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Estimating ecological integrity in the interior Columbia River basin

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Abstract

The adoption of ecosystem-based management strategies focuses attention on the need for broad scale estimates of ecological conditions; this poses two challenges for the science community: estimating broad scale ecosystem conditions from highly disparate data, often observed at different spatial scales, and interpreting these conditions relative to goals such as sustainability. The Interior Columbia Basin Ecosystem Management Project (ICBEMP), estimated relative composite ecological integrity by clustering conditions among proxy variables representing three component integrity ratings (forestland, rangeland, and aquatic integrity). Composite ecological integrity provides an estimate of relative system condition within the interior Columbia River basin assessment area that is responsive to changes in broad scale land management practices. Broadscale measures can be used to assess progress toward land management goals or as an aide for managers in selecting or prioritizing areas (watersheds) for treatment. Currently, federal land managers are using estimates of current composite ecological integrity and trends in ecological integrity to prioritize management activities and understand effects of management actions. Published by Elsevier Science B.V

Keywords: Ecological integrity; Ecosystem; Ecosystem management; Interior Columbia basin; Management support

1. Introduction

The Interior Columbia Basin Ecosystem Management Project (ICBEMP) was chartered, in part, to develop an overall assessment of ecosystems within the interior Columbia River basin (hereafter, Basin)[1] (Fig. 1), to determine their status and trend, and to describe the ecological risks and opportunities associated with federal management activities, see Haynes et al. (2001) for a description of the context for the

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The original work on ecological integrity was largely accomplished by James R. Sedell, Danny C. Lee, Paul E Hessburg, Bruce E. Rieman, Mark E. Jensen, Kenneth C. Brewer, Bradley G. Smith, J.L. Jones, Wendel J. Hann, Bruce G. Marcot, Richard W Haynes, and Thomas M. Quigley. We acknowledge their contribution, which is described in more detail in (Quigley, TM., Haynes, R.W., Graham, R.T. (Tech. Eds.),. 1996. Integrated scientific assessment for ecosystem management in the interior Columbia basin and portions of the Klamath and Great Basins. General Technical Report No. PNW-GTR-382. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 303 pp.).

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[1] The Basin is defined as that portion of the Columbia River basin within the United States and east of the crest of the Cascades, and that portion of the Klamath River basin and Great Basin in Oregon.

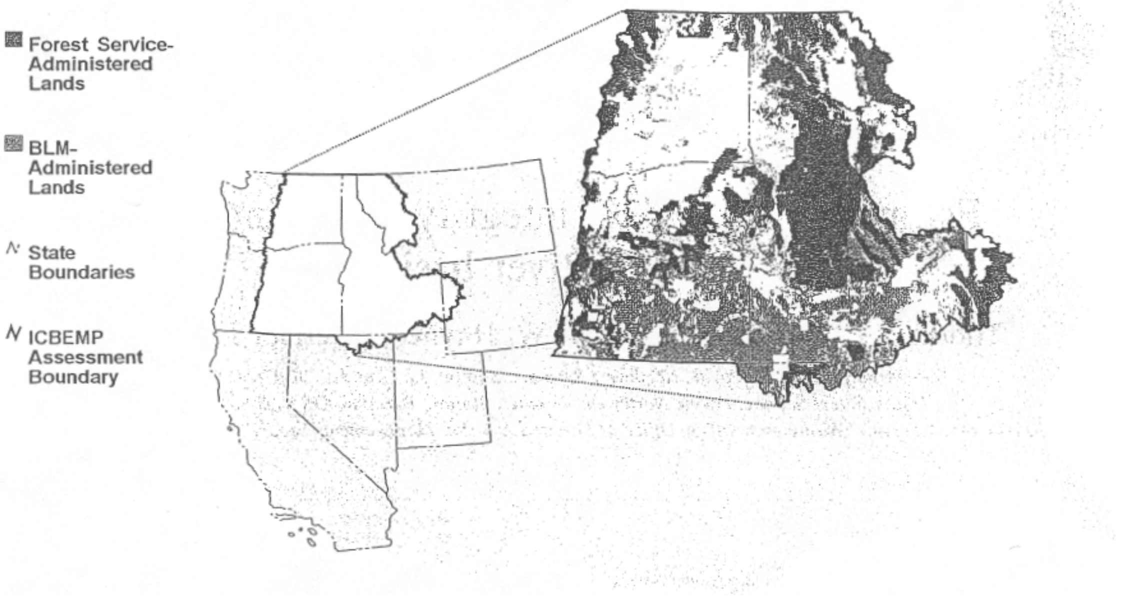

Fig. 1. The ICBEMP area is in the northwestern United States and includes portions of Idaho, Montana, Oregon, Washington, Utah, Nevada, and Wyoming.

assessment. Information gathered through the ICBEMP assessment process was used extensively to develop management alternatives aimed toward achieving specific goals on US Department of Agriculture (USDA), Forest Service (FS) and US Department of the Interior (USDI), Bureau of Land Management (BLM) public lands in the Basin (USDA and USDI, 2000). The ICBEMP relied on a framework (Haynes et al., 1996) to link diverse disciplines and address a range of goals for ecosystem management. These goals motivated much of the data collection and development of information about various processes and functions, presence and abundance of selected species, and characterization of various systems (see Quigley and Arbelbide (1997) for specific science assessments). The approach recognized the linked spatial and temporal hierarchies that exist within the Basin and the need to develop indicators so that changes in ecosystem conditions could be tracked.

The existence of specific goals for land management spurred the development of ecological integrity as a broad-scale measure. It could be used to assess progress toward land management goals or as an aide for managers in selecting or prioritizing areas (watersheds) for treatment. The challenge for the scientists associated with ICBEMP was to estimate current ecological integrity within the Basin and project trends in ecological integrity under proposed broadscale management alternatives. The information on ecological integrity within the Basin was developed primarily to answer four questions: (1) where within the Basin is ecological integrity high, moderate, and low? (2) where are opportunities to improve (restore) ecological integrity? (3) where are opportunities to produce desired goods, functions, and conditions with a low risk to ecological integrity? (4) what trends in ecological integrity are likely to result from alternative management strategies within the Basin? Subbasins[2] were chosen as the primary unit of analysis for this measure because they are hydrologic networks sufficiently large to approximate complete or nearly

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[2] The study area contains 164 subbasins, fourth level in the USGS hydrologic unit hierarchy (Seaber et al., 1987), that range from approximately 500 000-1 000 000 ha in size (see Hann et al., 1997).

complete aquatic ecosystems. Although the boundaries of subbasins are less meaningful to the terrestrial environment, we selected subbasins as a common boundary for purposes of terrestrial and aquatic analysis (see Haynes et al. (2001) for a description).

Analysis resulting in answers to questions 2 and 3 has been previously reported (Quigley et al., 1996; Rieman et a1., 2000). In that effort, forestland and rangeland conditions were each clustered into six spatially distinct groups. Each group was then described by common ecological conditions, risks to ecological systems, and opportunities to restore integrity and provide goods and services at low relative risk to ecological integrity.

The work reported here largely focuses on questions 1 and 4. In this paper, we describe development of our broad scale estimates of ecological integrity for the Basin and their application to the evaluation of three land management alternatives (Sl, S2, S3) outlined in the ICBEMP supplemental draft environmental impact statement (SDEIS) (USDA and USDI, 2000).

l.l. The management alternatives

Alternative S1 continues practices currently detailed in approximately 60 separate land management plans in the study area, including amendments and modifications to existing direction. Many existing plans are based on the assumption that ecological impacts can be mitigated (USDA and USDI, 2000). Under alternative S1, restoration of vegetation and its characteristic succession and disturbance patterns are usually not prioritized and restoration activities occur at relatively low levels. Providing a context for actions based on conditions at broad- and mid-scale[3] is not required. System components, from timber to wildlife species, are generally managed as individual resources (USDA and USDI, 2000).

Alternatives S2 and S3 “focus on restoring and maintaining ecosystems across the project areas and providing for the social and economic needs of people, while reducing short- and long-term risks to natural resources from human and natural disturbances” (USDA and USDI, 2000). Key factors that differentiate these alternatives from alternative S1 include: (1) integrated management direction across different scales, (2) a planning process (here called step-down) that places individual projects in context with both larger and smaller scale human and ecological processes and functions for a better understanding of cumulative results, (3) an adaptive management strategy that allows modification of management direction in response to new information, and (4) a spatially designated network of areas with key aquatic or terrestrial species or habitats, wildfire threats, or socioeconomic characteristics, most likely to benefit from maintenance or restorative actions (USDA and USDI, 2000).

Alternative S2 attempts to minimize short-term risk from management activities by requiring a step-down planning process to provide broad- and mid-scale context for proposed actions before conducting actions on-the-ground. Though initial actions are delayed because of this planning and analysis process, the intent of the alternative is to focus activities and resources in those areas where they would have the greatest chance of successfully restoring, maintaining or improving ecological systems. Restoration of vegetation and its characteristic succession and disturbance patterns is prioritized for specific conditions (e.g., low elevation dry forest types) and specific subbasins (e.g., subbasins with high risk to terrestrial and aquatic habitats). Protection is provided to specific watersheds for aquatic resources and for terrestrial resources by avoiding short-term risk and expanding strong habitat conditions.

Alternative S3 places considerably less emphasis on completing broad- or mid-scale step-down or context-setting planning processes prior to taking initial restoration and maintenance actions in many areas (i.e., it accepts a higher level of short-term risk), while aggressively taking actions to reduce long-term risk to natural resources from human and natural disturbances. As with alternative S2, restoration of vegetation and characteristic succession and disturbance patterns is prioritized for specific conditions (e.g., low elevation dry forest types) and specific subbasins (e.g., subbasins that have high risk to terrestrial and

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[3] In the ICBEMP assessment process, broad-scale landscapes and analyses covered large drainage basins (millions of hectares or more) and used 1 km^2 pixel resolution. Intermediate- (or mid-) scales covered subbasins to subwatersheds (tens of thousands to millions of hectares). Fine-scale analyses and maps covered subwatersheds to individual vegetation stands (tens of hectares to tens of thousands of hectares) (Hemstrom et al., 2001).

aquatic habitats). Alternative S3 identifies more subbasins as priority for restoration than alternative S2. Emphasis is placed on subbasins where activities would benefit human communities that are relatively isolated and less diverse. Protection is provided to specific watersheds for aquatic resources and for terrestrial resources by avoiding short-term risk and expanding strong habitat conditions (USDA and USDI, 2000).

1.2. Ecological integrity

The concept of integrity in ecosystems traces its roots to the land ethic defined by Leopold (1949). A rich, though mostly conceptual, literature exists on ecological integrity. Actual applications of this concept are not strongly represented. One expression of the concept, biotic or biological integrity, has been accepted in the aquatic ecology literature with specific meaning (Angermeier and Karr, 1994; Karr, 1981, 1991). Angermeier and Karr (1994) suggest a high state of biological integrity can be determined for a system that has little or no human influence. Their approach separates human influence and desire for specific elements of biological integrity from the measure of integrity itself, leaving society to choose among biological integrity levels with pristine (no human influence) as the highest attainable. Conversely, Kay (1993, p. 203), summarizing several papers on ecological integrity, states, “integrity can only be defined clearly (in terms of evaluative criteria) for specific ecosystems, in the context of humans which are an integral part of the ecosystem”. Kay concludes, that in defining ecological integrity, we must attempt to integrate everything we know about the ecological system and where we want it to be, including the sum of human preferences and concerns about the system. Kay’s conclusion .is consistent with the idea that defining and measuring ecological integrity is not strictly a scientific endeavor (Wickium and Davies, 1995). De Leo and Levin (1997) highlight the need for integrity measures that reflect the ability of ecosystems to maintain services valued by humans.

Also debated in the literature is the utility of the concept of ecological integrity for decision-making (e.g., Callicott, 1995; De Leo and Levin, 1997; De Soyza et al., 1997; Ramade, 1995; Yazvenko and Rapport, 1996). The debate generally surrounds three broad categories of potential measures: structural (maintaining all the parts), functional (maintaining processes and functions), and human uses (maintaining desired services).

Because no absolute measures of ecological integrity have been widely accepted, we adopted the concept that decision-making in the Basin could be improved using relative measures of ecological integrity (Steedman and Haider, 1993). ICBEMP scientists defined the primary attributes of a system that exhibits high ecological integrity and then, using proxies, compared existing conditions against these attributes. Thus, integrity, even in the absence of human influence, could be higher in some areas than in others. Results represent a relative rating of ecological integrity across the Basin and aid in understanding the relations among various ecosystem components and in focusing management resources.

2. Methods

2.1. Ecological integrity

The ICBEMP scientists followed six general steps in developing estimates of ecological integrity for the Basin. First, they developed descriptions of forestland, rangeland, and aquatic systems with high ecological integrity. Second, they listed factors that potentially contribute to levels of ecological integrity. Third, they selected proxies for these factors from among available data. Fourth, they rated forestland, rangeland, and aquatic integrity using the selected proxy variables summarized to river subbasins. Fifth, they derived composite ecological integrity ratings by clustering the proxy variables used to rate forestland, rangeland, and aquatic integrity. This resulted in a single, composite, rating of current ecological integrity for each subbasin. Sixth, they interpreted the results in terms of the questions driving the analysis.

Our definitions of systems with high ecological integrity are consistent with the broad categories debated in the literature (see Table 1). The definitions of ecological integrity retain integrated aspects and specifically include humans and their influence in the ecosystem (see Haynes et al., 1996). Each definition includes aspects of structure (e.g., assemblage of species, genetic diversity), function (e.g., adaptation

Table. l
Definitions for systems with high ecological integrity for each of the main ecological components (forestland, rangeland, and aquatic) and for the composite of these components[a]

Integrity component	A system with high integrity would include
Forestland and rangeland (terrestrial environment)	A mosaic of plant and animal communities consisting of well connected, high-quality habitats that supports a diverse assemblage of native and desired non-native species, all relevant stages of the life histories of these species, and the genetic diversity necessary for long-term persistence and adaptation in a variable environment
Aquatic	A mosaic of well-connected, high-quality water and habitats that supports a diverse assemblage of native and desired non-native species, all relevant stages of the life histories of these species, appropriate dispersal mechanisms, and the genetic diversity necessary for long-term persistence and adaptation in a variable environment
Composite ecological	A mosaic of system components that is resilient to natural disturbances, supports native and desired non native species, consists of a well-connected mosaic of terrestrial and aquatic habitats, has ecosystem functions and processes present and operating effectively, and generally exhibits high levels of terrestrial and aquatic integrity

[a] Adapted from definitions in Quigley et al. (1996).

to variable environments, high-quality habitats), and human values (e.g., mosaic of habitats, native and desired non-native species). The interactions among these aspects lead to considerable variation in any specific measure. In particular, the definitions are linked clearly to human values, which vary in spatial and temporal dimensions.

2.1.1. Indicators of integrity

ICBEMP scientists developed a list of indicators derived from the definitions of systems with high integrity that potentially contribute to broad levels of integrity (Table 2). The list highlights the types of indicators that could be used to characterize status of integrity. In most cases no consistent direct measures

Table 2
Factors potentially indicating level of integrity in forestland, rangeland and aquatic ecological systems[a]

Component of integrity	Potential indicators
Forestland	Level of expansion of exotic species Consistency of tree stocking levels with long-term disturbances Level of snags and down woody material Level of disruption to hydrologic regimes Absence or presence of wildfire Changes in fire severity and frequency
Rangeland	Level of expansion of exotic species Influence of grazing on vegetation patterns and composition Level of disruption to hydrologic regimes Changes in fire severity and frequency Level of increases in bare soil Level of expansion of woodlands
Aquatic	Presence of native fish and other aquatic species Distribution and connectivity of high-quality habitats Presence of relevant life history stages for native species Mosaic of strong, well connected populations of native and desired non-native fish Resilience of population of native and desired non-native fish to natural disturbances

[a] The list represents those thought to be of most importance to integrity in the Basin.

of the potential indicators were available across the Basin. Therefore, proxies for potential indicators were determined from information that was available in a consistent and complete way across the Basin. Proxies were chosen based on their potential to reflect trends toward or away from a system with high integrity.

2.1.2. Proxies for potential indicators of integrity

ICBEMP scientists selected 11 proxy variables to define integrity components within the Basin (Table 3). Seven variables were used to portray conditions of forestland (dry and moist forest), rangeland (dry grass or shrub, agricultural land, juniper and sagebrush), and aquatic (native fish and strong fish populations) systems. Four variables were used to represent modifying characteristics of the systems (moderate and low road density, fire frequency, and fire severity). GIS coverage for proxy variables was continuous either at the subwatershed or at the 1 km2 level of resolution, summarized to subbasins.

Potential vegetation was mapped using 1 km^2 resolution and summarized for each potential vegetation type in each subbasin (Jensen et al., 1997). Subbasins were considered forestland in this analysis when at least 20% of the land area was classified as dry, moist, or cold forest potential vegetation types. Subbasins were considered rangeland in this analysis when at least 20% of the land area was classified as rangeland or shrubland or juniper woodland potential vegetation types. Under these definitions, a number of subbasins were classified as both rangeland and forestland.

2.1.2.1. Dry and moist forest. These variables were selected to represent general conditions of the forest system. Empirical data from both the broad- and midscale landscape assessments (Hann et al., 1997; Hessburg et al., 1999) indicated that the early seral species of the dry and moist forest potential vegetation types were those most often sought for extraction of timber. Thus, these forested vegetation types were thought to represent the greatest potential for change from natural conditions.

2.1.2.2. Dry grass or dry shrub. These variables were selected to represent the dominant rangeland vegetation types that were most likely to have been impacted by past grazing practices and least resilient to exotic introductions and drought. Both broad- and mid-scale landscape assessments (Hann et al., 1997; Hessburg et al., 1999) found these potential vegetation types to be substantially changed from historical conditions, making them sensitive variables to assess broad shifts in rangeland conditions.

Table 3
Proxies used to characterize forestland, rangeland, aquatic, and composite ecological integrity in subbasins of the interior Columbia basin

Proxy variable[a]	Description	Integrity component
Percent dry forest	Percentage of subbasin area composed of dry forest potential vegetation types	Forestland, composite
Percent moist forest	Percentage of subbasin area composed of moist forest potential vegetation types	Forestland, composite
Dry grass or shrub	Percentage of subbasin area in dry grass or dry shrub potential vegetation types	Rangeland, composite
Agricultural land	Percentage of subbasin area in agricultural use	Rangeland, composite
Juniper and sagebrush	Percentage of subbasin area in western juniper or sagebrush potential vegetation types	Rangeland, composite
Native fish index	Community structure index of fish diversity, native, richness, and evenness	Aquatic, composite
Strong fish population index	Relative index of fish population strongholds	Aquatic, composite
Moderate or greater road density	Percentage of subbasin area with predicted road densities of moderate, high, and very high	Forestland, rangeland, aquatic, composite
Low road density	Percentage of subbasin area with predicted road densities of very low or unroaded	Forestland, rangeland, aquatic, composite
Fire frequency	Index of change from estimated historical fire frequency	Forestland, rangeland, composite
Five severity	Index of change from estimated historical fire severity	Forestland, rangeland, composite

[a] Proxy variables represent subbasin summaries of data developed in Hann et al. (1997), Lee et al. (1997), and Jensen et al. (1997).

2.1.2.3. Agricultural land. Much of the area currently in agricultural use was formerly native grassland and shrubland potential vegetation types. The definitions for systems with high integrity selected for analysis were biased against agricultural land uses, i.e., by definition a mosaic of native rangeland would have a higher integrity than land dominated by agricultural crops. This made the proportion of area in agricultural use a strong indicator of integrity.

2.1.2.4. Juniper and sagebrush. These variables were selected as indicators for the rangeland system because they have changed substantially during the last 150 years. Changes mostly have been associated with excessive livestock grazing, fire exclusion, and shifting climate conditions (Hann et al., 1997), and with reductions in the ability of associated ecological processes to recover after disturbance.

2.1.2.5. Native fish index. Lee et al. (1997) developed this index to represent the relative contributions of native fish species to fish community structure. It relied on data for 124 fish taxa within the Basin and incorporated the concepts of richness, diversity, and evenness into a single variable. Where the native fish index is high, the aquatic system has higher integrity (Lee et al., 1997).

2.1.2.6. Strong fish population index. Lee et al. (1997) developed this index to represent the number of subwatersheds within a subbasin where key salmonid populations are currently relatively abundant, where all the historical life history forms are present, and the trends are stable or improving. The variable was calculated for each subbasin based on empirical and projected status and trend data. Strong populations are indicative of systems with high integrity.

2.1.2.7. Fire frequency and severity. The landscape assessment of the ICBEMP estimated both fire frequency and severity at 1 km~ resolution, summarized to the subbasin level, across the Basin for current and historical conditions (Hann et al., 1997). The fire frequency variable represents the proportion of area in a subbasin where fire frequency declined between historical and current periods by at least one class. The fire severity variable represents the proportion of area in a subbasin where fire severity increased between historical and current periods by at least one class. The shifts in frequency and severity were generally a result of changing dynamics associated with such influences as domestic livestock grazing, . timber harvest, and fire exclusion. The changes in frequency and severity of fire are indicative of reductions in forestland and rangeland integrity.

2.1.2.8. Road density. The aquatic, terrestrial, and landscape assessments of the Basin (Hann et al., 1997; Lee et al., 1997; Marcot et al., 1997; Wisdom et al., 2000) consistently found roads to be associated with degraded systems. This finding is consistent with the broader literature (e.g., Forman, 2000; Forman and Alexander, 1998; Miller et al., 1996; Trombulak and Frissell, 2000). Although the presence of a road or its direct influence is not always the degrading factor, the activities generally associated with roads lead to potential degradation. For example, roads are associated with removal of snags and large old trees, introduction and spread of exotic plant species, illegal killing or taking of wildlife, increased siltation and erosion, and accidental fire ignition. Roads are also the primary means of access for vegetation treatments, recreation pursuits, and fire fighting. Hann et al. (1997) projected road densities across the Basin in six classes designed to facilitate modeling: none (<0.01 km/km^2), very low (0.01-0.06 km/km^2), low (0.06-0.43 km/km^2), moderate (0.43-1.06 km/km^2), high (1.06-2.92 km/km^2), and extremely high (>2.92 km/km^2). Lee et al. (1997) later compared information from these projections against known aquatic conditions and found that areas with estimated road densities of <0.06 km/km^2 were most generally associated with areas of low degradation and areas with estimated road densities of >0.43 km/km^2 were most generally associated with high degradation (Lee et al., 1997).

2.1.3. Integrity estimates

Cluster analysis (SAS, 1989) was used to organize subbasins into relative levels of integrity for forestland, rangeland, aquatic, and composite ecological integrity. The specific proxy variables used in each cluster analysis are shown in Table 3. Composite ecological integrity estimates were based on all proxies. The cluster analysis was used to differentiate subbasins into three categories of integrity (high, moderate, and low). For the aquatic and composite ecological integrity ratings, marginal adjustments were made to assigned classes based on collective knowledge of subbasin conditions, related analyses of specific subbasins, and supplemental information not available for all subbasins.

2.2. Trends in ecological integrity

The FS and BLM developed three broad alternatives describing objectives, priorities, standards, and guidelines to be used to manage Basin FS and BLM lands in the future (see USDA and USDI (2000) for a detailed description of the management alternatives). ICBEMP scientists developed projections of likely changes in forestland and rangeland vegetation on FS and BLM administered land, aquatic habitats, terrestrial habitats, disturbance regimes, and socioeconomic conditions under each alternative, to approximately 100 years into the future. These methods and outcomes are described in Hann et al. (2001), Hemstrom et al. (2001), Rieman et al. (2001), Raphael et al. (2001), and Crone and Haynes (2001), elsewhere in this volume.

We selected three broad level proxy variables from among the projected future conditions available to represent trends in ecological integrity. We compared the projected future conditions for these proxies under each alternative with current conditions across the subbasins. Using a 7-class scale from +3 to indicate strong improving trends in ecological integrity to -3 to indicate strong declining trends, we then summarized the trends and interpreted the results.

2.2.1. Road density

Trends in road density were used to indicate likely shifts in ecological conditions associated with the presence of roads. We modeled trends in road density at a 1 km^2 resolution across the entire Basin based on rule sets linking future activities described in the management alternatives with the current road density estimates reported in Hann et al. (1997). The rule sets translated assumptions about how road density changes would likely occur, for instance, two of the alternatives established priorities to reduce adverse road-related effects or limit new road building activities under specific conditions. For each alternative, each 1 km^2 was assigned an increasing, decreasing or stable trend in road density for each year over the next 100 years. The road proxy variable for a subbasin was assigned +1 if the net change in road density trends across an entire subbasin was projected to decrease by 20% or more, -1 if net road density trends across the subbasin were projected to increase by 20% or more, and 0 if net road density trends were not projected to change by + or -20%. These trends were used as an indicator of overall ecological conditions, varying inversely with road density.

2.2.2. Aquatic habitat condition

Aquatic habitat condition provided a general proxy for aquatic, riparian, hydrologic, and associated biotic conditions. Projections of aquatic habitat capacity were designed to represent the amount and quality, relative to potential, of aquatic habitat necessary to support the numbers, sizes or age states, and life history types of salmonids that occurred historically (see Rieman et al., 2001). Aquatic habitat capacity was modeled for each subwatershed between current and 100 years into the future for each management alternative. If habitat capacity for a given subwatershed increased by 20% it was defined as an increasing trend. If capacity declined the subwatershed was assigned a decreasing trend. If capacity remained the same or increased by less than 20% the subwatershed was assigned a stable trend. A weighted average habitat capacity trend was calculated for each subbasin in the two periods (current and. 100-year projection) based on area of included subwatersheds and their assigned trend. The aquatic habitat capacity proxy variable for a subbasin was assigned +1 if the weighted average for the subbasin showed at least a 20% improving trend, -1 if the weighted average showed at least a 20% decreasing trend, and 0 if the weighted average were between a 20% increasing and 20% decreasing trend.

2.2.3. Departure from the historical range of variability

Changes in terrestrial habitats, disturbance regimes, and vegetation mosaics can be represented by comparing historical vegetation patch size, composition, and structure to current and future vegetation characteristics (Hann et al., 1997). A composite proxy variable, called historical range of variability (HRV) departure, was developed to assess the departure of subwatershed patch composition, structure, size, and succession and disturbance processes from those expected to occur under natural succession and disturbance regimes (Hemstrom et al., 2001). The composite variable draws from the broad- and mid-scale landscape assessments of the Basin (Hann et al., 1997; Hessburg et al., 1999) by using rule sets and projected change in vegetation and succession and disturbance regimes between historical (approximately 50-100 years in the past), current, and 100 years in the future. It is possible that departure could increase in comparison to the HRV if succession and disturbance processes and patch characteristics are uncharacteristic to the natural processes that operate in the subwatershed. For instance, if the late seral vegetation component were to occur on a different environment (valley bottom as opposed to hill slope) than natural processes would support, the score would reflect a departure from the HRV. A weighted average for HRV departure was calculated using established rule sets by comparing historical, current, and future projections of vegetation composition and structure, fire severity and frequency, and similarity of landscape mosaics (Hann et al., 1997). The subbasin was assigned -I-1 if weighted future departure from HRV was calculated to decrease over current departure by 10% or more, -1 if departure from HRV was calculated to increase over current departure by 10% or more, or 0 if departure from HRV was not calculated to change by + or -10%.

3. Ecological integrity results

3.1. Current ratings across the Basin

Considering the 112 forestland subbasins (Fig. 2), 31% jointly had a low aquatic, forest land, and

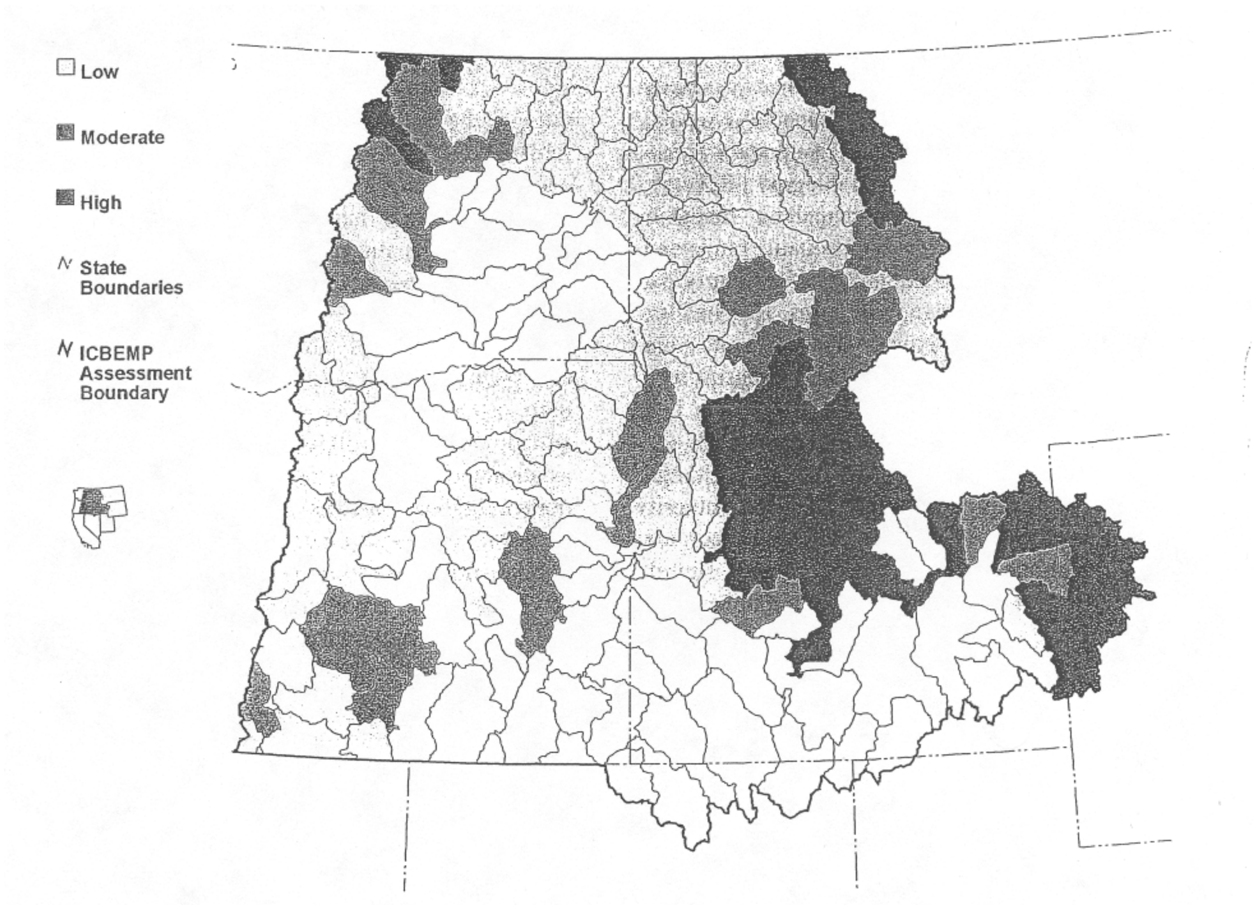

Fig. 2. Subbasins rated with high, moderate, or low forestland integrity within the assessment area.

Table 4
Correspondence of forestland and aquatic integrity ratings among those forestland subbasins[a] with a high (low) composite ecological integrity rating

High composite ecological integrity (29 subbasins)				Low composite ecological integrity (66 subbasins)			
Aquatic integrity rating	Forestland integrity rating			Aquatic integrity rating	Forestland integrity rating		
	High (%)	Moderate (%)	Low (%)		High (%)	Moderate (%)	Low (%)
Percent of forestland subbasins							
High	7	4	1	High	0	0	0
Moderate	10	3	1	Moderate	2	2	15
Low	1	0	0	Low	3	6	31

[a] One hundred and twelve subbasins were characterized as forestland subbasins.

composite integrity rating. Only 7% jointly had high aquatic, forestland, and composite integrity ratings. Just 10% had high forestland and composite integrity with a moderate aquatic integrity, whereas, 15% of the subbasins had low forestland and composite integrity with a moderate aquatic rating (Table 4). Thus, in forestland subbasins, composite integrity was more strongly influenced by the forestland integrity rating than the aquatic integrity rating. This logic seems reasonable given only 10% of all the subbasins rated high in aquatic integrity compared with 23% in forestland integrity (Table 5).

Results varied for the 91 rangeland subbasins (Fig. 3). Only 1% jointly had high aquatic, rangeland, and composite integrity ratings, but 45% jointly had low ratings. Of the rangeland subbasins, 13% had low rangeland and composite integrity and moderate aquatic integrity. Only 2% of the rangeland subbasins were rated with high aquatic integrity and 8% with high composite ecological integrity (Table 6). A higher proportion of the subbasins was rated with low rangeland integrity compared with low aquatic integrity (69% versus 54%; see Table 5). Thus, the integration of these components would likely show a slightly stronger influence from the rangeland component than from the aquatic component in its contribution to composite ecological integrity.

Combining the forestland and rangeland subbasins together to account for all 164 subbasins results in different outcomes. Where subbasins were rated for both forestland and rangeland integrity, we used the higher of the two ratings. This shows that 53% of the subbasins jointly had high, moderate, or low integrity ratings (the diagonal in the matrix) for aquatic and forestland (rangeland) integrity, 23% of the subbasins had lower aquatic ratings than forestland (rangeland) ratings, and 25% had lower forestland (rangeland) ratings than aquatic ratings (Table 7).

Across the 164 subbasins in the Basin, those rated as having high aquatic integrity (10%) are those that most closely resemble natural, fully functional aquatic ecosystems (Table 5). Subbasins rated as having moderate aquatic integrity typically support important aquatic resources, often with watersheds classified as strongholds for one or more native fish species in noncontiguous patterns. An important difference between high and moderate integrity is increased habitat fragmentation. Subbasins rated as having low aquatic integrity typically include isolated higher

Table 5
Percentage of subbasins rated as currently having high, medium, or low aquatic, forestland, rangeland, and composite ecological integrity

Integrity component	High rating (%)	Medium rating (%a)	Low rating (%)	Total subbasins considered (No.)
Aquatic	10	37	54	164
Forestland	23	18	59	112
Rangeland	8	23	69	91
Composite ecological	18	22	60	164

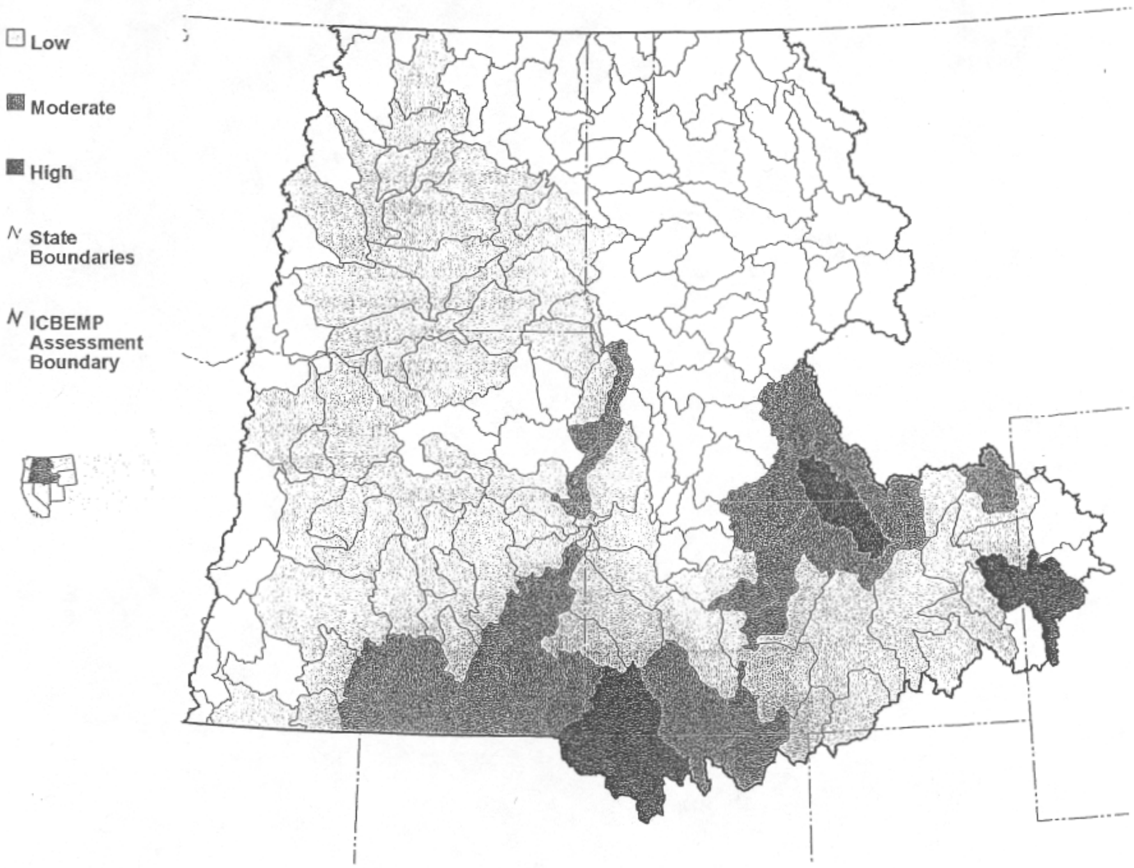

Fig. 3. Subbasins rated with high, moderate, or low rangeland integrity within the assessment area.

quality or unique habitats but lower overall condition. These habitats, it is assumed, would be addressed through finer scale analysis and decision processes (see Fig. 4).

The components of ecological integrity with high ratings ranged from 8% of the subbasins for rangeland to 23% for forestland (Table 5). Given that composite ecological integrity is an integration of the elements

Table 6
Correspondence of rangeland and aquatic integrity ratings among those rangeland subbasins[a] with a high (low) composite ecological integrity rating

High composite ecological integrity (eight subbasins)				Low composite ecological integrity (58 subbasins)			
Aquatic integrity rating	Rangeland integrity rating			Aquatic integrity rating	Rangeland integrity rating		
	High	Moderate	Low		High	Moderate	Low
Percent of rangeland subbasins							
High	1	0	1	High	0	0	0
Moderate	2	3	1	Moderate	0	1	13
Low	0	0	0	Low	0	4	45

[a] Ninety-one subbasins were characterized as rangeland subbasins.

Table 7
Percentage of subbasins with high, moderate, or low forestland, rangeland, and aquatic integrity ratings[a]

Aquatic integrity rating	Maximum forestland or rangeland integrity rating (%)		
	High	Moderate	Low
High	5	3	2
Moderate	10	7	20
Low	4	9	41

[a] For those subbasins with both a forestland and rangeland integrity rating (more than 20% of area in both forestland and rangeland), the higher rating is compared with the aquatic integrity rating. This provides a maximum rating for each of the 164 subbasins within the Basin assessment area.

used to cluster forestland, rangeland, and aquatic integrity, composite ecological integrity values reflect intermediate extents among the elements. Considerable overlap exists spatially among the components and composite ecological integrity (Figs. 2-5). The ratings are also a reflection of the proxy variables used.

Nearly two-thirds of the subbasins are rated as having low composite ecological integrity (60%; see Table 5). This is consistent with the overall findings of the science assessment of ICBEMP. Changes in fire regimes, introduction of exotic plant and animal species (terrestrial and aquatic), conversion of grassland and shrubland into agricultural land, change associated with increased road density, and excessive historical livestock grazing are major causes for these lower ratings.

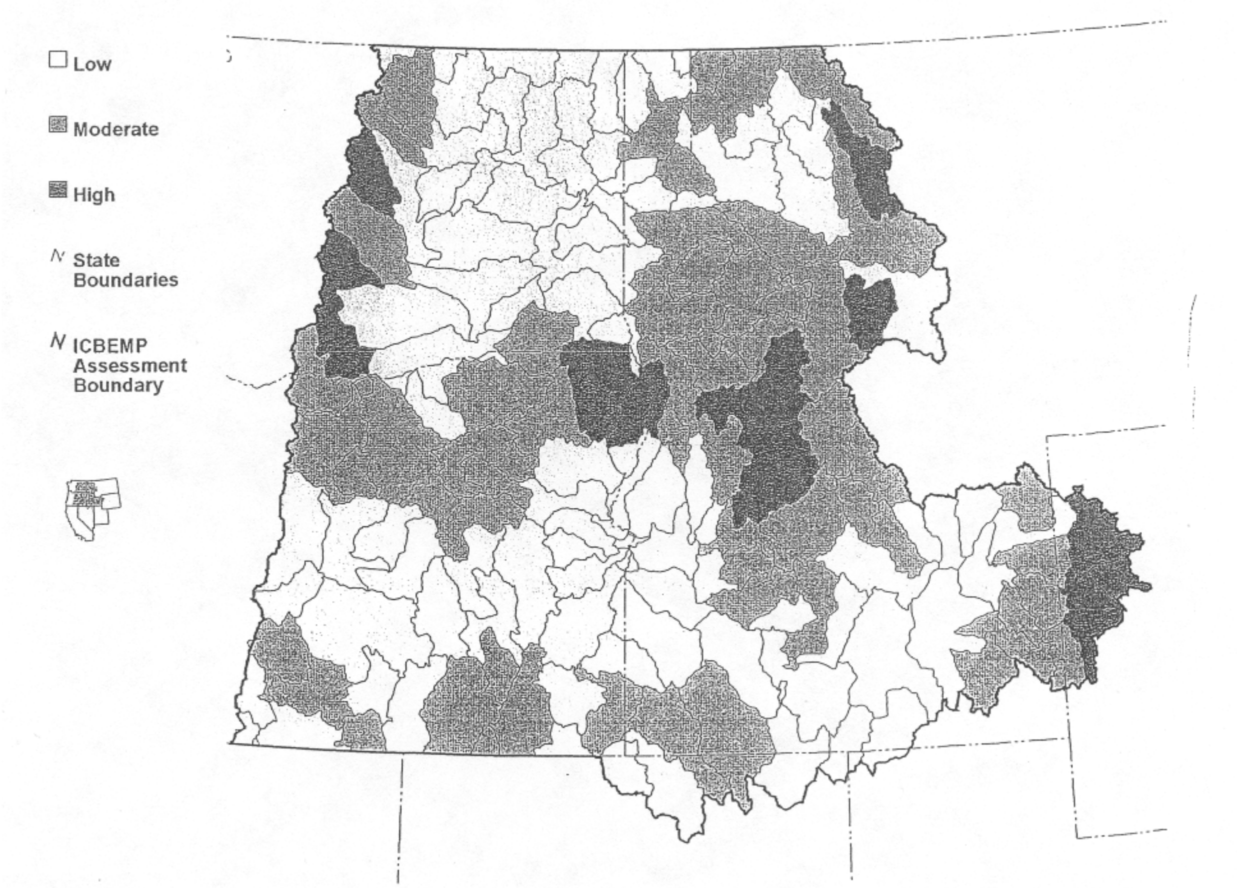

Fig. 4. Subbasins rated with high, moderate, or low aquatic integrity within the assessment area.

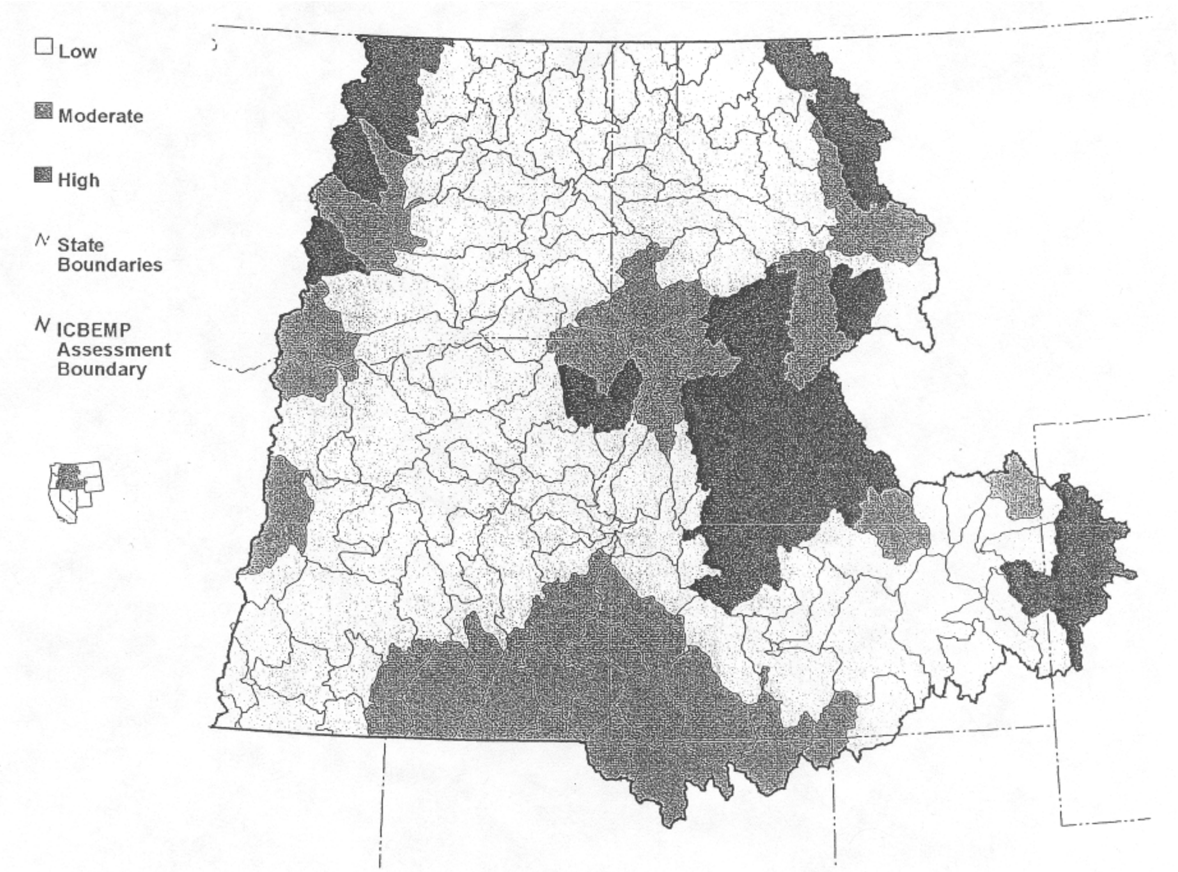

Fig. 5. Subbasins rated with high, moderate, or low composite ecological integrity within the assessment area.

3.2. Long-term trends in ecological integrity

Long-term trends in ecological integrity were rated on projected road density, departures from the historic range of variability, and aquatic habitat conditions at the subbasin level for the 164 subbasins with the project area. The ratings for the alternatives reflect only changes in management direction on FS and BLM administered lands but the ratings of long-term trends in ecological integrity are summarized to the subbasin level.

One question left unanswered by reference to the overall percentages, however, is whether areas of currently high ecological integrity decline. Table 8 shows that under all three alternatives just more than one-fourth (27 or 28%) of the FS and BLM area that is currently rated as having high ecological integrity shows a declining trend. This amounts to 6% of the total area of the Basin. A substantial difference among the alternatives is seen in those areas currently rated with low ecological integrity. Under alternative S1, 22% of that area that is FS or BLM administered is projected to continue to decline, compared with 3 and 8% of the area under alternatives S2 and S3, respectively. Alternatives S2 and S3 also show greater improvement in trends in FS and BLM area currently rated as having low integrity compared with alternative S1 (79% for S2 and 62% for S3 compared with 45% for Sl). Of the FS and BLM administered lands currently rated as having moderate integrity, 58% show improvement under alternative S2, while 44% show improvement under both alternatives S1 and S3. As can be seen in Table 8, the degree to which the subbasins with moderate or low current integrity show

Table 8
Trends in ecological integrity as a percent of area currently rated with low, medium, or high composite ecological integrity and as a percent of the entire Basin for each alternative

Current ecological integrity rating	Trend in ecological integrity	Alternative S1		Alternative S2		Alternative S3	
		Rating area	[a] Total basin[b]	Rating area	Total basin	Rating area	Total basin
Low	3	0	0	10	5	5	3
	2	13	7	41	21	20	10
	1	32	16	28	14	37	19
	0	33	17	18	9	30	15
	-1	22	11	3	2	8	4
	-2	0	0	0	0	0	0
	-3	0	0	0	0	0	0
Total low		100	51	100	51	100	51
Moderate	3	0	0	0	0	0	0
	2	4	1	6	2	2	1
	1	40	10	52	14	42	11
	0	45	12	36	9	44	12
	-1	11	3	6	1	11	3
	-2	0	0	0	0	0	0
	-3	0	0	0	0	0	0
Total moderate		100	26	100	26	100	26
High	3	0	0	0	0	0	0
	2	0	0	12	3	4	1
	1	37	9	25	6	29	7
	0	35	8	35	8	40	9
	-1	28	6	27	6	27	6
	-2	0	0	0	0	0	0
	-3	0	0	0	0	0	0
Total high		100	23	100	23	100	23

[a] Percent of rating area is the percent of Forest Service and Bureau of Land Management land within the subbasins with the trend rating as shown and with the same current ecological integrity rating

[b] Percent of total Basin is the percent of Forest Service and Bureau of Land Management land within the entire Basin with the shown trend in integrity and current ecological integrity rating. Note: numbers are rounded to the nearest integer.

improving or declining trends is a substantial difference among the alternatives.

Subtracting the percent of land projected to show declining ecological integrity trends from the percent of land projected to show improving trends demonstrates a significant difference among the alternatives. Alternative S2 shows a net improvement in ecological integrity over 56% of the total Basin during the 100 years following implementation. Alternative S3 shows a net improvement in ecological integrity of 39%. Both alternatives S2 and S3 contrast sharply with results for alternative S1, which shows a net improvement in ecological integrity of only 23% (see Table 8).

No subbasins showed moderate or strong declines in ecological integrity trends under any of the alternatives. Those subbasins showing decreasing trends were generally a result of continued and increasing departure from the HRV (Hemstrom et al., 2001) coupled with aquatic and terrestrial systems that were projected as stable. Thus, the downward contribution to overall integrity trends arising from succession and disturbance outside the HRV for these subbasins was not offset, as it was in subbasins showing stable or improving trends, by improving aquatic or terrestrial system trends.

Stable or improving aquatic contributions were generally projected to occur through the implementation of the alternatives across the basin. Thus, the aquatic contribution to trends in ecological integrity was either stable or improving. Reductions from the high timber harvest, grazing, and road construction activity levels of the recent past coupled with the FS and BLM management direction in the alternatives to conserve or restore aquatic systems were the primary drivers for the aquatic outcomes.

Terrestrial contributions to overall ecological integrity trends for all alternatives were mostly stable in subbasins dominated by rangeland systems and improving in the moist forest environments. Differences among the alternatives were more evident in areas where restoration was emphasized in alternatives S2 and S3. No subbasins are projected to decline in terrestrial contribution to overall integrity trends under any of the alternatives. The proxy was trend in road density. Although many terrestrial outcomes are strongly correlated with road density and use, some terrestrial outcomes are not indexed well by road density (Forman, 2000; Forman and Alexander, 1998; Trombulak and Frissell, 2000; Wisdom et al., 2000). For instance, in the rangeland setting, several of the species are projected to decline in population outcome across the Basin, yet road densities are not projected to increase for these areas (see Raphael et al., 2001). The conditions on some rangelands have been altered so substantially through changes in fire regimes, introduction of exotic species, and excessive historical livestock grazing, that restoring these areas to an approximation of historical conditions is not possible. Thus terrestrial habitat conditions in such settings is not well reflected by the relatively simple proxy we selected, although it is a useful indicator overall.

The strongest increasing trends in broad-scale vegetation patterns were in subbasins where vegetation is so altered through human activity that the planned level of mitigation and restoration activities are not sufficient to reverse continued departure from the HRV In both forestland and rangeland ecosystems these areas are predominantly the large landscapes where few restoration activities are planned and where departures already exist. In these subbasins, relying on mostly passive approaches to reset the frequency and severity of disturbance regimes is projected to require more than the 100-year time horizon. Improved conditions largely coincide with the subbasins designated for high priority restoration with concentrated mitigation and restoration activities in the FS and BLM management alternatives (S2 and S3). In these subbasins, prioritized efforts result within the next 100 years in reversing or slowing the trends in succession and disturbance. Alternative S2, which emphasizes a step-down or contextual approach to planning, increases the likelihood that management activities on adjacent lands will be complementary.

4. Discussion

Substantial differences in composite ecological integrity were evident across the Basin. By defining, a priori, the characteristics of a system with high integrity, this analysis was essentially an examination of departure from those characteristics. The paucity of consistent measures for the indicators of integrity renders the analysis to one that mostly examines departure from historical conditions. Where conditions have departed the most, one would expect lower levels of ecological integrity. Thus, certain types of human influence can result in declines in integrity, despite the fact that human values were highlighted in the definitions of. systems with high integrity. Our proxies were mostly reflective of lower levels of integrity for systems that had changed through human intervention. Thus, we likely would have relied on the same variables, because they were essentially the only variables available, if we had adopted definitions similar to those of Angermeier and Karr (1994).

Our results indicate that the management alternatives proposed for the Basin have their most dramatic differences, in terms of trends in ecological integrity, in those subbasins currently rated as having low or moderate composite ecological integrity, i.e., subbasins with high current integrity show similar trends across the alternatives and were generally targeted for actions that protect these conditions. This contrasts with subbasins currently rated as moderate or low integrity, where active restoration results in stable or improving trends in ecological integrity. A focused restoration effort, guided by an understanding of the context for conditions and a goal to maintain or enhance integrity, can be effective, as our results indicate for the subbasins prioritized for active restoration.

The results reported here, when coupled with the results reported by Rieman et al. (2000), respond to the four primary questions driving the analysis. An approach similar to the one reported here can (1) demonstrate where ecological integrity is high, moderate, and low, (2) where opportunities for restoration exist, (3) where opportunities to produce goods and services at low risk to ecological integrity exist, and (4) what trends in ecological integrity are likely to result from alternative management approaches. The lack of consistent indicators is likely to force reliance on proxy measures in the near term.

5. Conclusions

Some general observations can be drawn from an understanding of the pattern of composite ecological integrity that resulted from the legacy of human uses within the Basin. In general, subbasins that currently have high ecological integrity are wildland areas with little agricultural or industrial development. It is important to recall that our .measures of ecological integrity are relative measures for comparisons only within the interior Columbia basin. If global measures were available it is possible that more of the Basin would be rated as having high ecological integrity. For instance, the human population density of the Basin is well below the average for the United States and the Basin is well known for its scenic beauty and natural resources, so relative to other more populated areas the Basin may-be rated higher in ecological integrity. In general, subbasins currently rated as having low ecological integrity are those with agricultural or extractive resource uses. In other cases, ratings of low ecological integrity might reflect a subbasin that is being managed for a homogeneous pattern of vegetation that, by definition; would not be rated as having high ecological integrity. Low ecological integrity does not by definition lead to impoverished human conditions, as many of these subbasins include counties with above average per capita incomes derived from agriculture, manufacturing, or government functions.

High ecological integrity is threatened by rapidly expanding human pressures in several subbasins. These are subbasins where rapidly growing urban populations coincide with subbasins of moderate or high ecological integrity (such as northern Idaho and northwest Montana). In other subbasins, such as those in the central Idaho wildernesses, ecological integrity is high for large contiguous blocks and human population density is low and projected to remain low. The ecological integrity of these subbasins is more at risk from potential changes in fire, insect, and disease disturbance processes, complicated by decades of fire exclusion.

If ecological restoration is a management goal, measures such as those developed for forestland, rangeland, aquatic, composite ecological integrity, and trends in ecological integrity will be needed to understand current conditions and potential opportunities for restoration. The broad-scale measures of integrity and trends provided an important basis for prioritizing subbasins for management emphasis and restoration within FS and BLM planning in the Basin (USDA and USDI, 2000). To be most effective and efficient, restoration treatments will need to be prioritized at multiple scales (e.g., within a region such as the interior Columbia basin, within a subbasin, and within a subwatershed). The process is only now beginning in the Basin. Local land managers and technical specialists can undoubtedly propose an unlimited number of restoration treatments for subwatersheds within a given management unit. The key to successful restoration will be to focus treatments where they can most effectively achieve regional, subbasin, and subwatershed goals consistently. Absent this prioritization process, restoration treatments will likely be aimed at only local (e.g., subwatershed) goals that might not contribute to, and may unknowingly conflict with, regional goals.

In addition to driving regional and local management priorities, these efforts to define and measure composite ecological integrity and ecological integrity trends have already had profound policy impacts. The Committee of Scientists (1999)[4] proposed the achievement of ecological, social, and economic sustainability as the overall goal for management of the National Forests but that the priority is the maintenance and restoration of ecological sustainability to provide a

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[4] The Committee of Scientists was named by the Secretary of Agriculture in 1997 to provide technical and scientific advice on land and resource planning on the National Forests and Grasslands. They presented their report in March 1999.

sustainable flow of products, services, and other values for the American people. They recommend that ecological integrity be used as an integrative measure of ecological condition needed to judge the extent of ecological sustainability. A debate is now emerging about the definitions of integrity, measurement issues including the use of relative comparisons, and the role of scientists in providing judgments about the extent or level of various indicators.

References

Angermeier, PL., Kam J.R., 1994. Biological integrity vs biological diversity as policy directives: protecting biotic resources. Bioscience 44, 690-697.

Callicott, J.B., 1995. A review of some problems with the concept of ecosystem health. Ecosyst. Health 1, 101-112.

Committee of Scientists, 1999. Sustaining the People's Lands: Recommendations for Stewardship of National Forests and Grasslands into the Next Century. US Department of Agriculture, Washington, DC, 193 pp.

Crone, L.K., Haynes, R.W, 2001. Socioeconomic evaluation of the SDEIS alternatives. For. Ecol. Manage. 153,.147-160.

De Leo, G.A., Levin, S., 1997. The multifaceted aspects of ecosystem integrity. Conserv. Ecol. (online) 1 (1) 3 (URL:http://www.consecol.org/voll/issl/art3).

De Soyza, A.G., Whitford, WG., Herrick, J.E., 1997. Sensitivity testing of indicators of ecosystem health. Ecosyst. Health 3, 44-53.

Forman, R.TT., 2000. Estimate of area affected ecologically by the road system in the United States. Conserv. Biol. 14, 31-35.

Forman, R.TT, Alexander, L.E., 1998. Roads and their major ecological effects. Annu. Rev. Ecol. Syst. 29, 207-231.

Hann, WJ., Jones, J.L., Karl, M.G., Sherm, Hessburg, RE, Keane, R.E., Long, D.G., Menakis, J.P., McNicoll, C.H., Leonard, S.G., Gravenmier, R.A., Smith, B.G., 1997. Landscape dynamics of the basin. In: Quigley, T.M., Arbelbide, S.J. (Tech. Eds.), An Assessment of Ecosystem Components in the Interior Columbia Basin and Portions of the Klamath and Great Basins, Vol. 2. General Technical Report No. PNWGTR-405. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, pp. 337-1055.

Hann, W.J., Hemstrom, M.A., Haynes, R.W; Clifford, J.L., Gravenmier, R.A., 2001. Costs and effectiveness of multi-scale integrated management. For. Ecol. Manage. 153, 127-145.

Haynes, R.W, Graham, R.T, Quigley, T.M. (Tech. Eds.), 1996. A framework for ecosystem management in the interior Columbia basin and portions of the Klamath and Great Basins. General Technical Report No. PNW-GTR-374. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 47 pp.

Haynes, R.W., Quigley, T.M., Clifford, J.L., Gravenmier, R.A., 2001. Science and ecosystem management in the interior Columbia basin. For. Ecol. Manage. 153, 3-14.

Hemstrom, M.A., Korol, J.J., Hann, W.J., 2001. Trends in terrestrial plant communities and landscape health indicate the effects of alternative management strategies in the interior Columbia River basin. For. Ecol. Manage. 153, 105-125.

Hessburg, P.F., Smith, B.G., Kreiter, S.D., Miller, C.A., Salter, R.B., McNicoll, C.H., Hann, W.J., 1999. Historical and current forest and range landscapes in the interior Columbia River basin and portions of the Klamath. and Great Basins. Part 1. Linking vegetation patterns and landscape vulnerability to potential insect and pathogen disturbances. General Technical Report No. PNW-GTR-458. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 357 pp.

Jensen, M., Goodman, I., Brewer, K., 1997. Biophysical environments of the Basin (Chapter 2). In: Quigley, T.M., Arbelbide, S.1. (Tech. Eds.), An Assessment of the Ecosystem Components of the Interior Columbia Basin and Portions of the Klamath and Great basins, Vol. I. General Technical Report No. PNW-GTR-405. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Karr, J.R., 1981. Assessment of biotic integrity using fish communities. Fisheries 6 (6), 21-27.

Karr, J.R., 1991. Biological integrity: a long-neglected aspect of water resource management. Ecol. Appl. 1 (1), 66-84.

Kay, J.J., 1993. On the nature of ecological integrity, some closing comments. In: Woodley, S., Kay, 1., Francis, G. (Eds.), Ecological Integrity and the Management of Ecosystems. St. Lucie Press, Delray Beach, FL, pp. 201-212.

Lee, D.C., Sedell, J.R., Rieman, B.E., Thurow, R.F., Williams, J.E., 1997. Broadscale assessment of aquatic species and habitats. In: Quigley, T.M., Arbelbide, S.1_ (Tech. Eds.), An Assessment of Ecosystem Components in the Interior Columbia Basin and Portions of the Klamath and Great basins. General Technical Report No. PNW 405. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, pp. 1057-1496.

Leopold, A., 1949. A Sand County Almanac and Sketches Here and There. Oxford University Press, New York.

Marcot, B.G., Castellano, M.A., Christy, J.A., Croft, L.K., Lehmkuhl, J.F., Naney, R.H., Nelson, K., Niwa, C.G., Rosentreter, R.E., Sandquist, R.E., Wales, B.C., Zieroth, E., 1997. Terrestrial ecology assessment. In: Quigley, T.M., Arbelbide, S.J. (Tech. Eds.), An Assessment of Ecosystem Components in the Interior Columbia Basin and Portions of the Klamath and Great basins. General Technical Report No. PNW405. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, pp. 1497-1713.

Miller, JR., Joyce, L.A., Knight, R.L., King, R.M., 1996. Forest roads and landscape structure in the southern Rocky Mountains. Landscape Ecol. 11 (2), 115-127.

Quigley, T.M, Arbelbide, S.J. (Tech. Eds.), 1997. An assessment of ecosystem components in the interior Columbia basin and portions of the Klamath and Great basins. General Technical Report No. PNW-GTR-405. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Quigley, T.M., Haynes, R.W, Graham, R.T (Tech. Eds.), 1996. Integrated scientific assessment for ecosystem management in the interior Columbia Basin and portions of the Klamath and Great Basins. General Technical Report No. PNW-GTR-382. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 303 pp.

Ramade, F., 1995. Qualitative and quantitative criteria defining a “healthy” ecosystem. In: Rapport, D.J., Gaudet, C.L., Calow, P (Eds.), Evaluating and Monitoring the Health of Large Scale Ecosystems. Springer, Berlin, pp. 43-61.

Raphael, M.G., Wisdom, M.J., Rowland, M.M., Holthausen, R.S., Wales, B.C., Marcot, B.M., Rich, T.D., 2001. Status and trends of habitats of terrestrial vertebrates in relation to land management in the interior Columbia River basin. For. Ecol. Manage. 153, 63-88.

Rieman, B.E., Hessburg, P.F, Lee, D.C., Thurow, R.F., Sedell, J.R., 2000. Toward an integrated classification of ecosystems: defining opportunities for managing fish and forest health. Environ. Manage. 25 (4), 425--0-04.

Rieman, B., Peterson, J.T, Clayton, J., Howell, P., Thurow, R., Thompson, W., Lee, D., 2001. Evaluation of potential effects of federal land management alternatives on trends of salmonids and their habitats in the interior Columbia River basin. J. For. Ecol. Manage. 153, 43-62.

SAS, 1989. SAS/STAT User’s Guide, Version 6, Vol. 1, 4th Edition. SAS Institute, Inc., Cary, NC, USA.

Seaber, PR., Kapinos, F.P., Knapp, G.L., 1987. Hydrologic unit maps. Water Supply Paper No. 2294. US Geological Survey, Corvallis, OR, 62 pp.

Steedman, R., Haider, W., 1993. Applying notions of ecological integrity. In: Woodley, S., Kay, J., Francis, G. (Eds.), Ecological Integrity and the Management of Ecosystems. St. Lucie Press, Delray Beach, FL, pp. 47-60.

Trombulak, S.C., Frissell, C.A., 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conserv. Biol. 14, 18-30.

US Department of Agriculture, Forest Service and US Department of the Interior, Bureau of Land Management (USDA and USDI), 2000. Interior Columbia basin supplemental draft environmental impact statement, BLM/OR/WA/Pt-00/019-f1792. US Department of the Interior, Bureau of Land Management, Portland, OR (irregular pagination).

Wickium, D., Davies R.W., 1995. Ecosystem health and integrity? Can. J. Bot. 73, 997-1000.

Wisdom, MJ., Holthausen, R.S., Wales, B.C., Hargis, C.D., Saab, V.A., Lee, D.C., Hann, W.J., Rich, T.D., Rowland, M.M., Murphy, W.1., Eames, M.R., 2000. Source Habitats for Terrestrial Vertebrates of Focus in the Interior Columbia Basin: Broad-scale Trends and Management Implications, Vol. 1. General Technical Report No. PNW GTR-485. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR (CD-ROM).

Yazvenko, S.B., Rapport, D.J., 1996. A framework for assessing forest ecosystem health. Ecosyst. Health 2, 40-51.