establish biocriteria, reference sites, and attainability goals for water-quality regulation. Regions at the landscape level will continue to fulfill water-quality monitoring needs. Ecoregions at all hierarchical levels also have potential as a terrestrial management tool for planning, resource management, cumulative effects studies, restoration efforts, and biodiversity assessment.

As a framework for research and planning, ecoregions provide a natural complement to drainage basins. Both basins and ecoregions should be employed to adequately explore spatial patterns and management options. Spatial differences in landscape characteristics, ecosystems, or environmental resources are not often partitioned by topographic divides (Omernik and Griffith 1991). River basins, especially in areas of some relief, often straddle several ecoregions (Figure 4). They are too heterogeneous to clearly explain resource patterns. For example, a small headwater stream has more in common with streams in different basins in the same ecoregion (Figure 4a), than with another small tributary at a lower elevation in the same basin, but in a different ecoregion (Figure 4b).

Fish distribution patterns and chemical and physical habitat measures have been shown to be better explained by an ecoregional framework than a basin framework (Hughes and others 1987, 1994, Omernik and Griffith 1991). Basin frameworks are useful for re-

search involving fish distribution patterns, nutrient cycling, conservation of fish stocks, or watershed pollution loadings. Neither framework should be stretched beyond its ability to explain variability and patterns in the data.

An ecoregional framework assists in using inventory data more effectively; it ensures that sites within a region will be comparable and that site-specific results may be extrapolated to a wider area. The stratification of sites and sampling information into relatively homogeneous groups reduces apparent variability and increases precision in data analysis.

The usefulness of regions to land managers lies in the assumption that a subpopulation of streams or terrestrial sites within a relatively homogeneous area will respond similarly to a specific type of management. This gives a predictive capacity to management decisions and aids in the development of best management practices. Relating condition and attainability to the underlying capability of the system contributes to the search for the probable causes of condition. Once probable causes of degradation are identified, managers can set priorities for cost-effective restoration. Ecoregional frameworks, applied at appropriate scales, will conserve the limited time and extend the limited fiscal resources of land management agencies.

By organizing the complexity of the natural world at an accessible scale, the landscape-level regional framework will be a powerful management tool. While evaluation efforts will require time, interdisciplinary effort, and an extensive sampling program, the best test of the framework's validity in the meantime will be in its utility in cost-effective monitoring and assessment programs and in setting attainable goals for restoration efforts.

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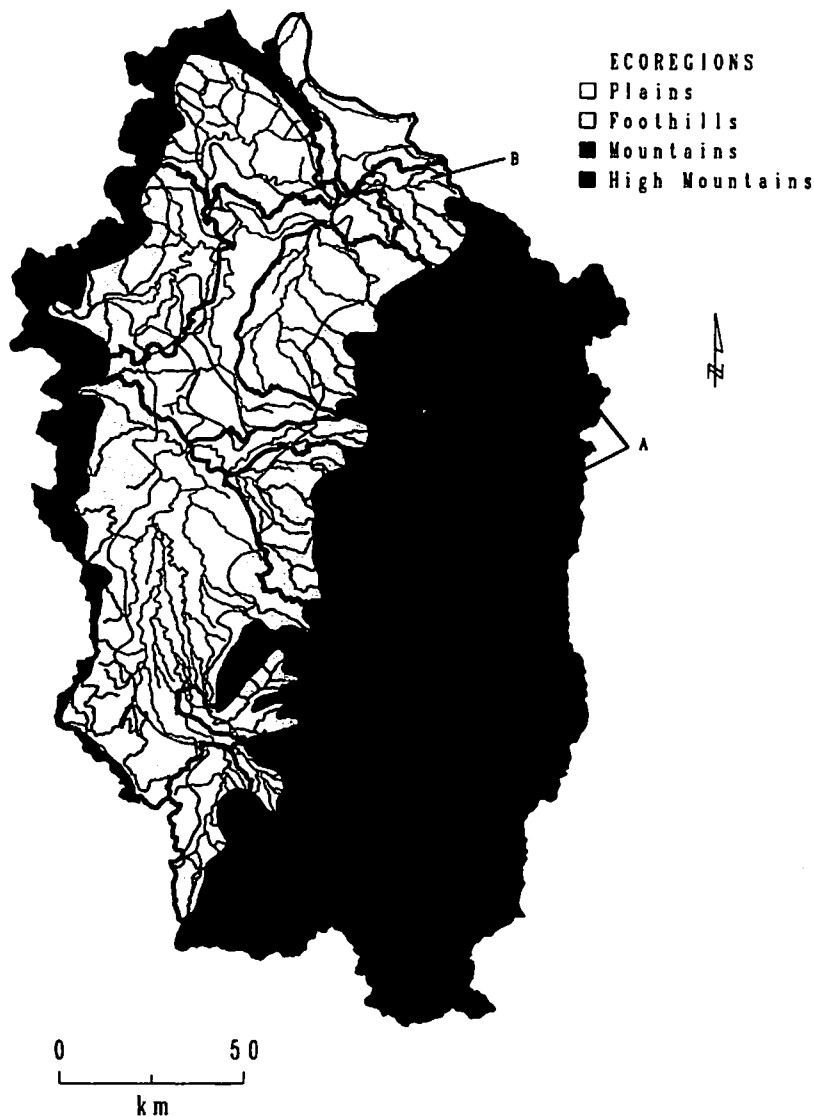


Figure 4. Ecoregion and watershed frameworks overlaid. Headwater streams in neighboring basins (a) and a low-elevation tributary stream (b).

Laboratory in Corvallis, Oregon, through contract 68-C4-0019 to ManTech Environmental Research Services Corporation. It has been subjected to the agency's peer and administrative review and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. The research has also been funded in part by the US Forest Service grant PNW 90-481.

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Appendix

Description of Landscape-Level Ecoregions

The relative importance of determining factors in regional boundary decisions may change depending upon the objectives of a project. The objectives of this project were to develop regions with a view toward fish

habitat. However, because these regions were developed through a collection of landscape characteristics, they should prove useful for other purposes as well. Boundaries of the landscape-level regions described below define discrete areas of potential natural capability, but the regional descriptions also include present-day land-use and resource activities. The landscape-level regions are illustrated in Figure 3.

Alluvial Fans, Lacustrine Beds, Aeolian Hills

The Grande Ronde valley near La Grande, Oregon is a broad, flat valley at an elevation of approximately 785–850 m (2600–2800 ft). The climate is semiarid, with annual precipitation amounts varying between 32.5 cm (13 in.) in the dry southern valley to 60.0 cm (24 in.) at the eastern end of the valley. The valley lies in a down-faulted graben that once was a lakebed. Three landscape-level regions comprise the Grande Ronde Valley:

Alluvial fans are found where the Grande Ronde river and other major streams enter the valley and drop their sediment load. The sloping alluvial fans have the best drained soil for cultivation, and they are the location for the major town sites in the Grande Ronde valley (Hampton and Brown 1964).

Lacustrine beds cover the largest area of the valley. They are poorly drained, having once been submerged under shallow lakes and wetlands before the canal and drainage systems were built. The reclaimed land is used for hay, commercial grass seed, or pasture.

Aeolian hills are composed of wind-deposited materials derived from basalt and loess. In these areas the soil is deep and well drained. Ten-mile-long Sand Ridge stands 6–27 m (20–90 ft) above the level of the valley. The undulating region of loess has no permanent streams (Hampton and Brown 1964).

The historic meandering drainage pattern of the Grande Ronde River has been changed by extensive channelization that now separates the river from its floodplain. Landowners have diverted many tributary streams as well. Most areas in the valley support irrigated agriculture, winter wheat, alfalfa, peas, bluegrass seed, and pasture. Restricted channels are often downcut with steep eroding banks. Vegetation in areas not cultivated consists of bunchgrasses and annual forbs. In more natural areas, the riparian vegetation includes willows (*Salix* sp.) and cottonwoods (*Populus trichocarpus*). The valley boundaries are distinctively marked where the base of the colluvial slope meets the valley floor.

Fault Scarp, Colluvial Slope

The Fault Scarp region occurs on basalt blocks that have broken off subsequent to vertical faulting and formation of the valley graben. The Colluvial Slope is talus

and colluvial soil deposited at the base of the fault scarp. Elevations of the region range from 830 to 1000 m (2722–3280 ft). Precipitation amounts vary from 32.5 to 60.0 cm annually (13–24 in.), with more moisture occurring in the upper elevations at the forest margin. Springs are common along the margin of the colluvial slope, issuing from the fractured substrate. The soil of the Fault Scarp, formed in loess and volcanic ash on slopes of 5%–40%, is too thin and stony for cultivation. The thin soil does not support trees on drier south-facing slopes. Wheatgrass (*Agropyron spicatum*), fescue (*Festuca idahoensis*), and shrubland make this area suitable for grazing or wildlife habitat. Soil, substrate, and vegetation are similar for this region and the next two regions; however, the distinguishing features here are steep gradient and irregular land surface. The upper boundary of the Fault Scarp is marked by the forest margin and by a drop in elevation to the irregular scarp surface. The upper boundary of the Colluvial Slope is marked by the top of the band of talus and colluvial soil at the base of the fault scarp. The sharp transition to the valley floor alluvium and lacustrine deposits marks the lower boundary of the colluvial slope.

Hilgard Faulted Plateau

The Faulted Plateau is a block of uplands dissected by numerous northwest trending vertical faults. It is created by slightly northwesterly dipping basalt flows south of the Grande Ronde River meeting southeasterly sloping flows on the north side of the river. Elevations range from 700 to 1500 m (2300–5000 ft). Precipitation amounts vary from 35.5 to 76.0 cm annually (14.2–30.4 in.), with the bulk of it falling as snow. The thin, stony soils are derived from bedrock and support mainly grasses such as wheatgrass (*Agropyron spicatum*) and fescue (*Festuca idahoensis*). As a result, the predominant land use is grazing. Trees, mostly ponderosa pine (*Pinus ponderosa*) below 1200–1360 m (4000–4500 ft), follow the drainages or occur on pockets of forest soil. Because they are incised in the fault lines, the stream channels of the plateau follow a trellis pattern. The trees in the riparian areas are confined to the incised drainages, creating a more shaded streambed and, thus, the potential for cooler water temperatures than would be expected in an open grassland. The dominant substrate is cobble (10–30 cm) and large gravel (1–10 cm). The plateau perimeter is bounded by the transition to continuous forest cover and the change in topography to forested mountain ridges.

Starkey Grasslands

The Starkey Grasslands are rolling uplands at an elevation of 1050–1250 m (3500–4125 ft). Precipitation

ranges from 35.5 to 76.0 cm annually (14.2–30.4 in.), most of it accumulating as snow. The region has been grazed heavily by livestock since the 1840s (Skovlin 1991). This area has soil and vegetation similar to the previous region, the Hilgard Faulted Plateau. The difference lies in the absence of vertical faulting in the basalt substrate, which gives a more random, rolling quality to the landscape. The drainage pattern is dendritic. Years of grazing pressure have created low, wide streambanks with little riparian cover and elevated water temperatures. The dominant substrate is cobble (10–30 cm). In areas not so heavily grazed, the riparian cover includes willows (*Salix* sp.), cottonwoods (*Populus trichocarpa*), and alder (*Alnus* sp.). The transition to forest cover at upper elevations marks the boundary of the Starkey Grassland.

Range River Bottom

Several disjunct areas form the range river bottom, the alluvial flats, and lower terraces of the Grande Ronde River and its major tributaries. These areas were delineated on the basis of alluvial soils and flat topography. Although the river bottom areas are not large, they influence the river ecosystem in terms of productivity and human impact. They are found at elevations of 950–1150 m (3116–3772 ft). In isolated areas the soil is suitable for cultivated crops, such as alfalfa, although in the Starkey Grasslands the river bottom is used mainly for grazing. Even in these grazed areas, the streams are not free of the effects of channelization. McCoy Creek, a tributary of the Grande Ronde River, was extensively channelized following a flood in 1964. The complex system of meanders and marshes was cut off from the stream channel (McIntosh and others 1994). In fenced cattle enclosures, the riparian cover returns to willows (*Salix* sp.) on tributary streams. The dominant substrate is cobble (10–30 cm). The boundaries of the disjunct river bottom regions are determined by the extent of alluvial soil.

High Meadows

The Sheep Creek and Fly Creek meadows are high elevation (1250–1350 m) alluvial flats that have a high water table. Most pool habitats, so important to anadromous salmonids for refuge and rearing, are found in unconstrained reaches such as these meadow areas. Here the valley bottom is wider, and the stream, if not channelized, has a more dynamic interaction with its floodplain and riparian areas. The altitude and year-round moisture make these areas unsuitable for cultivation, but they are grazed heavily by cattle. The streambanks are composed of fine alluvial soil. Riparian vegetation, if present, is willow (*Salix* sp.). The meadow

boundaries are determined by the margin of the forested slopes.

Basalt Xeric Forest Zone, Tuff Xeric Forest Zone

The xeric forest corresponds roughly to the ponderosa pine zone, areas where creeping ground fires kept forests open and free of shrubs until the era of extensive timber cutting and fire suppression. The topography is rolling to steep (slopes 3%–60%) at elevations of 900–1500 m (3000–5000 ft). Precipitation amounts range from 35.5 to 76.0 cm annually (14.2–30.4 in.), most of it accumulating as snow. The major distinction between these two regions is that in the Tuff Xeric Forest, the geology is pyroclastic, soft tuff; in the Basalt Xeric Forest Zone, the geology is basalt, andesite, hard rhyolite, and hard tuff. In both areas, the soil erodes easily if disturbed, although the presence of rock fragments in the basaltic soils makes it less erodible. The major land use is grazing and timber harvest. The riparian vegetation in ungrazed areas is willow (*Salix* sp.) and cottonwood (*Populus trichocarpa*). In grazed areas, only the larger trees survive and banks are eroded and downcut. The dominant substrate is large gravel (1–10 cm) and cobble (10–30 cm). The lower boundary of these regions has been affected by land clearing for grazing and agriculture. The upper boundary is no longer visible because of the encroachment of true firs (*Abies* sp.), Englemann spruce (*Picea englemannii*), and larch (*Larix occidentalis*) into lower elevations. As a result, the region boundaries are a model of an historical condition.

Basalt Mesic Forest Zone, Tuff Mesic Forest Zone, Andesite Mesic Forest Zone

The higher elevation mesic forest is found at 1350–2000 m (4500–6500 ft), where annual precipitation levels increase to 62.5–87.5 cm (25–35 in.) and moisture stress is minimal. Grand fir (*Abies grandis*) stands are interspersed with lodgepole pine (*Pinus contorta* Dougl. ex Loud.) and western larch (*Larix occidentalis*), which generally repopulate burned areas. Fires at these elevations were more likely to be conflagration fires (Skovlin 1991), unlike the cooler, creeping fires of the ponderosa pine forest. This zone extends into lower elevations near springs or on cooler north-facing slopes with ashy soils, particularly in stream canyons. The boundary between this region and the open forest zone has been blurred by large areas of larch and Douglas fir (*Pseudotsuga menziesii*) thickets invading dryer areas, a result of logging and fire suppression practices over the last 100 years. The distinctions between the geology of the basalt and tuff zones are the same as described for the xeric regions above. The Andesite Mesic Forest Zone is in an area of

conflicting geologic information. It may be included with the tuff or basalt zones at some future date after sufficient field work has clarified the geologic character of the landscape.

Metamorphic Zone

The Grande Ronde River and its tributaries are highly constrained in this area with tributary junctions at right angles to the river. The elevation varies from 1150 to 1350 m (3772–4428 ft). Precipitation amounts range from 35.5 to 76.0 cm annually (14.2–30.4 in.). The region is composed of volcanic and sedimentary rock that is partly metamorphosed to schists, greenstones, and quartzite (Hampton and Brown 1964). Other areas of this rock type in the Blue Mountains of Oregon occur at the edge of granitic zones. The Grande Ronde River has cut through the resistant metamorphosed rock to create a deep canyon as the region was uplifted. The vegetation in the grazed forest is typical of the xeric forest zone. Boundaries of the region were determined by the extent of the metamorphosed rock. The region is quite small; only after an evaluation of the regions through sampling will it become clear whether the area is large enough to have an effect on the biota.

Intrusive Xeric Forest Zone, Intrusive Mesic Forest Zone

In an area that is composed almost entirely of basalt, changes in substrate can be significant in terms of stream physical habitat, as well as geomorphology and vegetation type. In the intrusive zone, the rocks are mainly quartz diorite (Hampton and Brown 1964). The granitic stream substrate takes the form of large boulders or sand, with a noticeable lack of mid-sized cobbles. The soil is sandy and very permeable. The tributary headwa-

ter streams draining the intrusive and neighboring metamorphic areas are generally dry by the late summer low-flow period. Streams draining the basaltic areas, on the other hand, maintain a low, but more constant flow throughout the year. The mineral resources of the Blue Mountains are found in the margins of the intrusive areas. Gold mining activity lines the headwaters of the Grande Ronde River. Survey crews in 1941 found that the river had entirely disappeared beneath the dredge and fill rubble left by the miners (McIntosh 1994). Tailing piles still fill the floodplain, constraining the river and feeding it with sediment. Because of dramatic changes in forest structure in the last century of logging, fire suppression, and grazing, forest type boundaries have been drawn from evidence from the literature. Field work and additional historical research will be necessary to more accurately estimate forest expectations and reference conditions. The boundaries of this region were determined by the extent of granitic geology.

Subalpine Zone

The subalpine zone is located at elevations above 2000 m (6100 ft) and is dominated by subalpine fir (*Abies lasiocarpa*), white-bark pine (*Pinus albicaulis*), and alpine tundra. Alpine meadows are dominated by grasses with mixed forbs. The subalpine areas have not escaped grazing pressures. In areas that are overgrazed, recovery is exceedingly slow. The soil is well developed, but it has a relatively thin humus layer (Franklin and Dyrness 1973). Most of the exposed bedrock is unweathered granite or ancient seafloor sediments scraped off as the Pacific plate began diving (in a geological sense) beneath the continental margin 200 million years ago. Precipitation occurs mainly in the winter as snow. The region extends from treeline at its lower boundary to the summits of unvegetated peaks.