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Toward an Integrated Classification of Ecosystems: Defining Opportunities for Managing Fish and Forest Health[1]

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ABSTRACT / Many of the aquatic and terrestrial ecosystems of the Pacific Northwest United States have been simplified and degraded in part through past land-management activities. Recent listings of fishes under the Endangered Species Act and major new initiatives for the restoration of forest health have precipitated contentious debate among managers and conservation interests in the region. Because aggressive management activities proposed for forest restoration may directly affect watershed processes and functions, the goals of aquatic and terrestrial conservation and restoration are generally viewed as in conflict. The inextricable links in ecological processes and functions, however, suggest the two perspectives should really represent elements of the same problem; that of conserving and restoring more functional landscapes. We used recent information on the status and distribution of forest and fish communities to classify river subbasins across the region and explore the potential conflict and opportunity for a more integrated view of management. Our classification indicated that there are often common trends in terrestrial and aquatic communities that highlight areas of potential convergence in management goals. Regions where patterns diverge may emphasize the need for particular care and investment in detailed risk analyses. Our spatially explicit classification of subbasin conditions provides a mechanism for progress in three areas that we think is necessary for a more integrated approach to management: (1) communication among disciplines; (2) effective prioritization of limited conservation and restoration resources; and (3) a framework for experimentation and demonstration of commitment and untested restoration techniques.

Aquatic ecosystems of the Inland Northwest share a management history with native forests of the region that has extensively changed both. The plight of native fishes is well documented. Degradation and fragmentation of stream habitats (Williams and others 1989, Hicks and others 1991, Nehlsen and others 1991, Frissell 1993, Henjum and others 1994, Lee and others 1997) has led to local and regional extirpations (Frissell 1993) and diminished genetic and life-history diversity (Walters and Cahoon 1985, Rieman and McIntyre 1993, Lesica and Allendorf 1995, Lichatowich and Mobrand 1995). Degraded watersheds threaten the stability and persistence of remaining native fish populations and could trigger cascading effects on the structure and functioning of entire ecosystems (Willson and Halupka 1995, Bilby and others 1996, Willson and others 1998). Even without further habitat losses resulting from human disturbance, many remnant habitats and populations may not retain adequate diversity and redundancy to persist (Frissell and others 1993, Reeves and others 1995, Rieman and others 1997), much less the productivity to sustain important fisheries.

Changes in forest ecosystems of the region seem to mirror those of aquatic ecosystems. Many forests have been changed significantly in their structure, composition, and patterns (Franklin 1992, Lehmkuhl and oth-

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[1]The use of trade or firm names in this paper is for reader information only and does not imply endorsement of any product or service by the US Department of Agriculture.

ers 1994, Huff and others 1995, Hessburg and others 1999a). Native forest landscapes have been simplified and fragmented through timber harvesting, road construction, domestic livestock grazing, and fire suppression. Changes in vegetation patterns and associated conditions for fuels and fire behavior now appear to threaten larger, more frequent stand replacement wildfires than occurred in the past (Agee 1994, Huff and others 1995, Hann and others 1998, Ottmar and others (in press), and the influence of insect and pathogen disturbances has been expanded (Harvey and others 1992, Harvey 1994, Hann and others 1997, Hessburg and others 1994, 1999a).

Growing recognition of the degraded condition of public forests and fisheries has precipitated fierce political and scientific debate over such issues as listings under the Endangered Species Act, salvage logging, lost timber and recreation values, and growing costs of fire protection (Rieman and Clayton 1997). Emerging discussions typically focus on a single facet of a multifaceted problem, for example: treating forests to modify their existing fuel conditions, density, or composition while assuming that such treatments will benefit all other resources (Rieman and Clayton 1997). Alternatively, large aquatic conservation areas have been suggested as a primary management emphasis with passive management of fish habitats, and other strategies for addressing problems of associated forest landscapes subordinated to or consistent with the primary emphasis (Everett and others 1994). Because past land management activities have contributed directly to the degradation of watersheds, proposals for active forest restoration have been viewed with skepticism and as renewed threats to sensitive aquatic species (Rieman and Clayton 1997). Little attention has been given to the potential benefits for whole terrestrial–aquatic systems.

An ecosystem approach (sensu Attiwill 1994, MacKenzie 1997, Quigley and Arbelbide 1997) has been proposed for the management of resources in large and complex landscapes. Progress in the restoration of large ecosystems such as the Great Lakes (MacKenzie 1997) lends hope for the integration of disparate goals and competing sociopolitical and economic demands typified in much of the historical management of terrestrial and aquatic ecosystems of the Inland Northwest. There is also growing scientific understanding of the important linkages between terrestrial and aquatic environments. Terrestrial landscapes, for example, can be characterized by natural patterns of vegetation resulting from disturbances such as fire (Cissel and others 1998, Hessburg and others 1999b,c) that influence erosional, hydrologic, and geomorphic processes as well as vegetative communities. In turn these link to a host of processes that may strongly influence the complexity, diversity, and productivity of aquatic environments (Naiman and others 1992, Reeves and others 1995, Bisson and others 1996, Poff and others 1997). Healthy watersheds and aquatic communities are ultimately supported by healthy forests (Franklin 1992, Naiman and others 1992). The growing realization is that land management has altered whole ecosystems. In the larger view, challenges for conserving and restoring aquatic communities and forests represent not simply issues of resource allocation and competing demands, but facets of the same problem—a need to conserve and restore more functional landscapes.

For several reasons, restoration of landscapes that may sustain healthy forests and native fish populations is no simple task. First, although there has been substantial progress in landscape ecology and in the theoretical integration of disciplines, applied terrestrial and aquatic ecologists and managers have limited experience in talking to one another. From our own experience Forest Service research disciplines are still narrowly focused, often working at different scales in wholly different landscapes. Research and management projects are often focused where problems seem tractable or convenient, and not necessarily where they are most urgent. Methods and jargon often are quite distinct. The lack of common language, landscapes, and scales impedes development of any semblance of integrated management or restoration efforts.

Second, the disruption of terrestrial and aquatic ecosystems in the Inland Northwest is largely the result of urbanization and management practices that emphasized resource extraction. Major portions of these landscapes have already been altered irreversibly, and rapid population growth (Haynes and others 1996) portends increasing natural resource demands. Although conservation-minded professionals and environmentally oriented citizens often see every remaining piece as critical, many systems may never be restored to something resembling their natural condition or productivity. In this world of limited time and monetary resources, it is essential to clearly establish priorities and recognize significant conservation and restoration opportunities.

Third, because terrestrial and aquatic management goals have often been in conflict, attempts to communicate and integrate science and management across disciplines remain contentious and suspect. Landscape management and proposed restoration methods are unproven (Noss and Scott 1997); restoration of watershed processes and forest structure and patterns are largely conceptual topics with little application in the real world. Successful restoration will entail some risks

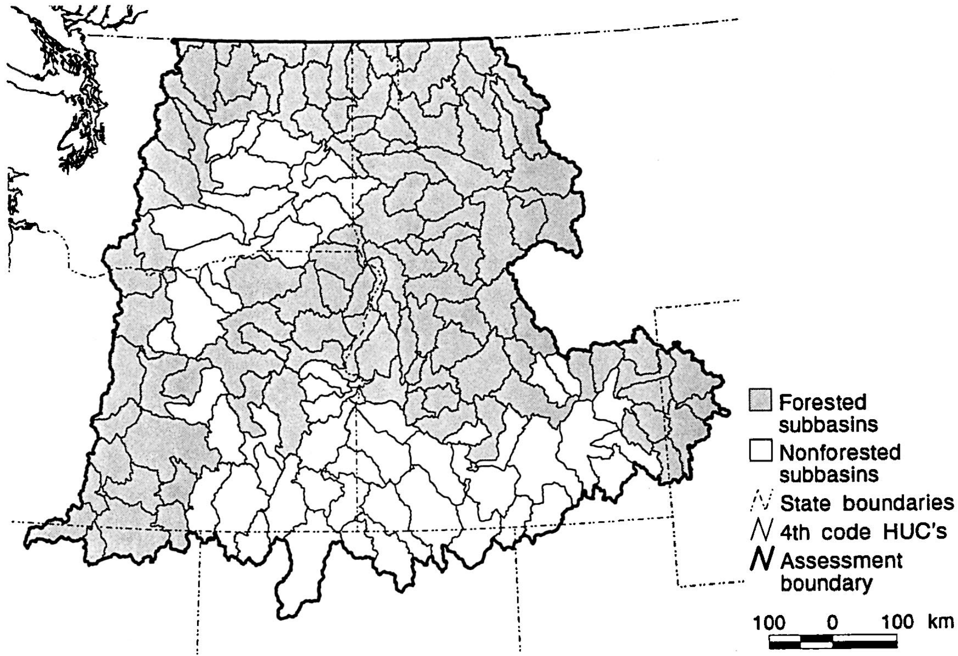

Figure 1. The Interior Columbia River Basin and portions of the Klamath and Great basins. Fourth code subbasins are shown in outline; forested subbasins are shaded. Subbasins were considered forested in this analysis when at least 20% of the land area could be classified to one or more of the following broad forest potential vegetation groups: dry forest, moist forest, or cold forest (see also Figure 8).

as well as a commitment to and continuity of management that extends over unprecedented spatial and temporal scales. Conservation-oriented managers and regulatory agencies are suspicious that the institutional commitment may dissolve with the next election, budget crisis, or staff change.

In our view, then, important progress in management of terrestrial and aquatic ecosystems on public lands will depend on at least three things: (1) integration and communication among research and management disciplines; (2) effective prioritization of research, analytical, and management (conservation/restoration) resources; and (3) demonstration of both the ability and commitment to work at the temporal and spatial scales required to be effective. We hypothesize that because of a common history of past management disturbances, the apparent need to restore forests by active management will often coincide both spatially and temporally with the need to restore more functional aquatic networks. By extension, opportunities to conserve functional and healthy forests may coincide with opportunities to conserve functional and healthy aquatic ecosystems as well. An important challenge for managers is to explicitly identify those opportunities as well as the conflicts.

In this paper, we explore the spatial pattern of opportunities and conflicts related to the management of forest and aquatic ecosystems within the Interior Columbia River Basin of the coterminous United States (Figure 1). We attempt to integrate current knowledge of the conditions in terrestrial and aquatic ecosystems of this region by drawing on information developed as part of the recent Interior Columbia River Basin Ecosystem Management Project (ICBEMP) (Hann and others 1997, 1998, Quigley and Arblebide 1997, Lee and others 1997, 1998, Hessburg and others 1999a, Ottmar and others, in press). We focus on broad-scale patterns of departure from historical condition in aquatic and terrestrial communities throughout the region. We use the existing information from the ICBEMP to classify river subbasins by themes that highlight opportunity for more integrated terrestrial and aquatic ecosystem management and prioritization of management resources. We argue that these themes provide a logical template for experimental management and the integration of analyses at finer scales.

In our analysis, we rely on information on native fishes as an indicator of the condition in aquatic ecosystems. Although issues are similar across both forest and rangeland vegetation types of the region (Lee and others 1997), issues and opportunities for management vary substantially by physiognomic condition. We considered only forested lands to better focus the analysis and our discussion.

The changes in both aquatic and forest communities provide a context for emerging discussions regarding forest and ecosystem health and management designed to conserve or restore them. Those discussions are often contentious; a result, in part, due to a confusion in terms (Callicot and Mumford 1996). In this paper, an ecosystem is healthy when it has the capacity to realize its inherent potential, when it exhibits metastability (sensu Botkin 1990), and the capacity for self-repair when disturbed (sensu White and Pickett 1985, p. 7), and where minimal external support from management is needed (from Karr 1992). We use the term *restoration* when we suggest passive or active management to produce an ecological outcome that moves toward a healthy condition. We acknowledge that full restoration may be impossible, in many cases, and include passive and active management to produce an ecological outcome that may be only a functional facsimile of a former condition.

Background and Study Area

To develop the themes, we used indicator variables that represented current conditions of fish and forest communities and levels of human disturbance at a broad landscape scale (approx. 1:1,000,000 map scale). We used river subbasins, formally defined as the fourth level in the USGS hydrologic unit hierarchy (Seaber and others 1987), as our unit of comparison (Figure 1). Our goal was to identify meaningful similarities among subbasins, while preserving their unique identity. We organized subbasins along a set of ecological themes that highlighted similarities of subbasins grouped within a theme. While there were substantive intertheme differences, themes generally reflected recurring patterns that were often coupled to common management histories and geographic settings. Themes were not intended as a means of classifying subbasins for a cookbook of management prescriptions; rather, they provided a simple synthesis of common management history, resultant conditions, management opportunities, and potential ecological risks.

We relied on information generated in the ICBEMP. We utilized data developed to characterize current conditions and changes in fish (Lee and others 1997) and forest (Hann and others 1997, Hessburg and others 1999a, Ottmar and others, in press) landscapes across the Inland Northwest. GIS coverages for indicator variables were continuous either at a subwatershed or at 1-km resolution respectively, summarized to subbasins.

Study Area

The ICBEMP assessments addressed all lands of the Interior Columbia River Basin (hereafter, the basin) east of the crest of the Cascade Mountain Range, and those portions of the Klamath River and Great basins in Oregon (Figure 1). The assessment area included over 58.3 million ha distributed across Idaho, Montana, Nevada, Oregon, Washington, California, and Wyoming. Portions of the Klamath River and Great Basin included in the assessment area comprised 1.5 million and 4.2 million ha, respectively. The assessment area was comprised of 46% forestland and 54% rangeland and other nonforest types.

Within the USGS hydrologic unit hierarchy, hydrography and topography were used to define subbasins within the Basin. The ICBEMP further defined subwatersheds nested within watersheds (Jensen and others 1997), nested within subbasins (Figure 2). Within the assessment area, 164 subbasins are defined. Examples of subbasins include the Bitterroot River in Montana (Figure 2), the South Fork Boise River in Idaho, the Middle Fork John Day River in Oregon, and the Wenatchee River in Washington. Subbasins averaged about 350,000 ha in surface area, while watersheds averaged 20,000 ha, and subwatersheds averaged 8,000 ha. Divisions followed the hierarchical framework of aquatic ecological units described by Maxwell and others (1995). Subbasins and subwatersheds were our basic units of analysis.

Fish Assessment

Lee and others (1997), Rieman and others (1997), and Thurow and others (1997) described in detail the methods used and information available in the ICBEMP aquatic assessment. Briefly, information on the status and distribution of 143 fish taxa, representing all known native and introduced forms, was summarized from existing databases and current inventories across the region. Seven salmonids were selected as key indicators of aquatic ecosystem condition because they were widely distributed, relatively sensitive to environmental disturbance or change, well studied, and broadly represented in existing inventories. Key salmonid species were bull trout *Salvelinus confluentus,* westslope cutthroat trout *Oncorhynchus clarki lewisi,* Yellowstone cutthroat trout *O. c. bouvieri,* interior redband trout and steelhead *O. mykiss,* and ocean- and stream-type chinook salmon *O. tshawytscha* (Lee and others 1997). More than 150 biologists across the region worked to characterize the status of each form within subwatersheds across the basin. At a first level, each of the salmonids was characterized as present, absent, or unknown. When a species was present,

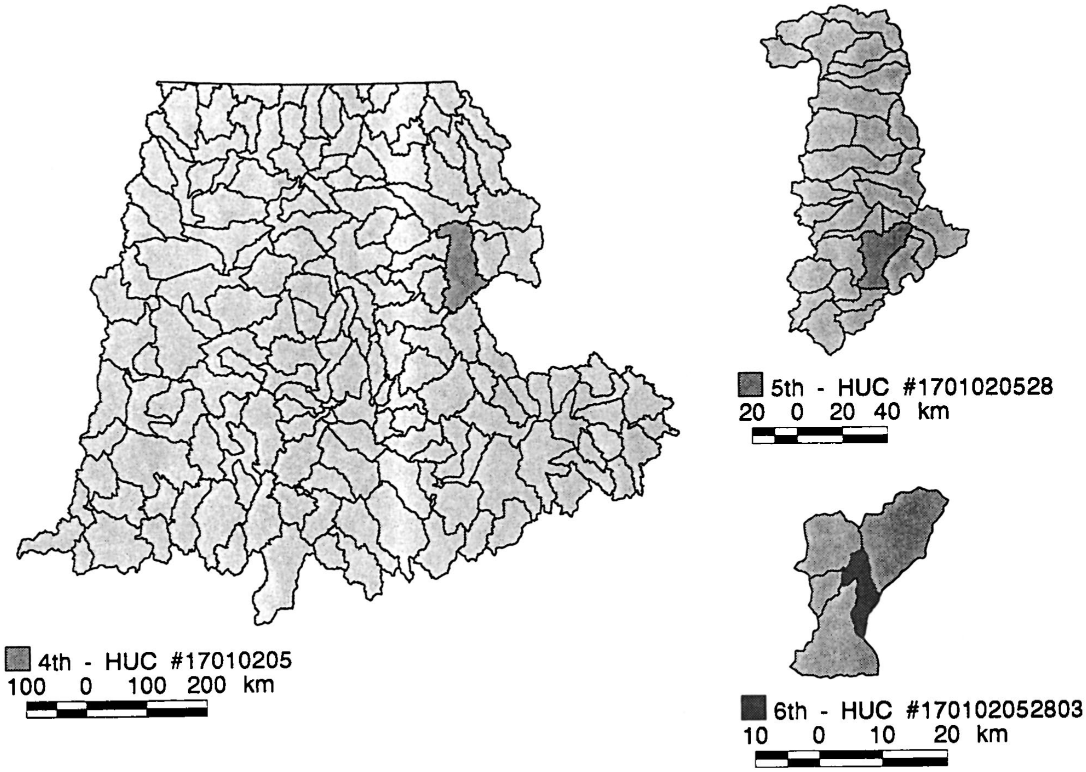

Figure 2. Hierarchical organization of subwatersheds, watersheds, and subbasins in the Interior Columbia River Basin and portions of the Klamath and Great basins.

additional information was used to characterize a subwatershed as predominantly spawning and rearing area or as seasonal habitat (migratory corridors, wintering or staging areas). Spawning and rearing areas were further classified as strong or depressed depending on current trends in fish abundance, and the proportion of potential life-history forms present. When these data were unavailable for a given subwatershed, species were classified as present but status unknown. Depending upon the salmonid species, the classes unknown and present–unknown represented 12%–60% of the current potential range.

To integrate the aquatic and terrestrial perspectives, we needed complete coverages for the data of interest. It was therefore necessary to extrapolate the likely distribution and status of salmonids to unsampled subwatersheds. To that end, complete coverages of variables representing characteristics of vegetative communities, climate, geology, landform, and human disturbance were summarized to subwatersheds and used to develop associations between fish distributions and landscape patterns. Classification tree analysis (Clark and Pregibon 1992, Lee and others 1997) was used to assign a probabilistic status and distribution of fishes in unsampled subwatersheds, and a complete probabilistic distribution of species within the basin.

Information on the distribution of all other fish species was used in an association analysis (Ludwig and Reynolds 1988, Lee and others 1997) to classify all watersheds into one of 15 species association groups. Indices of species diversity and of the relative influence of introduced species on the structure of current communities, at both watershed and subbasin scales, were derived as additional measures of the current condition of aquatic ecosystems (see below). Results demonstrated that fish communities had changed dramatically across the basin. Several species were found to be regionally extinct, while the range of many others was substantially reduced through habitat fragmentation and loss and the introduction of exotic fishes. Road density, representing both pattern and intensity of human access and development, was one of the best indicators of degradation to aquatic ecosystems (Lee and others 1997). Despite apparent declines, healthy populations and communities of native fishes still persisted in parts of the basin. Subwatersheds that support healthy populations represent cores for the conservation of remnant biological diversity and restoration of more functional aquatic ecosystems (Lee and others 1997).

Forest Landscape Assessment

Changes in forest landscapes were evaluated at both broad and meso-scales in the ICBEMP. Landscape spatial patterns were assessed at a meso-scale (1:24,000); the context of those patterns and interactions was assessed at a broad-scale (1:1,000,000). In the broad-scale assessment (Hann and others 1997), change in vegetation structure (structural class), composition (cover type), and fire, insect, and pathogen disturbance regimes was modeled at 1-km resolution with continuous data for the basin. Change in structure and composition was summarized for potential vegetation groups (logical aggregations of plant series-level potential vegetation types) in each of 13 province-scale ecological reporting units. Change was modeled from an historical baseline established as approximately the year 1900. Detailed descriptions of historical and current map coverages, database development, and modeling methods are available in Hann and others (1997).

The mid-scale assessment (Hessburg and others 1999a, Ottmar and others, in press) used a stratified random sampling procedure to characterize historical and current vegetation composition and structure of 337 subwatersheds from 43 sampled subbasins, on all ownerships within the basin. In part one, Hessburg and others (1999a) compared historical and current landscape spatial patterns, structure, composition, and vulnerability to 21 major insect and pathogen disturbances. In part two, Ottmar and others (in press) linked changes in landscape patterns to changing potential fire behavior and smoke production.

Predicted shifts from early seral forest species such as ponderosa pine and western larch to late seral species such as grand fir and subalpine fir were evident in both broad- and mid-scale assessments. In general, spatial patterns of the structure of current forests were simpler when compared with historical forests. Observed structural changes were consistent with management activities that have been implicated in the overall simplification of structural complexity, namely, fire exclusion, timber harvest, and domestic livestock grazing. Simplification of spatial patterns of structure was associated with significantly reduced area in stand initiation (new forest) and old forest structures, with compensating increases in area of intermediate structural classes (stem exclusion, understory reinitiation, and young multistory structures).

Forest landscapes also changed in their vulnerability to insect, pathogen, and fire disturbances. As a result of fire exclusion, selective harvesting, grazing, and insects and pathogens temporarily replaced fire as dominant agents of pattern formation, and current forest patterns are now more fine-grained and homogeneous. Fuel loads appear to have increased in nearly all forested landscapes except those recently visited by wildfires. In general, many areas that historically displayed nonlethal underburning fire regimes currently exhibit mixed severity and lethal fire regimes. Many areas that historically displayed mixed severity regimes currently display lethal fire regimes. Forested landscapes had become more susceptible to large wildfires, and the likelihood of effective fire control had become increasingly uncertain. Road densities and potential vegetation groups (e.g., dry forest, moist forest, or cold forest) were among the best predictors of change from historical patterns.

Despite widely apparent changes, some subbasins exhibited relatively minor evidence of alteration as a result of management. Many such areas still support most of the original floral and faunal species and communities (Marcot and others 1997). Areas such as these represent important building blocks for the conservation and restoration of native habitats of terrestrial species of the basin.

Methods

Theme development stemmed from two objectives. First, each theme should be broadly accurate descriptions of ecological conditions within member subbasins and sufficiently dissimilar from other themes to avoid confusion. Second, theme membership should be defined following a tractable rationale that minimized ambiguity. We used cluster analysis to assist in theme development, guided by our interpretation of ecological patterns.

We used standardized continuous data to cluster forested subbasins according to the broad-scale condition of fish and forest communities. Subbasins were used as the basic sample unit because they were sufficiently large hydrologic networks to support a near complete expression of native fish species, interacting subpopulations, and life histories that may be expected over distinct ecological regions. Subbasins are also often isolated from larger river basins by dams or natural barriers to species movement. In many cases, subbasins approximate complete or nearly complete aquatic ecosystems. Subbasins were considered forested in this analysis when at least 20% of the land area could be classified to one or more of three broad forest potential vegetation groups (PVGs): dry forest (including the ponderosa pine, dry Douglas fir, and dry grand fir/dry white fir potential vegetation types); moist forest (including the western red cedar, western hemlock, moist

Table 1. Indicator variables used to characterize status of forest and aquatic ecosystems in subbasins of the Interior Columbia River Basin[a]

Variable	Description
dry_pct	percentage of subbasin area composed of dry forest potential vegetation types
moist_pct	percentage of subbasin area composed of moist forest potential vegetation types
fire_fq	index of change from estimated historical fire frequency
fire_sv	index of change from estimated historical fire severity
high_rd	area of moderate, high, and very high road densities
low_rd	area unroaded or with low or very low road densities
strong_idx	relative index of fish population strongholds
native_idx	community structure index of fish diversity and evenness

[a]Variables represent subbasin summaries of data developed in Hann and others (1997) and Lee and others (1997) .

grand fir/white fir, moist Douglas fir, and wet subalpine fir/Engelmann spruce potential vegetation types); and cold forest (including the mountain hemlock, cold subalpine fir/Engelmann spruce, and whitebark pine/subalpine larch potential vegetation types). Of the 164 subbasins that comprised the basin, 112 met this criterion.

We selected eight variables for the analysis (Table 1). Two were used to portray the condition of aquatic and two the condition of forest communities. Four other variables represented the potential management opportunities and conflicts based on secondary or modifying characteristics of the landscapes.

We represented the aquatic conditions with information on fishes. *Strong_idx* was a relative index of the number of key salmonid populations currently exhibiting strong population numbers and trends and presence of diverse life history strategies relative to projected historical conditions. *Native_idx* was an index developed by Lee and others (1997) to indicate the relative contribution of native species to overall community structure. Diversity indices were calculated by adapting Hill's (1973) diversity metric, as presented in Ludwig and Reynolds (1988), and presence data for 124 fish taxa (Lee and others 1997). This approach was consistent with the view of diversity indices as comparative measures that attempt to incorporate both richness and evenness into a single value. *Native_idx* (Z) was based on measures of abundant taxa, using native and nonnative taxa combined ($T1$), abundant native taxa only ($N1$), and very abundant native taxa ($N2$). The native index was defined as:

$$Z' = (N1/T1) \cdot (N2 - 1)/(N1 - 1)$$

$$Z = Z'/Z'_{\max}$$

which was the ratio of abundant native species to abundant taxa, times native evenness, scaled by the maximum observed value ($Z'_{\max}$) of the intermediate product (Z'). Both *strong_idx* (Figure 3) and *native_idx* (Figure 4) were generated for all watersheds within a subbasin and averaged over each subbasin to generate a single subbasin value.

For the condition of forest communities, we chose variables that indicated the approximate degree of change in fire disturbance regimes from that which would be expected for the biophysical environments that comprised each subbasin: fire_sv—the proportion of total subbasin area where fire severity increased between historical (1900) and current periods by at least one class (i.e., nonlethal to mixed severity, mixed to lethal, or nonlethal to lethal severity), and fire_fq—the proportion of total subbasin area where fire frequency declined between historical and current periods by at least one class. Fire severity classes were: nonlethal (underburning or ground fires that kill <30% of the prefire basal area or <10% of the prefire overstory vegetation); mixed (mixed stand replacement and underburning fires that kill 30%–80% of the prefire basal area, or 10%–90% of the prefire overstory vegetation); and lethal (stand replacement fires that kill >80% of the prefire basal area or >90% of the prefire overstory vegetation). Fire frequency classes were: very frequent (0- to 25-year fire-free interval), frequent (26- to 75-year fire-free interval), infrequent (76- to 150-year fire-free interval), very infrequent (151- to 300-year fire-free interval), and extremely infrequent (>300-year fire-free interval). Figures 5 and 6 display historical and current fire severity and fire frequency patterns within subbasins, respectively.

We used roads as measures of human influence and potential degradation in aquatic and forest ecosystems as well as a measure of the potential access for active management of forests. Roads represent possible targets for restoration activities (i.e., road obliteration to restore hydrologic processes) and the infrastructure potentially necessary for economically efficient forest manipulation. The pattern and distribution of road-related disturbance was indicated by high_rd—the proportion of total subbasin area with road densities estimated as moderate density or above (≥ 0.7 mi/mi^2), and low_rd—the proportion of total subbasin area in Congressionally designated wilderness or other administratively set-aside roadless or essentially unroaded (≤ 0.1

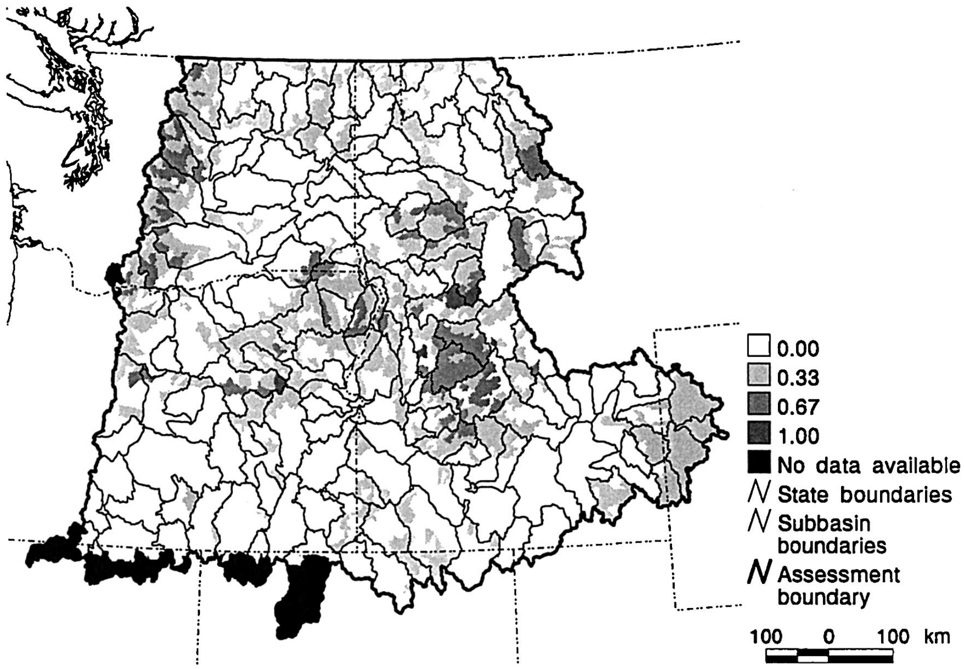

Figure 3. Distribution of the relative number of strong populations of key salmonids among watersheds within forested subbasins of the Interior Columbia River Basin and portions of the Klamath and Great basins. See Lee and others (1997) for data development procedures.

mi/mi^2) area. Moderate and higher road densities were used as indicators of established access for timber management, and other activities such as mining, domestic livestock grazing, developed site recreation, and fuelwood harvest that might directly influence both forest and aquatic conditions. Conversely, wilderness and roadless areas were used to indicate landscapes affected primarily by the suppression of wildfire. Figure 7 displays predicted current road densities across the basin.

Forest potential vegetation groups represent the potential productivity and species composition of forests that may ultimately influence the relative economic significance and flexibility in timber harvest. Because extractive interests will remain an important dimension in future management, we used areas in the dry and moist forest PVGs, dry_pct and moist_pct respectively, as our final variables (we did not include the cold forest PVG because the three PVGs represent all forest groups, thus only two are necessary to capture all the information). Empirical data from both the broad- and mid-scale landscape assessments (Hann and others 1997, Hessburg and others 1999a) indicated that the early seral species of these PVGs were those most sought after for timber harvest while the inherent climatic differences influence relative productivity. Figure 8 displays the distribution of all three forest PVGs in the 112 forested subbasins.

We used cluster analysis (SAS 1989) to organize subbasins into six distinctive ecological themes. Applying an iterative clustering procedure, we chose six themes as the minimum number that demonstrated clear differences between clusters while simultaneously providing a reasonable ecological interpretation. Cluster analysis assigned subbasins to a theme based on resemblance to a cluster centroid (subbasins that best exemplified the themes).

Results

Of the six themes resulting from our analysis (Table 2, Figure 9), four were clearly dominant, with 20–24 subbasins each. The remaining two themes had 10 and 14 subbasins. Below, we describe the characteristics of subbasins grouped by theme. We begin the description with a brief synopsis, followed by a general description of the associated forests, fishes, and our interpretation of the management implications. Mean values of indicator variables used in clustering highlight some important differences that separate themes (Table 2). Variables used in cluster analysis were standardized to a mean value of zero and standard deviation of one, when summarized for all forested subbasins. Mean values are expressed in standard deviation (SD) units. For example, the mean percentage of dry forest area within subbasins in forest theme 1 was approximately 1 SD below the overall mean of all subbasins. To further aid interpretation, high positive values of variables fire_fq,

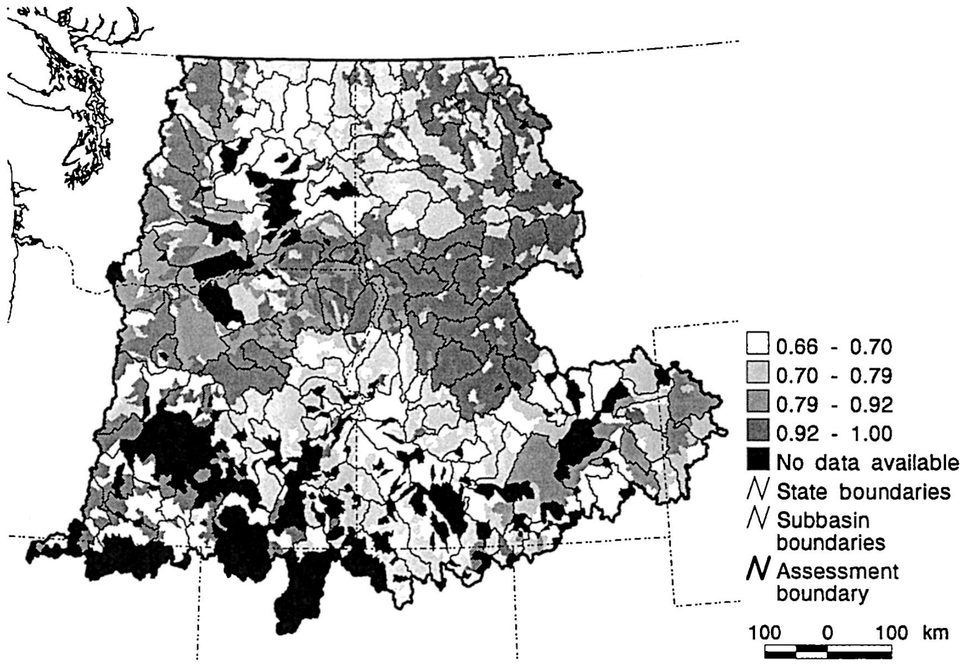

Figure 4. Distribution of *native_idx,* a measure of native fish community integrity, among watersheds within forested subbasins of the Interior Columbia River Basin and portions of the Klamath and Great basins. See Lee and others (1997) for data development procedures.

fire_sv, low_rd, high_rd, *strong_idx,* and *native_idx* denoted a closer resemblance to historical conditions, while high negative values indicated greater departure from historical conditions. We refer to values depicted in Table 2 below, but refer also to additional information included in the ICBEMP aquatic and landscape ecology assessments (Hann and others 1997, Lee and others 1997, Hessburg and others 1999a, Ottmar and others, in press).

Theme 1: Wild and Minimally Roaded, Cold and Moist Forests

Synopsis. Subbasins of this theme were among those exhibiting the least departure from historical conditions in either forest or aquatic ecosystems. Subbasins were dominated by wilderness and roadless area. Such areas may represent the best opportunity to conserve elements of ecosystems most closely resembling natural or historical conditions. About 9% of the forested area (Table 2, Figure 9) clustered in this theme.

Forests. Forests within these subbasins were predominantly high-elevation cold or cold and moist vegetation types. Forest composition had been simplified primarily by fire exclusion and to a lesser extent grazing. Mean changes in fire severity and frequency were the lowest among the themes.

Fishes. Fish assemblages and populations associated with this theme were in good to excellent condition. The fish indexes were among the highest found in the Basin (Table 2, Figure 9). Although introduced fishes were often present, they rarely dominated these subbasins. Strongholds for multiple species often existed in subwatersheds throughout these subbasins. Depressed populations were associated primarily with species with migratory life histories (e.g., anadromous salmonids and bull trout) that faced increasing threats and more hostile conditions in migratory corridors or rearing environments outside these subbasins.

Management implications. Because these subbasins deviated least from historical conditions in either forest or aquatic ecosystems, active restoration would be a low priority relative to other areas. The primary management opportunity would be to conserve existing conditions. In many cases, landforms are steep, soils are moderately to highly erosive, and sensitive to roading. Developing roaded access into these areas would be expensive and carry a high risk for disruption of watershed processes. Where vegetation management is important, prescribed fire may represent the best opportunity to reestablish more typical fire regimes. Both managed and natural ignitions could play an important role in restoring forests. Timber production opportunities are also limited due to the lack of an existing road network, high costs of mitigating the most deleterious effects of roads on aquatic habitats, and low to intermediate timber productivity relative to subbasins dominated by more productive, moist potential vegetation types.

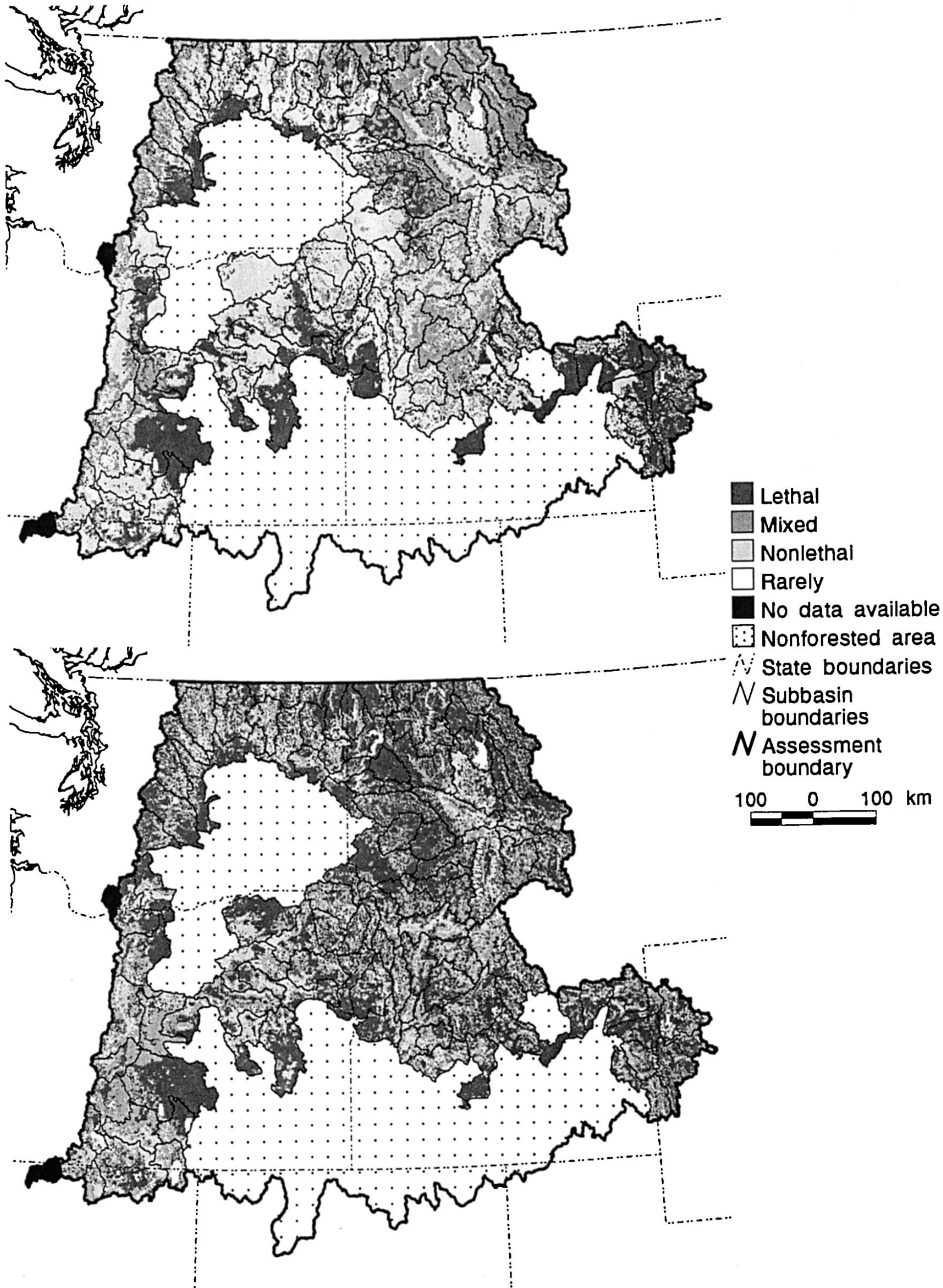

Figure 5. Distribution of broadscale (1-km² pixels) historical (above) and current (below) fire severity classes within the Interior Columbia River Basin and portions of the Klamath and Great basins. Fire severity classes were: nonlethal (underburning or ground fires that kill <30% of the prefire basal area or <10% of the prefire overstory vegetation); mixed (mixed stand replacement and underburning fires that kill 30%–80% of the prefire basal area, or 10%–90% of the prefire overstory vegetation); and lethal (stand replacement fires that kill >80% of the prefire basal area or >90% of the prefire overstory vegetation).

Theme 2: Semi-Wild and Moderately Roaded Areas

Synopsis. These subbasins represent forest and aquatic conditions varying from fair to relatively healthy (Table 2). Blocks of wilderness or roadless area and cold or moist forest types were associated with the best conditions. Forests and fishes were more likely to be altered in lower- and mid-montane settings. This theme was represented by about 18% of the subbasins (Figure 9).

Forests. Headwaters areas were likely to be moist and cold forests that were least altered in structure and composition. Mid- and lower-elevation dry and moist

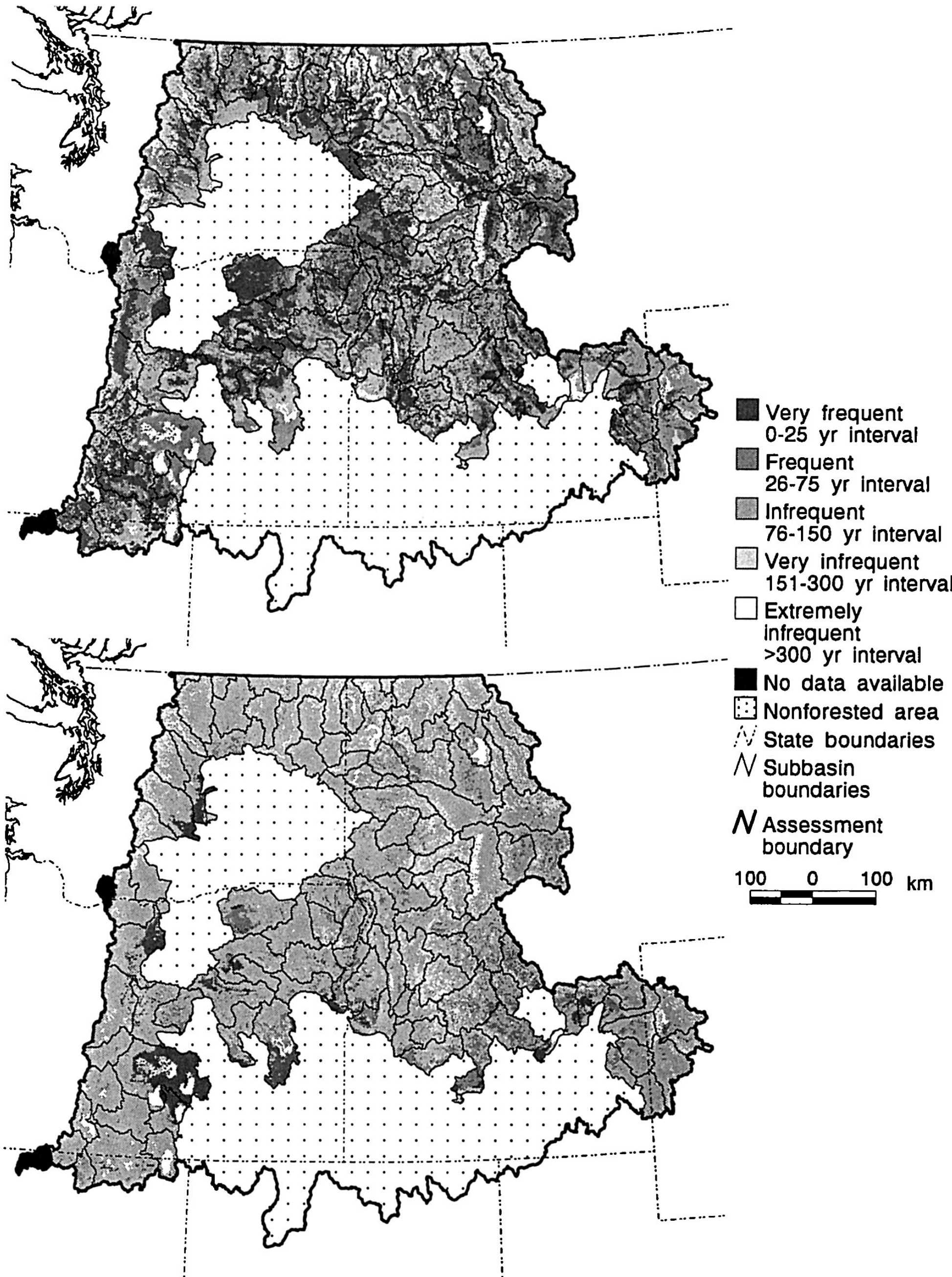

Figure 6. Distribution of broadscale (1-km^2 pixels) historical (above) and current (below) fire frequency classes within the Interior Columbia River Basin and portions of the Klamath and Great Basins. Fire return intervals of fire frequency classes were: very frequent (0–25 years), frequent (26–75 years), infrequent (76–150 years), very infrequent (151–300 years), and extremely infrequent (>300 years). See Hann and others (1997) for development of the information.

forests were changed more substantially by management. Higher road densities were generally found at lower and mid-elevations in the dry and moist forest types. Dry forest types tended to move from nonlethal to mixed and lethal fire severities with declining fire frequency. Moist forest types tended to move from mixed to lethal fire severity with reduced fire frequency. Significant areas had been accessed by roads, and most accessed areas were substantially modified in their structure and composition.

Fishes. The fish indexes were generally highest in higher elevation and unroaded portions of these subbasins although healthy conditions also occurred within the matrix of more intensively managed lands at lower

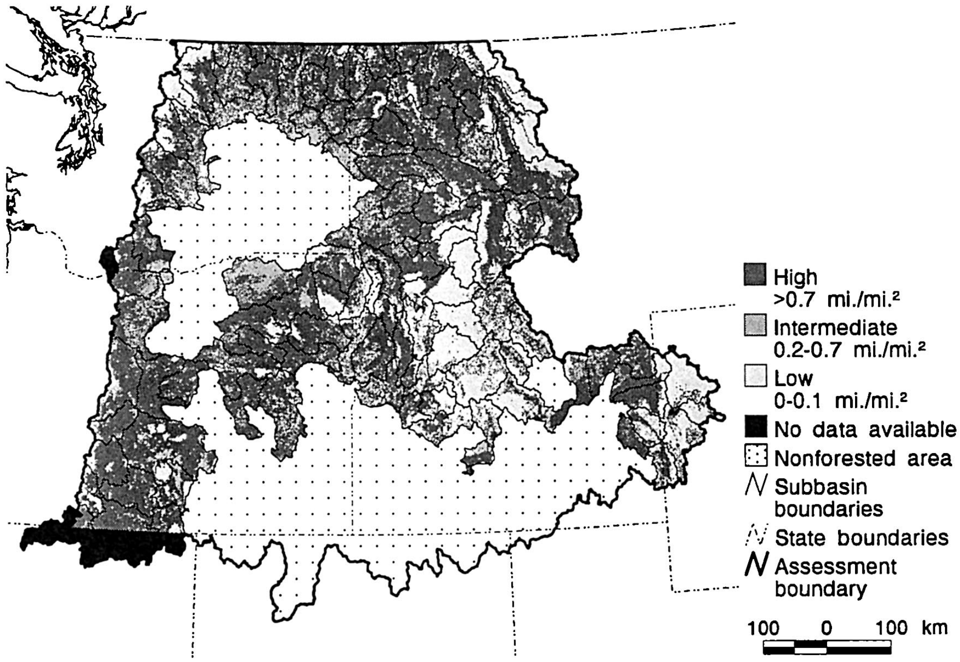

Figure 7. Broadscale (1-km^2 pixels) map of predicted road densities within the Interior Columbia River Basin and portions of the Klamath and Great Basins. Estimated road density classes were: low_rd (0–0.1 mi/mi^2), int_rd (0.2–0.7 mi/mi^2), and high_rd (>0.7 mi/mi^2). See Hann and others (1997) for development of the information.

elevations. Connectivity among subwatersheds via a passable river corridor remained in all of these subbasins. The most altered conditions for aquatic systems often appeared to be in the moderately to heavily roaded low- and mid-elevation forests.

Management implications. The primary management opportunity from both aquatic and forest perspectives is to conserve the integrity of high-elevation and headwaters landscapes and actively restore more productive and lower risk conditions in middle and lower montane settings. Restoring spatial patterns of low elevations forests in these areas could substantially reduce the absolute area currently exhibiting mixed and lethal fire regimes and the adjacency of mixed and lethal fire-prone areas. Restoring watershed conditions at lower elevations could expand the interconnected network of productive aquatic habitats.

Theme 3: Mixed and Opposing Conditions

Synopsis. In these subbasins, conditions in forest and aquatic ecosystems often did not coincide. This theme was represented by about 13% of the forested area of the Basin (Table 2, Figure 9).

Forests. Forests in these subbasins had the highest departures in mean fire frequency and severity (Table 2).

Fishes. Subbasins of this theme exhibited only average numbers of subwatersheds with strong salmonid populations, but most fish communities were still dominated by native species. Native species diversity and evenness as indicated by *native_idx,* averaged second highest among all clusters (Table 2). The relatively favorable condition of aquatic systems in this theme may exist because these subbasins are highly productive and resilient in the face of disturbance or perhaps because cumulative effects of historical management disturbances on streams lag behind changes in adjacent forest landscapes.

Management implications. Maintaining and improving the productivity of the aquatic ecosystems and restoring forests will likely require active management. Opportunities may exist to restore forest and aquatic conditions simultaneously, but there appears to be a real potential for conflicting goals. Relatively healthy aquatic conditions appear to overlap poor forest conditions, so there may be limited opportunity to emphasize forest treatments in areas with little risk to watershed concerns. Potential conflicts of management objectives within these subbasins highlight the need for detailed risk analysis.

Theme 4: Mixed Conditions, Moist Forests

Synopsis. These subbasins exhibited moderate to high levels of departure from historical conditions in both forest and aquatic communities. The need for restora-

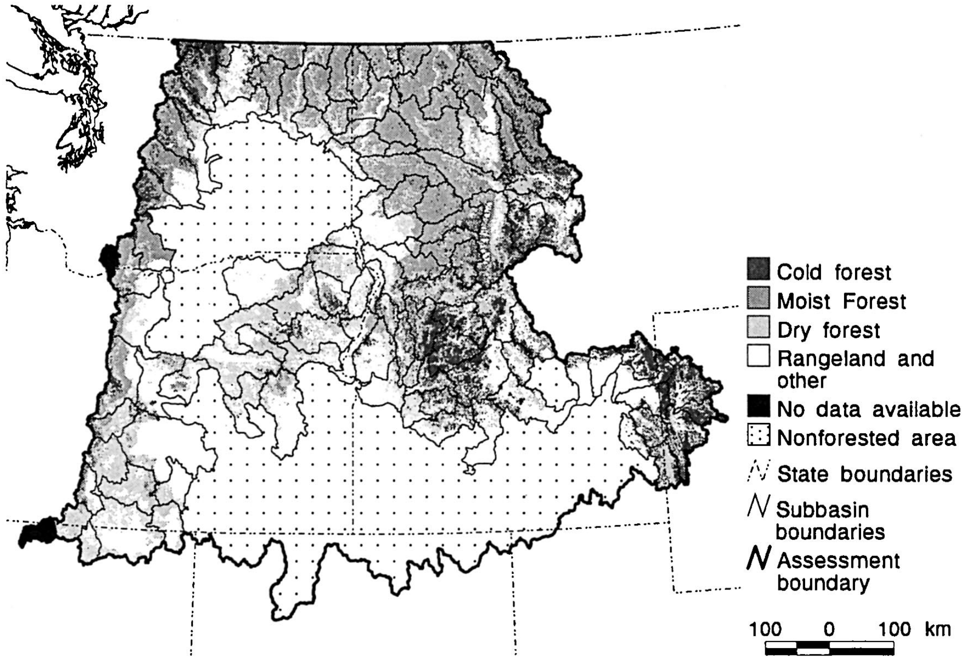

Figure 8. Distribution of broadscale (1-km^2 pixels) forest potential vegetation groups (PVGs) of the Interior Columbia River Basin and portions of the Klamath and Great basins. PVGs were developed by aggregating series-level potential vegetation types. See Hann and others (1997) for development of the information.

Table 2. Standardized means for eight variables used in cluster analysis to develop six ecological themes for forested subbasins of the Interior Columbia River Basin[a]

	Indicator variables							
Forest theme	*dry_pct*	*moist_pct*	*fire_fq*	*fire_sv*	*high_rd*	*low_rd*	*strong_idx*	*native_idx*
1	*−0.97*	*−0.28*	*1.20*	*0.47*	*1.87*	*1.97*	*0.97*	*0.39*
2	−0.23	−0.26	−0.11	−0.41	1.02	1.09	1.07	0.96
3	−0.22	0.42	−0.53	−0.85	−0.22	−0.32	0.03	0.76
4	−0.91	1.30	0.41	−0.25	−0.75	−0.57	−0.50	−0.41
5	1.34	−0.84	−0.41	0.48	−0.75	−0.67	−0.47	−0.06
6	0.30	−0.33	−0.17	0.36	−0.08	−0.41	−0.39	−0.99

[a]Positive values represent the least departure from historical conditions for *native_idx, strong_idx, low_rd, high_rd, fire_fq,* and *fire_sv.* Positive values represent larger subbasin areas in *dry_pct,* and *moist_pct* than the mean area of all subbasins.

tion in both aquatic and forest ecosystems and the productive nature of forests in this theme may imply both distinct risk and opportunity for management. This theme was represented by about 19% of the forested area of the Basin (Table 2, Figure 9).

Forests. Forests of this theme were dominated by productive, moist potential vegetation types, displayed some of the highest road densities seen across the Basin (Table 2), and contained little unroaded area. Predicted fire severity had increased over large areas.

Fishes. Some scattered subwatersheds supported strong populations of several species, but in general, most subbasins were represented by depressed populations of salmonids and often dominated by introduced fishes. Where subwatersheds were still connected through mainstem river corridors, migratory life histories may still occur and rebuilding larger more spatially diverse networks of habitats and populations is possible. Reconnection of many populations and recovery of a broader representation of potential habitats and life histories will often require extensive watershed restoration.

Management implications. Departure from historical conditions in both aquatic and forest ecosystems was associated with extensive land management reflected by high road densities. Recovery of both aquatic and

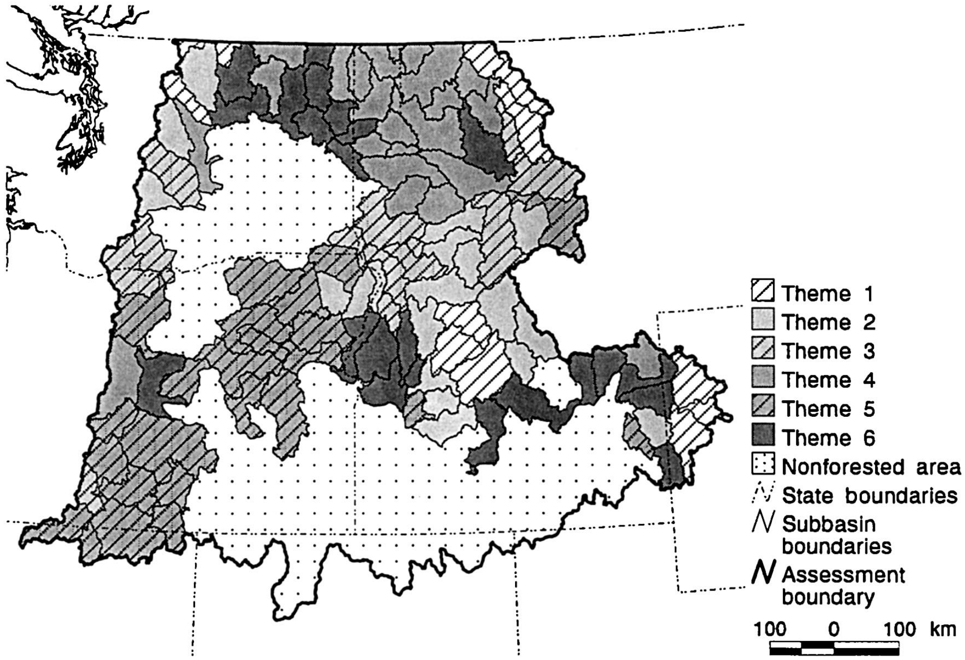

Figure 9. Spatial distribution of six ecological themes representing the combined status of fish and forest communities in forested subbasins of the Interior Columbia River Basin and portions of the Klamath and Great basins.

terrestrial ecosystems will likely require active restoration efforts. Because these are productive forests and because areas of productive aquatic habitats and intact aquatic communities still exist, these may be logical subbasins for such investment. Opportunities for active forest restoration are enhanced by existing, although often surplus, road networks. In many places, road removal could lead to improved watershed conditions.

The presence of large areas in moist forest types expands management opportunities. Historically, mixed and lethal fire regimes were dominant, suggesting large, intense disturbance events with relatively long recovery periods. Accordingly, managers might focus work in individual watersheds over short time intervals and leave extended periods for recovery. Significant restoration activities focused over short time periods (5–10 years), with longer recovery intervals (30–50 years), may minimize the need for extensive, permanent road networks and enable large-scale watershed restoration.

Theme 5: Mixed Condition, Dry Forests

Synopsis. This group of subbasins closely resembled those in theme 4, both in degree of departure from historical conditions and status of forest and aquatic communities. Subbasins of this theme, however, were dominated by dry forest (Table 2). Although restoration needs were common within theme 4, alternatives for management may differ with the character and productivity of forests. This theme was represented by about 21% of the forested area of the basin.

Forests. Forests of these subbasins were in relatively poor condition, were extensively roaded, and included little or no wilderness or roadless area. Forests were dominated by dry forest PVGs and displayed greatly decreased mean fire frequency (Table 2).

Fishes. Relatively few subwatersheds supported strong salmonid populations. Our measure of community structure (*native_idx*) was near the mean for all subbasins, suggesting that introduced fishes were important but not necessarily dominant in these subbasins.

Management implications. Restoration needs are similar to those suggested for theme 4 subbasins, but active forest management will likely require more frequent entry and maintenance of a more extensive road network. Forests were generally less productive than those of theme 4. Historical fire regimes were primarily nonlethal and mixed, with frequent fire return intervals implying a need of more frequent silvicultural and prescribed fire treatments to maintain desirable tree density relations and composition. In the near term, timber values in dry forests will not likely support low-impact (e.g., helicopter yarding) operations as often as in more productive moist forests, and some road networks may be needed in the long term to facilitate active management. Because current road densities were high in some areas, there may be opportunities for extensive forest restoration and subsequent elimination of unnecessary or redundant roads. Restoration activities that emphasize use of existing rather than new road networks and elimination of roads most deleterious to watershed processes may hold some promise, but opportunities for restoring aquatic conditions appear more limited than in preceding themes.

Theme 6: Poor Conditions

Synopsis. A final group of forested subbasins were in poor condition from both forest and fish perspectives. Aquatic ecosystems were especially degraded and remaining populations of native fishes were often isolated in fragments of remnant habitat. Subbasins supported relatively few, widely scattered strongholds and exhibited the poorest condition for fish communities of all forest themes. This theme was represented by about 20% of the forested area of the basin.

Forests. Forests were similar in their composition and degree of departure from historical conditions to those in theme 5; however, there was a more diverse mix of dry and moist forest conditions in theme 6 subbasins, and changes in fire frequency were not as pronounced (Table 2). Road densities were lower than those observed in either theme 4 or theme 5.

Fishes. Subbasins displayed the poorest overall aquatic habitat conditions. Fragmentation of aquatic habitats was strongly influenced by agricultural and other development on lower elevation private lands adjoining forested areas. Because introduced fishes abound, and habitat fragmentation was likely widespread and permanent, opportunities to restore aquatic ecosystem conditions were limited.

Management implications. The primary opportunity for management of aquatic resources may be to conserve remnant habitats of native fishes and maintain high water quality in areas that support desirable nonnative fisheries or other recreational values. Management in these areas would of necessity resemble a collection of remnant habitat reserves with little conflict among management priorities in the matrix and correspondingly little opportunity for restoring more ecologically functional aquatic networks. Forest restoration activities could represent low risks to remaining critical aquatic habitats or to the distribution of sensitive species, assuming they were sited with recognition of those areas.

Discussion

Assessments of forest and aquatic ecosystems of the basin revealed that both have undergone important change from historical conditions. Changes in forest ecosystems often paralleled those in aquatic ecosystems. In our analysis, 9% of all subbasins were represented by the best conditions (theme 1) from both forest and aquatic perspectives. An additional 18% followed a similar pattern in at least a major portion of each subbasin (theme 2), but most subbasins fell into themes 4, 5, or 6, suggesting mixed or degraded conditions in fish and forest communities. Only 13% (theme 3) of the subbasins displayed divergent trends in fish and forest communities. Patterns of human access indicated by road density, and ostensibly past management, appear to be good predictors of departure from historical conditions and indicators of current conditions of both forest and fish communities (Hann and others 1997, Lee and others 1997).

Continued population growth, development, and growing demands on renewable resources presage continued degradation of aquatic systems and their associated native fishes, not recovery. To date, resolution of this trend has been strongly impeded because solutions to individual issues, such as forest health and salvage logging, seemingly conflict with the notion of conserving or restoring quality habitats for native fishes.

Conservation and restoration efforts will succeed or flounder depending upon the level of investment in effective management practices and the perceived consonance of management goals. The goal of conserving and expanding aquatic habitats might be perceived as in direct conflict with vegetation and fuels management goals. Restoration of structure, composition, and functioning of forest ecosystems more consistent with natural disturbance processes, however, may provide significant benefits to the function of whole ecosystems. We suggest that efforts to restore forests could be viewed as an opportunity to restore more functional watersheds without unduly risking those critical to short term conservation of native fishes. There are three primary elements that must be integrated to be successful: (1) conservation of key remnant aquatic and associated terrestrial habitats and populations as building blocks for the future; (2) restoration of degraded watersheds to a more functional condition; and (3) restoration of more natural spatial patterns of forest structure and composition, including patterns of dead and down structure that would reduce the landscape risk of large and damaging wildfires.

Conservation

The acknowledgment of landscape issues in recent conservation strategies and implementation of watershed and ecosystem analysis protocols (FEMAT 1993, Montgomery and others 1995, USDA 1995) represent important steps and a conceptual advance in land-use management influencing aquatic ecosystems (Montgomery 1995). The intent of these strategies is to prevent disruption of watershed processes through careful, before-the-fact analysis (Montgomery 1995), but even the best models and analyses fashioned in data-rich environments retain important uncertainties. Our ability to actively manage whole landscapes and allocate human-related disturbance is still unproven, and we cannot predict or control many of the natural disturbances that will challenge and shape these systems in the future (Frissell and Bayles 1996). Until the efficacy of new and promising approaches can be demonstrated, we believe it is necessary to buffer against uncertainty with networks of subwatersheds that are not further compromised by human disturbance. We suggest that it is also both prudent and preferable to experiment with restoration in ecologically less important areas.

The focus on conservation of critical elements is clearly articulated in other work (Brussard and others 1998, Noss and Scott 1998). Habitats supporting the most productive, diverse, or otherwise critical populations provide the best opportunities for ensuring short-term persistence. They also provide an essential nucleus for rehabilitating more complete networks in the future. An emphasis on conservation in such areas does not necessarily mean forest management activities must stop. It does imply that any management must clearly minimize or eliminate risks that might compromise the ability of populations to persist. Because there is a strong association in the condition of aquatic and forest communities, conservation of existing highly functional landscapes should be a common goal for both fisheries and forest managers in nearly 30% (themes 1 and 2) of the forested subbasins across the basin. The need for intensive forest management (i.e., new road-based activities) can not be easily justified in the remnant productive aquatic habitats. Because road systems are often less well developed in these subbasins, implementation of more benign harvest and yarding techniques and the reintroduction of prescribed managed or natural fire could play the primary role in maintaining disturbances essential to these forests.

Watershed Restoration

We have argued that long-term persistence of aquatic biological diversity and sustainable and productive fisheries will depend on more than the current distribution of productive habitats. It will also depend on restoring watershed processes that create and maintain habitats across broad stream networks. At the same time that an attempt is made to conserve the condition of some healthy subwatersheds, there must be an active effort to manage other subwatersheds with the intent of restoring more complete and functional systems. As Bisson and others (1996) suggested, bold steps and experimentation will be necessary to make progress.

Many subbasins in the basin support a patchwork of productive and degraded subwatersheds. As our data suggest, the best remaining aquatic habitats are often found in upper montane and subalpine ecosystems associated with cold and/or moist forest types that also are in relatively good condition. Subwatersheds of middle and lower montane environments provide some important elements, but most have suffered significant habitat loss, and have been exposed to degrading effects of timber harvest, domestic livestock grazing, and roading. Active watershed restoration that includes obliteration of the most deleterious roads could be an important step to expanding the network of productive habitats. Low- and middle-elevation forest landscapes often show the greatest departure in forest conditions and the greatest need of active manipulation of vegetation (Hann and others 1997, Hessburg and others 1999a). Where active restoration needs of forest and aquatic ecosystems coincide, existing road networks could represent a key to progress in both. Existing roads provide ready access for active vegetation management, whether by silvicultural means or prescribed fire, and generally exist where departure in forest composition is most significant. Existing roads are often a focal problem in watershed function and the condition of aquatic habitats. By focusing projects in heavily roaded landscapes rather than dispersing them across a basin (sensu Franklin 1992, Reeves and others 1995), forest restoration in whole subwatersheds could be accomplished expeditiously. By concentrating efforts spatially, management activity could also be focused temporally, enabling longer recovery periods for watershed processes, and minimizing the need for extensive and ongoing road maintenance or reconstruction. Existing road densities often exceed those needed for more modern, environmentally benign logging systems. The obliteration of unnecessary or especially damaging roads could accompany many projects that actively seek repatterning of forests.

Forest Restoration

Intensifying fire regimes have been associated with increasing forest homogeneity, and future wildfires will likely burn with increased severity and extent (Agee 1988, Huff and others 1995, Hann and others 1997, Ottmar and others, in press). This is clearly an issue from the forest perspective and also from the aquatic view. Although historical wildfires may have been important to the maintenance of aquatic ecosystems (Reeves and others 1995), small or isolated populations could be vulnerable in the short term to the effects of intense fires (Rieman and Clayton 1997, Rieman and others 1997). Minimizing the risks of large and uncharacteristic fires could be important to the short-term persistence of some populations. Threats from such fires are likely to be most important in aquatic ecosystems and landscapes that are already highly simplified and fragmented (Rieman and Clayton 1997).

The intensification of fire regimes over large geographic areas has clearly become the leading forest health issue and a dominant issue in forest resource management. Substantial resources will be focused on the active manipulation of vegetation through timber harvest, thinning, and prescribed fire. Those resources could be prioritized for work that creates the greatest potential ecological benefits with the least possible risk. The geographic extent of forest restoration needs and the reality of scarce resources make it clear that active manipulation cannot proceed everywhere it might seem needed. Similarly, not all landscapes supporting important aquatic species or populations can be placed in reserves. We suggest the logical priorities for active management of forests will be those subbasins where there is a mosaic of degraded and healthy conditions among the subwatersheds (e.g., themes 2, 4, and 5). If restoration in forests does lead to restoration of watershed process and function, it might ultimately lead to expansion of the networks and diversity of habitats available to native fishes (Frissell and others 1993, Lee and others 1997). Even if it does not, the opportunity to repattern relatively large forest areas without imposing undue risk to currently important aquatic habitats may be common. By working strategically it may be possible to establish mosaics of fuel and forest conditions that reduce the landscape risk of extremely large or simultaneous fires without intensive treatment of every subwatershed.

We do not propose that native disturbance processes critical to the maintenance of productive fish habitats are readily replaced through active management. There is much we do not understand about interactions between natural disturbance of terrestrial ecosystems and the spatial distribution and temporal succession of aquatic habitats and species. It has been argued elsewhere (Rieman and Clayton 1997) that risks associated with active management may well outweigh risks associated with uncharacteristically large fires, but aquatic and terrestrial systems have been significantly altered from natural conditions, and in many cases recovery without some intervention may be unlikely.

Active watershed and forest restoration has not been an emphasis of historical land management. Neither have past management projects been intent on perpetuating landscape patterns and disturbance processes consistent with native biophysical conditions. There is a great deal to learn, and work will of necessity be experimental with uncertain results. Because a mosaic of aquatic and fish habitat conditions often exists in subbasins where active forest management might play a role, it should be possible to minimize risks in areas supporting critical habitats by prioritizing experimental or risky activities to areas of least concern from an aquatic view. By focusing restoration activities away from watersheds and key areas most directly influential to productive and critical aquatic habitats, risk associated with direct watershed disturbance is minimized, experience with establishment of more characteristic vegetation and fire patterns is gained, and a broader distribution of productive watersheds might be possible. Managers could begin the experimental and adaptive work that may ultimately demonstrate both an ability and utility for work in more sensitive landscapes.

Summary

In our introduction we proposed that successful ecosystem management on federal lands will depend on communication and integration, effective prioritization, and demonstration of conservation and restoration at unprecedented scales. We believe that the classification of subbasins based on the ecological conditions associated with two dominant issues in land management provides a useful template from which to start.

The process of joint classification forced integration and communication. Through that we learned that terrestrial and aquatic ecosystems that shared a common management history often also shared common patterns and trends, suggesting that there may thus be common goals for the future. Common management goals and the inextricable link between terrestrial and aquatic ecosystems suggest that management efforts can benefit both.

Active restoration of watershed processes and forest landscapes and the development of more ecologically benign land-use policies will be required. In our view, ecosystem management implies moving from strength to greater strength, that is, conserving what already works well while establishing or approximating more complete and natural structure, composition, functioning, and process where necessary and possible. Where management objectives and conditions in terrestrial and aquatic ecosystems are in conflict, the greatest care and investment in analysis and activities may be required. Making these patterns spatially explicit is, to us, an important first step in the prioritization of management resources.

Because much of the basin has been substantially altered by past management, the success of ecosystem management efforts at all scales will ultimately rest on the successful restoration of ecological processes across large landscapes. Management efforts will be highly contentious because there is little practical experience or demonstrated institutional commitment. These are clearly big experiments with important risks. We suggest that a classification of landscapes such as we have proposed provides a logical framework for that experimentation. By focusing intensive restoration initially in areas of greatest potential ecological benefit and least risk, the skills and opportunity to move into more sensitive areas will likely emerge.

The classification presented in this paper focused on subbasins within the basin because of the clearly defined issues and their relevant scales. This particular application should be useful to managers making decisions about the distribution of management resources at regional scales. We believe, however, that a similar process will work at finer scales. Because human disturbance and patterns of access are strongly associated with the condition of aquatic and terrestrial ecosystems, the commonality in management goals, opportunities, and conflicts should extend to watershed, subwatershed, and perhaps even project levels of management. The challenge ahead is to calculate and coordinate management of terrestrial and aquatic systems at all levels rather than to continue to work at cross purposes. We suggest that a relatively simple classification provides a framework for starting that integration.

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