United States Department of Agriculture

Forest Service

Pacific Northwest Research Station

United States Department of the Interior

Bureau of Land Management

Research Paper
PNW-RP-545
March 2003

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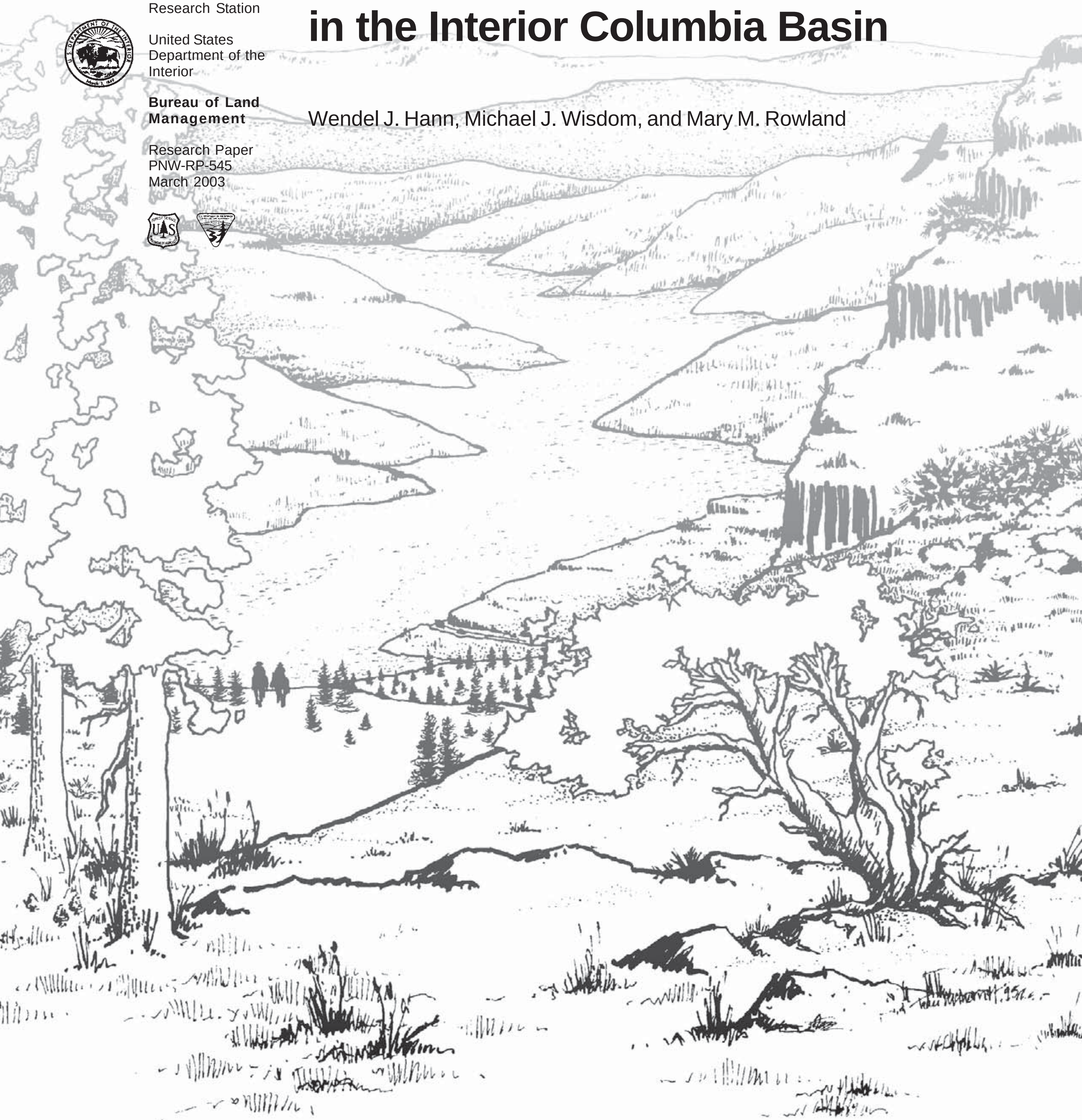

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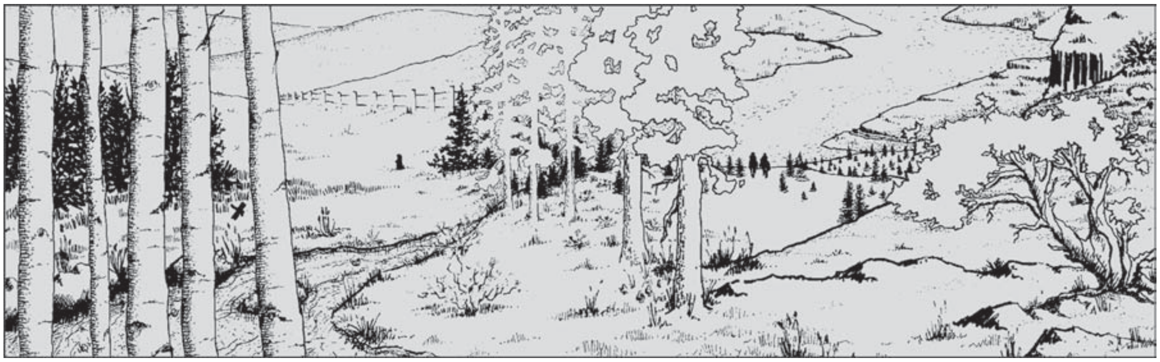

Disturbance Departure and Fragmentation of Natural Systems in the Interior Columbia Basin

Wendel J. Hann, Michael J. Wisdom, and Mary M. Rowland

Interior Columbia Basin Ecosystem Management Project: Scientific Assessment

Thomas M. Quigley, Editor

U.S. Department of Agriculture
Forest Service
Pacific Northwest Research Station
Portland, Oregon
Research Paper PNW-RP-545
March 2003

Abstract

Hann, Wendel J.; Wisdom, Michael J.; Rowland, Mary M. 2003. Disturbance departure and fragmentation of natural systems in the interior Columbia basin. Res. Pap. PNW-RP-545. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 19 p.

We integrated landscape data from science assessments of the interior Columbia basin (basin) into one variable that functions as a robust index of departure from native conditions. This variable, referred to as the disturbance departure and fragmentation index, is a spatially explicit measure of landscape quality and resiliency. Primary causes of departure and fragmentation include fire exclusion, timber harvest, mining, oil and gas development, livestock grazing, invasive species, road networks, and the interface of these activities with agricultural and urban development. We derived four classes of the disturbance departure and fragmentation index: very high, high, moderate, and low. Very high departure and fragmentation was associated with low-elevation subwatersheds dominated by agricultural and urban lands. High departure and fragmentation was found in subwatersheds containing a mix of agricultural lands with low-elevation forests, woodlands, or rangelands. Subwatersheds with moderate departure and fragmentation were associated with low- to mid-elevation forests, woodlands, or rangelands in public ownership. Subwatersheds with low departure and fragmentation typically occurred at higher elevations, on public lands within or near wilderness areas, roadless areas, or national parks. Because the disturbance departure and fragmentation index represents the composite effects of management activities that do not mimic native or natural processes, the index appears useful as a planning tool for integrated restoration of wildland landscapes.

Keywords: Disturbance departure, fragmentation, historical range of variability, interior Columbia basin, land use planning, landscape ecology, resiliency, similarity index, wildland landscapes.

Summary

We developed a disturbance departure and fragmentation index as a composite estimate of departure of current landscapes from their natural or native conditions. The index is an integration of landscape variables that measure departure of succession and disturbance regimes, composition and structure of vegetation, and associated mosaic patterns at coarse, mid, and fine scales. Departure from natural or native conditions was associated with both active (e.g., timber harvest and road-building, livestock grazing) and passive (e.g., fire exclusion) management, as such activities typically have not mimicked natural processes or resulted in landscapes that resemble native conditions. Departure from the natural frequencies and severities of disturbance (disturbance regimes), departure from natural recovery rates or pathways from disturbance (succession regimes), and fragmentation of mosaics and disturbance regimes have widespread, substantial effects on resiliency and quality of wildland landscapes. We define wildland landscapes as the environmental conditions present under historical disturbance and succession regimes. Departure has resulted in conditions unlikely to provide habitats needed to support historical diversity and richness of native species, or to maintain basic soil and hydrologic components. Fragmentation has occurred as a result of both active and passive management that does not represent natural disturbance processes. Decreasing patch size has resulted in fragmentation of habitats and their connectivity. At the same time, increasing patch size has resulted in fragmentation of disturbance and succession regimes. The disturbance departure and fragmentation index provides an efficient means of characterizing these patterns and processes on large landscapes for integrated restoration planning and management.

Preface

The Interior Columbia Basin Ecosystem Management Project was initiated by the Forest Service and the Bureau of Land Management to respond to several critical issues including, but not limited to, forest and rangeland health, anadromous fish concerns, terrestrial species viability concerns, and the recent decline in traditional commodity flows. The charter given to the project was to develop a scientifically sound, ecosystem-based strategy for managing the lands of the interior Columbia River basin administered by the Forest Service and the Bureau of Land Management. The Science Integration Team was organized to develop a framework for ecosystem management, an assessment of the socioeconomic and biophysical systems in the basin, and an evaluation of alternative management strategies. This paper is one in a series of papers developed as background material for the framework, assessment, or evaluation of alternatives. It provides more detail than was possible to disclose directly in the primary documents.

The Science Integration Team, although organized functionally, worked hard at integrating the approaches, analyses, and conclusions. It is the collective effort of team members that provides depth and understanding to the work of the project. The Science Integration Team leadership included deputy team leaders Russell Graham and Sylvia Arbelbide; landscape ecology—Wendel Hann, Paul Hessburg, and Mark Jensen; aquatic—Jim Sedell, Kris Lee, Danny Lee, Jack Williams, Lynn Decker; economic--Richard Haynes, Amy Horne, and Nick Reyna; social science—Jim Burchfield, Steve McCool, Jon Bumstead, and Stewart Allen; terrestrial—Bruce Marcot, Kurt Nelson, John Lehmkuhl, Richard Holthausen, Randy Hickenbottom, Marty Raphael, and Michael Wisdom; spatial analysis—Becky Gravenmier, John Steffenson, and Andy Wilson.

Thomas M. Quigley
Editor

United States Department of Agriculture

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Introduction

Wildland landscapes are declining in quality and resiliency across most areas of the world (Lavorel 1999, Sala et al. 2000, Walker et al. 1999). The quality of wildland landscapes, defined as the degree to which native conditions and processes occur over large areas, has been substantially reduced during the past century (e.g., see Hann and Bunnell 2001; Hann et al. 1997, 1998; Hardy et al. 2001; Hemstrom et al. 2001). The result has been a rapid increase in extinction rates of native species (Flather et al. 1994, 1998).

Resiliency, or rate and degree to which such wildland landscapes and their native biota renew the natural cycle of functions, processes, and conditions following disturbance (Allen and Hoekstra 1992, Hann et al. 1997), also has declined in concert with quality (Noss 2001). Fire exclusion, timber harvest, mining, oil and gas development, livestock grazing, invasive exotic flora and fauna, road networks, and the interface of these activities with agricultural and urban development all have contributed to declining wildland quality and resiliency, as such activities typically do not mimic processes in native systems (Hann et al. 1997, 1998; Landres et al. 1999; Morgan et al. 1994).

Pre-European conditions and processes in the Western United States, as estimated by the historical range of variability (HRV), provide a useful baseline for assessing current and future quality and resiliency of wildland landscapes (Hann et al. 1997, 1998; Hardy et al. 2001; Hemstrom et al. 2001; Huston 1994; Landres et al. 1999; Morgan et al. 1994). We define native conditions as the plants and animals that are indigenous to a specified area, the relations of these native species to each other and their environment, and the associated background processes that occurred in such areas before European settlement of the interior Columbia basin (referred to as basin, fig. 1). Native conditions are synonymous with those fitting within the HRV, as measured just before European settlement of the basin (Hann et al. 1997).

Because native landscapes respond to the cumulative effects of all disturbance regimes, the degree to which landscapes have departed from HRV can be integrated and mapped to provide an accurate index of conditions (Caprio and Graber 2000; Hann et al. 1997, 1998; Hardy et al. 2001; Hemstrom et al. 2001; Quigley et al. 1998; Rieman et al. 2000). However, development of an integrated index can be difficult: multiple input variables can have opposing trends that confound results, or the algorithms used to synthesize multiple variables may not provide an equitable representation of all such variables. Yet, successful prioritization and planning to maintain or restore quality and resiliency of landscapes depends in large part on the ability to assess and map the composite departure from natural systems, based on the combined effects of major landscape patterns and processes (Allen and Hoekstra 1992, Sayre et al. 2000). A composite measure provides an important component for the design of landscape plans to restore a diverse array of wildland resources (Caprio and Graber 2000, Hann and Bunnell 2001, Hann et al. 2001, Hardy et al. 2001, Hemstrom et al. 2001, Quigley et al. 1998, Rieman et al. 2000).

In designing a composite, integrated index of departure from native conditions, two problems are apparent from past approaches. The first is that most efforts have focused on departure from a specific disturbance regime (such as fire regime), from composition and structure of a particular ecosystem (such as forests), or from a particular set of native species (such as fish) (Caprio and Graber 2000, Quigley et al. 1998, Rieman et al. 2000). These indices are useful for developing management priorities for the associated disturbance regimes, ecosystems, or sets of species, but do not provide a composite estimate for prioritization and planning of holistic restoration of large landscapes and all associated resources. The second problem is that most efforts focus on data from one scale, such as the broad or coarse scale for a large area (Hardy et al. 2001), or the fine scale for a smaller area (Caprio and Graber 2000). Such approaches fail to integrate the departure of characteristics

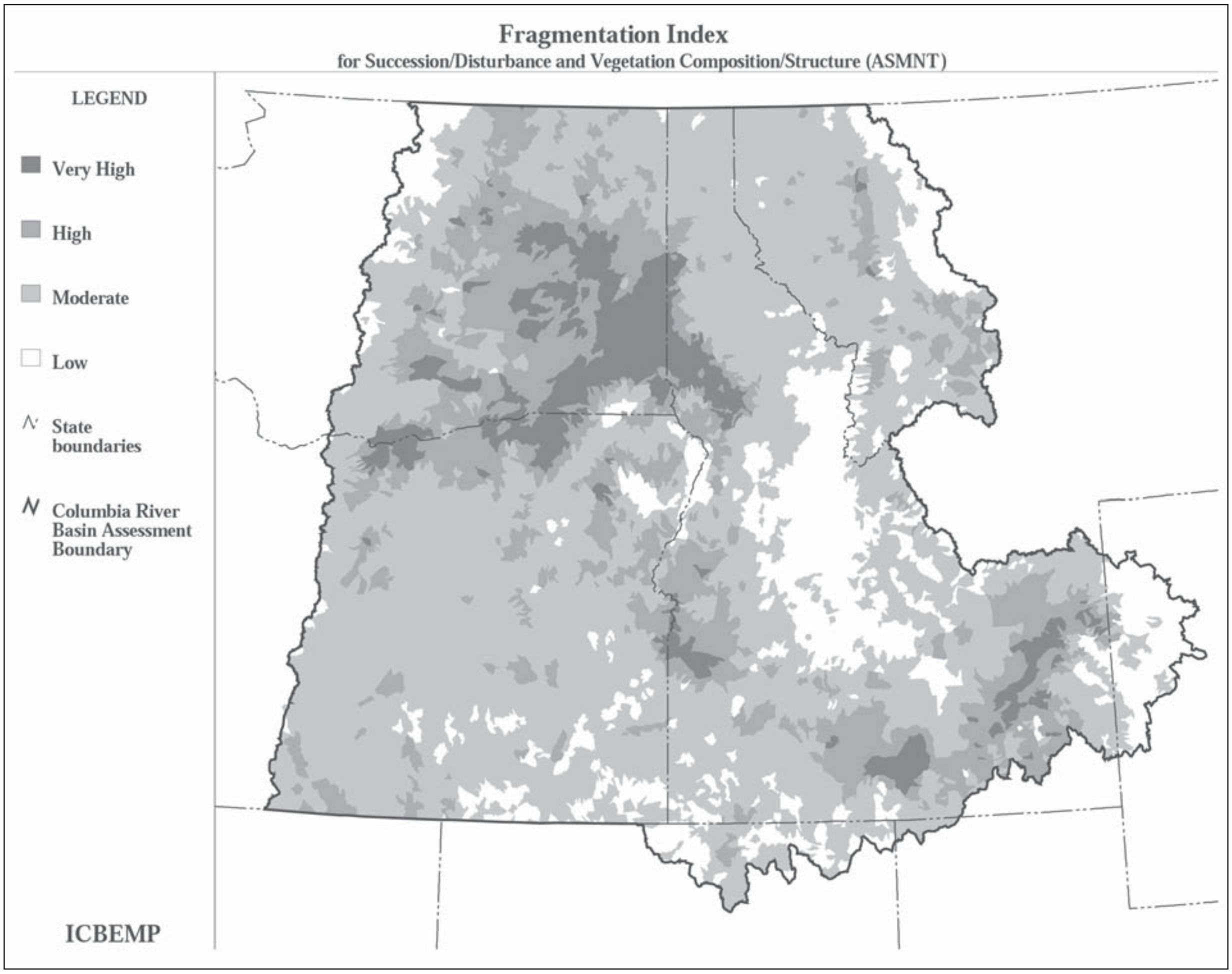

Figure 1—Boundaries of the Interior Columbia Basin Ecosystem Management Project (ICBEMP) science assessment area and mapped classes of the disturbance departure and fragmentation index in the basin. The ICBEMP science assessment area includes eastern Washington, eastern Oregon, most of Idaho, northwestern Montana, and small portions of Wyoming, Nevada, and Utah.

expressed at different scales, and therefore fail to account for important processes that may change across scales.

For integrated restoration planning across large areas, a desirable index is one that accounts for the integrated departure of landscape disturbance regime, composition and structure of vegetation, and associated mosaic pattern, and that also can index departure of fine-scale characteristics such as snag density or populations of selected species. Landscape disturbance processes can be measured at both coarse and mid scales, whereas mosaic patterns are generally a mid-scale measure (Hann et al. 1997, Hessburg et al. 1999). We define broad or coarse scale as regional landscape extents (such as the basin, an ecological province, or a subbasin) that are mapped with a large pixel or polygon size (such as 1 km^2), with estimates from each pixel representing the dominant class of an underlying composite of patches or stands. We define mid scale as the conditions and patterns common to subregional landscape extents (such as multiple watersheds or subwatersheds) that are mapped with a moderate pixel or polygon size (such as 4 ha), with the pixel size generally equivalent to or smaller than a patch or stand. By contrast, fine scale is defined as patch or stand characteristics mapped and summarized at a resolution typically smaller than 1 ha.

Because past measures of landscape departure have not addressed a large set of resources holistically, or have not considered multiscale patterns and processes, we sought to overcome these deficiencies by characterizing and mapping a multiscale "disturbance departure and fragmentation index" (ICBEMP theme number 933, similarity/fragmentation index for succession/disturbance and vegetation composition, assessment data; www.icbemp.gov/spatial) for the interior Columbia basin (fig. 1). We specifically selected a comprehensive and relevant set of coarse-scale variables for analysis that also were proxies for mid- and fine-scale conditions, provided rationale for their selection, and developed from them a composite index of disturbance departure and fragmentation. Our purpose in developing this composite index was to characterize subwatersheds according to their overall departure from native systems at a landscape scale. Subwatersheds (6^{th} hydrologic unit codes, as defined by Gravenmier et al. [1997] and Quigley et al. [1996]) average 7700 ha, and are used commonly for landscape assessment and planning in the basin (e.g., Hemstrom et al. 2001, Raphael et al. 2001). Characterization at this scale, therefore, is useful for developing integrated restoration strategies for wildland resources that have declined in quality and resiliency across large landscapes such as the basin.

Our work was conducted as part of the Interior Columbia Basin Ecosystem Management Project (ICBEMP). The ICBEMP was established in January 1994 through a charter signed by the Chief of the USDA Forest Service (FS) and the Director of the USDI Bureau of Land Management (BLM). The charter directed that work be undertaken to develop and adopt an ecosystem-based strategy for management of lands administered by the FS and BLM (FS-BLM) within the basin. The project developed a framework for ecosystem management and a scientific assessment of the ecological, biophysical, social, and economic conditions existing in the basin. Scientists prepared many publications to aid technology transfer of key science findings; they also projected environmental consequences from implementation of broad-scale management scenarios and alternatives (e.g., Hemstrom et al. 2001, Raphael et al. 2001). These projections, along with more than 100 supporting research publications (www.icbemp.gov), provide information that can be used effectively in land use planning for FS- and BLM-administered lands in the basin.

Study Area

The science assessment area of ICBEMP extends over 58 million ha in Washington, Oregon, Idaho, Montana, and small portions of Wyoming, Nevada, and Utah (fig. 1). Fifty-three percent of the basin is public land administered by FS-BLM, which was the focus of the ICBEMP environmental impact statement (USDA Forest Service and USDI Bureau of Land Management 2000). For the ICBEMP, the basin was subdivided into four nested spatial scales (Gravenmier et al. 1997, Jensen et al. 1997): (1) ecological reporting unit (ERU), (2) subbasin, (3) watershed, and (4) subwatershed. Ecological reporting units, of which there are 13, range in size from about 740 000 to 6 800 000 ha (mean size of about 2 375 000 ha). The 164 subbasins average about 345 000 ha, whereas the 2,562 watersheds average about 22 500 ha each. There are 7,654 subwatersheds, with a mean size of 7700 ha. Quigley et al. (1996) described these spatial scales and the diverse ecological components of the basin in detail. Hann et al. (1997) further described landscape systems occurring in the basin.

Methods

Description and Purpose of Index

Our goal in developing the disturbance departure and fragmentation index was to integrate several landscape variables to derive one composite variable that represented the overall pattern and effects from a myriad of underlying landscape processes. We derived our index by combining and extrapolating landscape data from multiple scales relative to HRV departure. The resulting index was designed to estimate the level of deviation from historical succession and disturbance regimes, structure and composition of vegetation, and the associated mosaic patterns. As part of this process, a diverse set of landscape variables was integrated to yield four classes of disturbance departure and fragmentation that ranged from low to very high. Low departure and fragmentation was designed to index landscapes with high wildland resiliency and quality, which could be used to prioritize areas for maintenance of such conditions. By contrast, increasingly higher classes of departure and fragmentation indexed landscapes with increasing loss of wildland resiliency and quality, with increasing opportunities for integrated restoration.

Concepts and data underlying the development of the disturbance departure and fragmentation index are from Keane et al. (1996), Hann et al. (1997, 1998), Hemstrom et al. (2001), and Hessburg et al. (1999). The index is a composite measure of departure from HRV, as caused by the cumulative effects of human activities that do not mimic native patterns and processes. Primary management activities associated with this departure include past fire exclusion, timber management, livestock grazing, road development, mining, oil and gas development, dams and water diversions, agricultural conversions, and invasions of exotic plants and animals (app. 1; Hann et al. 1997, 1998; Hemstrom et al. 2001). Such management practices do not lead uniformly to departure but may result in departure if not designed or mitigated in ways that sustain natural or native characteristics at multiple scales (Hann et al. 1998, Landres et al. 1999, Morgan et al. 1994). Levels of disturbance departure and fragmentation also were designed to index the relative change in patch size, composition, and arrangement; frequency and intensity of fire events; timing and severity of tree mortality associated with insect defoliation and pathogen events; successional rates and pathways; timing and intensity of ungulate grazing; composition of native versus nonnative vegetation; and human activities and presence.

Hann et al. (1997) and Hessburg et al. (1999) found that landscapes dominated by active management, such as road development and timber harvest, depart in vegetation mosaic and fragmentation patterns by becoming more fragmented (more heterogeneous) than historical systems. By contrast, areas dominated by passive management, such as fire exclusion (suppression) and custodial (nonactive) protection of terrestrial resources, depart by becoming less fragmented (more homogenous) than were historical systems. Keane et al. (1996) and Hann et al. (1997) observed that succession and disturbance processes change in opposite ways than do the vegetation mosaic and fragmentation patterns documented by Hessburg et al. (1999). That is, as the vegetation mosaic has become more fragmented (more heterogeneous) under active management, the associated succession and disturbance regimes have become less fragmented (more homogenous) than those in historical systems. In contrast, vegetation under passive management has become less fragmented (more homogenous) than historical, while succession and disturbance regimes have become more fragmented (more heterogeneous).

Although the changes in mosaic and fragmentation of vegetation under management are different than those of succession and disturbance processes, the departure of all such variables from historical conditions is consistent in its spatial pattern and correlation (Hann et al. 1997). Consequently, these many changes can be measured efficiently as a composite variable. Accordingly, the disturbance departure and fragmentation index is designed to capture these diverse changes in landscape patterns and processes relative to de-parture from historical (late 19th-century) conditions at multiple scales. The variable indexes fine-scale, within-stand composition and structure of vegetation, as well as coarse-scale composition and mid-scale spatial arrangement and pattern of vegetation, and is strongly associated with changes in landscape patterns and processes from historical to current periods, reflecting causal management activities. For example, density of large snags and large logs affects survival of a large number of vertebrates of conservation concern in the basin (Wisdom het al. 2000). Snag and log densities decline with increasing road density, timber harvest, and wildfire suppression (Hann et al. 1997), all of which are correlated with increasing levels of the disturbance departure and fragmentation index. Consequently, the variable appears to function as a reasonable index of landscape quality for terrestrial resources.

The disturbance departure and fragmentation index also corresponds to resiliency because the recovery rate of native vegetation and natural ecosystem processes after disturbance is associated closely with variables that compose the departure index. For example, resiliency of native vegetation in rangelands is increasingly disrupted by invasion of exotic plants and by increased road density, increased frequency and intensity of wildfire events, and excessive livestock grazing, all of which are correlated with increasing levels of disturbance departure and fragmentation of either the vegetation mosaic or ecosystem processes (app. 1).

Reference Period for Measuring Disturbance Departure and Fragmentation

For our analysis, we defined the historical period for native conditions as the late 19th century (circa 1850-1890), based on the methods and assessment of Hann et al. (1997). Landscapes during this time functioned largely without the pervasive, subsequent influences of European settlement and provide a useful reference for comparing current and future changes in the basin's patterns and processes at landscape scales (e.g., see Hann et al. 1997, 1998; Hemstrom et al. 2001; Raphael et al. 2001). This reference period, however, reflects climate and associated succession and disturbance dynamics that may be different than current and potential future climates (Tausch et al. 1993). Consequently, to better address the dynamics of native conditions in current and future climates, we modeled HRV for 400 years (Hann et al. 1997, Hemstrom et al. 2001). From this data, we developed variables reflecting native conditions and ranges of such conditions that represent general patterns of succession and disturbance dynamics across time.

Nevertheless, we acknowledge that climate change, such as that from global warming, may affect future ranges of native conditions in ways that are different from past dynamics (Tausch et al. 1993). Such change in climate, therefore, will increase the probability that future landscapes will increase in departure from HRV. The spatially explicit effects of such climate change, however, have not been estimated for local scales such as those of the watershed or subwatershed, given the high uncertainty about future effects at such scales. Improved predictions of future climate change are needed to provide reliable estimates of such change across landscapes and to modify our disturbance departure and fragmentation index for future uses. We assume that future improvements in predictions of climate change in the basin can be used as the basis for like improvements in our index.

Deriving the Variable

The disturbance departure and fragmentation index was derived as four classes (low, moderate, high, and very high), with very high representing the greatest level of deviation from historical conditions. These classes were developed directly from values of a similarity index of current landscapes to natural or native landscapes (table 1). The similarity index was in turn derived from unique combinations of three broad-scale variables: (1) landscape management pattern, (2) landscape vegetation pattern, and (3) potential vegetation group pattern (table 2). In combination, these variables reflect multiscale changes in coarse-scale vegetation composition and disturbance regimes, mid-scale landscape mosaic pattern, and fine-scale attributes reported in Hann et al. (1997), Hessburg et al. (1999), and Keane et al. (1996). These multiscale patterns and processes, as represented in the three variables, are highly correlated with a much larger and diverse set of landscape variables related to human disturbances and their effects in the basin (as described earlier). Consequently, these three variables appeared most useful in accurately representing the major patterns and effects of human activities and management on the quality and resiliency of wildland landscapes in the basin.

Table 1—Area and percentage of the interior Columbia basin by class of similarity index, and by class of disturbance departure and fragmentation index, as estimated for 7,467 subwatersheds in the basin

Similarity index	Disturbance departure and fragmentation index	Area	Basin
		Hectares	*Percent*
0	Very high	4 002 600	6.8
Total	Very high	4 002 600	6.8
1	High	183 700	0.3
2	High	2 669 600	4.6
3	High	8 646 600	14.8
Total	High	11 499 900	19.7
4	Moderate	21 305 200	36.4
5	Moderate	11 205 400	19.2
6	Moderate	1 187 200	2.0
Total	Moderate	33 697 800	57.6
7	Low	3 511 100	6.0
8	Low	2 802 500	4.8
9	Low	2 174 600	3.7
10	Low	776 900	1.3
Total	Low	9 265 000	15.8
Total	All classes	58 465 400	100

Data used to derive the three variables were obtained from several sources: (1) coarse-scale vegetation composition and structure mapping (Hann et al. 1997); (2) historical to current change in vegetation data derived from photo interpretation (Hessburg et al. 1999) and oblique photographs (Losensky 1995); (3) change in fine-scale vegetation features from historical to current estimated from plot data (Hann et al. 1997); and (4) changes in composition, succession, and disturbance processes estimated from empirically based modeling (Keane et al. 1996) (summarized in app. 1). The landscape management pattern variable was specifically developed from coarse-scale data on current and historical landscape management patterns, land ownership, and road density. By contrast, the variable of landscape vegetation pattern was developed from coarse-scale data on current and historical system dynamics, potential vegetation group, and fire regime patterns. The variable of potential vegetation group pattern was derived from a coarse-scale site stratification that grouped potential vegetation types based on terrain and climate features, and was subsequently used to classify each vegetation pattern as uniform, mosaic, or mixed for each subwatershed (table 2; Hann et al. 1997; see ICBEMP Web site metadata, www.icbemp.gov, for all three variables).

Table 2—Classes of the disturbance departure and fragmentation index and its input variables: landscape management pattern (LMP), landscape vegetation patterns (LVP), and potential vegetation group pattern (PVGPT)[a]

Disturbance departure and fragmentation index	Landscape management pattern	Landscape vegetation pattern	Potential vegetation group	Potential vegetation group pattern
Very high	Traditional commodity (TC)	Agricultural (AGL)	Other: Agricultural Rock Urban Water	Mixed (<60% composition of one PVG)
High	Traditional reserve (TR)	Agricultural, rangeland, forest (ARF)	Rangeland: Alpine Cool shrub Dry shrub Woodland	Mosaic (³60% and <80% composition of one PVG)
Moderate	Moderate similarity to native (MN)	Forest and rangeland (FRL)	Riparian: Riparian herb Riparian shrub Riparian woodland	Uniform (³80% composition of one PGV)
Low	High similarity to native (HN)	Forest (FTL)	Forest: Dry forest Moist forest Cold forest	
		Rangeland (RGL)		

[a] Note that rows do not indicate relations between variables.
The variable PVGPT was entered as a combination of 1 of 3 patterns and the associated PVGs as follows: if the pattern was "uniform," it was entered with only 1 PVG; e.g., uniform—moist forest; if the pattern was "mixed" or "mosaic," it was entered with both the primary and secondary PVGs; e.g., mosaic—dry forest—agricultural. Not all combinations of LMP/LVP/PVGPT occur in the basin; e.g., the LVP "agricultural" occurs in only 3 of the 299 unique combinations of the 3 input variables.

The assignment of the similarity index to each subwatershed was based on results of a multivariate cluster and ordination analysis, which identified subwatersheds that grouped together according to their similarity in relation to the three broad-scale variables. The cluster and ordination analysis was conducted by using a data matrix of the approximately 300 combinations of the three variables (app. 2). Results from the cluster and ordination analyses were then used to develop the similarity index, ranging from 0 to 10, and to assign this index to each subwatershed. A detailed list of data sources used in these analyses is provided in appendix 1. Assignment of the similarity index to each subwatershed resulted in a ranking of subwatersheds from 0 (lowest) to 10 (highest), based on the similarity of the succession/disturbance regime, vegetation composition and structure, and landscape pattern compared to that estimated from HRV (Hann et al. 1997, Hessburg et al. 1999, Keane et al. 1996).

The inverse of the similarity index yields the degree of disturbance departure and fragmentation. Consequently, we established four classes of disturbance departure and fragmentation, based on clear breaks in the frequency distribution of the similarity index values (table 1). Each subwatershed was assigned to one of the four classes of disturbance departure and fragmentation, as follows, in relation to values of the similarity index: very high—0 similarity; high—1, 2, or 3 similarity; moderate—4, 5, or 6 similarity; and low—7, 8, 9, or 10 similarity (table 1).

These four classes, and the resulting spatial pattern of the index across the basin, appeared to identify consistent and substantial differences in landscape conditions across the basin (fig. 1). Importantly, this assignment of classes reflected similar patterns in associated landscape variables, as described earlier.

Results and Discussion

Spatial Patterns and Amounts

Very high departure and fragmentation occurred primarily in low-elevation subwatersheds of eastern Washington and southern Idaho; these areas are dominated by private lands and used mostly as agricultural and urban areas (fig. 1). By contrast, high departure and fragmentation was found in subwatersheds that contain a mix of agricultural lands with low-elevation forests, woodlands, or rangelands; these areas were typically adjacent to subwatersheds of very high departure and fragmentation (fig. 1). Subwatersheds in the high class reflected diverse land uses that span a wide mix of land ownerships and management philosophies.

Subwatersheds in the very high class represent those lands where substantial investments in agriculture have helped maintain soil and water capability (Hann et al. 1997). Because of this investment, resiliency may not be at high risk, but habitat quality is low. Subwatersheds in the high class represent those lands where substantial management activities have occurred in recent times; such activities may have altered disturbance regimes such that they cannot recover without aggressive restoration. These environments typically have been invaded by exotic species or are highly vulnerable to such invasion. The close proximity and intermingling of these lands with agricultural lands increase their exposure to invasive species. These environments are typically warmer, and changes in natural succession and disturbance intervals or severities can be substantial. In addition, the close proximity and intermingled nature of these wildlands with urban and urban interface areas place them at risk from urban-associated disturbances (Collins et al. 2000). Conversely, this interface of wildlands with urban areas may place urban areas at risk, such as when intense wildfires start in wildlands and spread to adjacent urban areas (Collins et al. 2000).

By contrast, the moderate class occurred largely in subwatersheds with high public ownership composed of low- to mid-elevation forests, woodlands, or rangelands; these areas were widespread and particularly common in eastern Oregon, northern Washington, northern Idaho, and northwestern Montana (fig. 1). Subwatersheds with low departure and fragmentation typically occurred at higher elevations with rugged terrain, and were composed of public lands associated with or adjacent to wilderness areas, roadless areas, and national parks (fig. 1). These subwatersheds have undergone the least change from historical conditions and represent areas of highest quality and resiliency.

Most of the basin was characterized as having moderate departure and fragmentation (table 1); this finding reflects the dominance of low- to mid-elevation forests, woodlands, and rangelands that have experienced less severe human-induced changes in succession/disturbance regime and landscape mosaics. These areas contrast strongly with subwatersheds dominated by agricultural and urban lands that were classified as having very high or high departure and fragmentation. The moderate departure subwatersheds generally have fairly high resiliency because of their more moist environments and because basic soil and hydrologic processes are largely intact (Hann et al. 1997). Habitat quality, however, may be low because of past management activities that have substantially changed vegetation composition, structure, and patch mosaics.

Subwatersheds of very high departure and fragmentation composed 7 percent of basin lands, reflecting a relatively low amount of the most intensive land uses (table 1). However, the high class composed 20 percent of basin lands, indicating that low resiliency and quality occurred over a substantial area that was composed of wildlands intermingled with agricultural and urban lands.

Subwatersheds in low departure and fragmentation composed 16 percent of basin lands, reflecting a substantial portion of wildlands with high resiliency and sustainability. Areas in the low class, however, were concentrated in two large blocks in central Idaho and western Montana (fig. 1). Few other areas of low departure and fragmentation occurred across most of the basin, except for scattered areas in southeastern Oregon and southwestern Idaho. The moderate departure class dominated the basin (table 1), representing a substantial portion of the land base with moderate resiliency but potentially low habitat quality.

The spatial distribution of the different classes resulted in a high degree of contagion for each class. Subwatersheds with very high departure and fragmentation, associated with large agricultural and urban areas, had the most highly concentrated or clumped distribution. By contrast, subwatersheds with either high or low departure had more uniform distributions, with small areas of each scattered throughout the basin.

Subwatersheds in the high class typically formed a ring around those in the very high class, whereas subwatersheds in the moderate class generally surrounded those of the low class. Large, contiguous areas of the high class were typically found in areas dominated by dry rangelands, which have been substantially affected by invasive, exotic plants and excessive livestock grazing (Hann et al. 1997). The large, contiguous areas of the low class were typically found in large blocks of wilderness and roadless areas, where lack of access, naural fuel loadings, and high lightning ignitions have maintained historical fire regimes and provided high wildland resiliency and quality (Hann et al. 1997).

Management Applications

The disturbance departure and fragmentation index reflects the composite effects of changes from the natural or native system at multiple scales. As such, this composite variable may be useful for efficient and effective land use planning within and across land ownerships. For example, classes of this variable can be used to identify how much area is in departure from the historical or natural regime, with summaries possible at many spatial scales. Large groups of subbasins, watersheds, or subwatersheds could be ranked and mapped according to their class of departure and fragmentation, and results used to identify key management issues associated with each class. Such rankings could be used as an effective foundation for "coarse-filter" land use strategies, which by definition assume that conservation and restoration of a representative set and amount of native habitats in time and space will meet the needs of all associated native flora and fauna (Marcot et al. 1994, Noss and Cooperrider 1994). Such coarse-filter strategies help ensure that suitable environments for all native flora and fauna are managed in an efficient and holistic manner, as opposed to "fine-filter" strategies designed to meet the needs of few or single species in specific environments (Hunter 1991).

In one recent application, Wisdom et al. (2002) used the classes of disturbance departure and fragmentation index to rank landscape quality and resiliency for terrestrial resources as part of a coarse-filter approach. Specifically, Wisdom et al. (2002) used the index, in combination with estimates of habitat abundance, to map the composite abundance, quality, and resiliency of habitats for 44 terrestrial species of conservation concern. Areas were characterized as one of three conditions: (1) habitats where little change in abundance, quality, or resiliency has occurred since the historical period; (2) habitats where abundance was high but quality and resiliency were moderate; and (3) habitats where abundance, resiliency, and quality were low.

Results from Wisdom et al. (2002) appear useful as a basis for broad-scale landscape planning for this large set of species of conservation concern. Wisdom et al. (2002) suggested that the approach could be used to guide managers in maintaining habitats in a relatively unchanged state from historical conditions (condition 1), to improve habitats where quality and resiliency have declined (conditions 2 and 3), to restore habitats in areas of extirpation or low abundance (condition 3), and to improve connectivity where spatial gaps have developed (condition 3). Such planning is a coarse-filter approach, developed for a large set of vertebrates of conservation concern, for efficient use in broad-scale conservation and restoration of critical habitats.

Hann et al. (1998) found that when land use, ecosystem health, and species diversity are out of balance with inherent disturbance processes and biophysical capabilities, the landscape system tends toward disequilibria and eventually recalibrates to a new equilibrium with reduced biophysical capability and lower species diversity. Subwatersheds with a disturbance departure and fragmentation index of high and very high are likely at great risk of this recalibration or may have already permanently lost biophysical capability. Rieman et al. (2000) concluded, "terrestrial and aquatic ecosystems that shared a common management history often also shared common patterns and trends." In our analysis of multiple variables as inputs to the disturbance departure and fragmentation index, we found that these shared patterns and trends are common to landscapes because each landscape integrates these effects through time. Hemstrom et al. (2001) used similarity to HRV and other ecological indices, as well as human land uses, as key measures for assessing landscape health. Hemstrom et al. (2001) concluded that "past types and levels of human use have caused extensive changes that run counter to the historical ecological conditions." In our analysis of disturbance departure and fragmentation, we also found that management activities and land uses dating from the time of European settlement to the current period have "run counter" to the natural or native landscape conditions and dynamics. A reversal of this trend will require substantial changes in design and implementation of management activities and land use.

Throughout the conservation biology literature, issues of fragmentation of natural patches and of patch connectivity are a concern (Forman and Godron 1986, Noss and Cooperrider 1994, Shafer 1990). Our use of data on patch fragmentation and homogenization from Hessburg et al. (1999) as part of the disturbance departure and fragmentation index accounts for issues of patch size and connectivity. Moreover, results from our index for current landscapes suggest that fragmentation and homogenization of patches may be of substantial concern in the basin. We emphasize, however, that fragmentation or homogenization of succession and disturbance regimes, as well as the associated, multiscale effects on composition and structure of vegetation, are of equal concern. Dis-ruption of key processes, such as change in fire regimes or widespread invasion of exotic species, may present more risk to native species and bio-physical capabilities in the long term than do de-parture of patch sizes and connectivity (Huston 1994). Our disturbance departure and fragmentation index is designed to account for these processes and effects in a holistic manner.

Hann et al. (2001) identified many changes that are required to implement cost-effective, integrated, multiscale management. One of these, the "development and update of a consistent set of broad-scale data," is addressed substantially by the disturbance departure and fragmentation index. This index could be consistently mapped and updated across areas much larger than the basin to evaluate and monitor departure from natural or native conditions. Hemstrom et al. (2001) conclude that focused and prioritized restoration within the basin would produce substantial improvements in landscape health compared to current management. In analysis of multiscale planning issues at a national scale, Hann and Bunnell (2001) identify "three fundamental issues that appear to stymie achievement of multiple land and fire management objectives." Their third issue is the lack of "a system to monitor or summarize changes across large areas" to provide cumulative context for local managers, and to display the regional and national consequences and benefits of programs and policies to regional and national managers. The disturbance departure and fragmentation index could provide the basis for this type of integrated monitoring system. In addition, Hann and Bunnell (2001) emphasize the need for identification and prioritization of areas requiring maintenance or restoration at multiple landscape scales to achieve national objectives in the most cost-effective manner. The disturbance departure and fragmentation index could be a key component to this type of prioritization, allowing spatial identification of low-departure areas for maintenance and moderate- or high-departure areas for restoration. A key benefit to the methods used for the disturbance departure and fragmentation index is the multiscale nature of integrating finer scale data into an index across an area of large extent. The input variables can then be individually addressed at finer scales of planning and prioritization in order to address more specific issues of departure or fragmentation.

Applications of the disturbance departure and fragmentation index across large spatial extents may have high utility, but fine-scale applications within small areas should be avoided, owing to the relatively coarse nature of our estimates for areas the size of a subwatershed or larger. The classification of low, moderate, high, and very high is relative and has a potential error of approximately 20 percent for small groups of subwatersheds or watersheds within a subbasin, ERU, or the basin; this accuracy is similar to that for other watershed or subwatershed variables, as described by Hann et al. (1997) and Wisdom et al. (2000). Consequently, our index should not be used to identify departure and fragmentation for a small number of subwatersheds or watersheds. Moreover, because the classes are relative, they should be used in this context, rather than as an absolute estimate of conditions.

Consideration of these caveats will enable users to apply the disturbance departure and fragmentation index in an effective and efficient manner as a key component of landscape planning. We urge managers to consider the use of this variable in the development of landscape plans for restoration of wildland resources in the basin. Moreover, we suggest that researchers further test the efficacy of our index as a composite indicator of a large group of individual landscape variables. Such comprehensive approaches to test and apply landscape variables for multiple, integrated management applications will likely be of keen interest in the future, considering the many diverse wildland resource issues, and the paucity of methods available for holistic and efficient management of these resources.

Acknowledgments

Steve Bunting, Penny Morgan, Miles Hemstrom, and Becky Gravenmier provided helpful reviews of our paper. Becky Gravenmier and Arthur Miller conducted data and GIS analyses for our work, and Dani Huck assisted in preparing the manuscript for publication. The Pacific Northwest Research Station and other ICBEMP funding sources from the USDA Forest Service and USDI Bureau of Land Management supported the work. Data, maps, and associated documentation and source materials are available from the ICBEMP Web site: www.icbemp.gov. Source materials from earlier publications also are available on the ICBEMP Web site.

English Equivalents

1 hectare (ha) = 2.47 acres

1 kilometer (km) = 0.621 mile

1 square kilometer (km^2) = 0.386 square mile

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Appendix 1

Table 3—Variables related to the disturbance departure and fragmentation index developed for the Interior Columbia Basin Ecosystem Management Project (ICBEMP)

Variable	Time period/scale	ICBEMP theme ID export name	ICBEMP theme name	Relation to disturbance departure and fragmentation index	Source and related publication(s)
Disturbance departure and fragmentation index	Current/HUC6[a]	933 BDBSIM	Similarity/fragmentation index for succession/ disturbance and vegetation composition/structure (ASMNT)	Same variable	This article www.icbemp.gov
Landscape management pattern	Current/HUC6	974 BDBLMP	Landscape management pattern	Input variable	www.icbemp.gov
Landscape vegetation pattern	Current/HUC6	939 BDBLVP	Landscape vegetation pattern	Input variable	www.icbemp.gov
Potential vegetation group pattern	Current/HUC6	950 BDBPVGPT	Potential vegetation group pattern	Input variable	www.icbemp.gov
Succession/ disturbance regimes (SDR)	Current/ historical/HUC6	SDR		Associated variable	Hann et al. 1997 ICBEMP unpublished data
Forest health vulnerability	Current/HUC6	988 BDBFHV	Current forest health vegetation vulnerability	Associated variable	www.icbemp.gov
Rangeland health vulnerability	Current/HUC6	990 BDBRHV	Current rangeland health vegetation vulnerability	Associated variable	www.icbemp.gov

Table 3—Variables related to the disturbance departure and fragmentation index developed for the Interior Columbia Basin Ecosystem Management Project (ICBEMP) (continued)

Variable	Time period/scale	ICBEMP theme ID export name	ICBEMP theme name	Relation to disturbance departure and fragmentation index	Source and related publication(s)
Similarity of current to historical	Current/1 km		Similarities of current and historical compositions of succession/disturbance regimes, fire regimes, and physiognomic types within potential vegetation groups (PVGs)	Findings proxied via BDBLVP	Tables 3.31, 3.205, and 3.206 in Hann et al. 1997
Regional and subbasin landscape pattern similarity to HRV[b]	Current/subbasin		Regional and subbasin landscape similarity to native (HRV), other, traditional reserve, and traditional commodity landscape patterns	Findings proxied via BDBLMP, BDBPVGPT	Tables 3.181, 3.182, 3.183, 3.184, 3.185, and 3.186 in Hann et al. 1997
Ownership pattern	Current/HUC6	OWNPAT	Ownership pattern	Input to BDBLMP	www.icbemp.gov
Historical regime pattern	Historical/HUC6	Fire regime pattern		Findings proxied to SDR	ICBEMP unpublished data
Current fire regimes	Current/1 km	954 BGBCFRSD	Disturbance-current fire regimes (SDEIS)	Findings proxied to SDR	Hann et al. 1997 Morgan et al. 1996 www.icbemp.gov
Historical fire regimes	Historical/1 km	955 BGBHFRSD	Disturbance-historical fire regimes (SDEIS)	Input to fire regime pattern	Hann et al. 1997 Morgan et al. 1996 www.icbemp.gov
Exotic plant invasion vulnerability	Current/HUC6	935 BDBEPIV	Exotic plant invasion vulnerability	Findings proxied via BDBPVGP, BDBLMP	www.icbemp.gov

Table 3—Variables related to the disturbance departure and fragmentation index developed for the Interior Columbia Basin Ecosystem Management Project (ICBEMP) (continued)

Variable	Time period/scale	ICBEMP theme ID export name	ICBEMP theme name	Relation to disturbance departure and fragmentation index	Source and related publication(s)
Hydrologic impacts index	Current/HUC6	936 BDBHII	Hydrologic impacts index	Findings proxied via BDBLMP	www.icbemp.gov
Road density	Current/HUC6	722 BDBRDDN6	Road density (predicted) by HUC6	Findings proxied via BDBLMP	www.icbemp.gov
Current and historical vegetation	Current and historical/1 km	807 BGBVEG	CRBSUM current and historical vegetation (DEIS)	Base vegetation data input	Hann et al. 1997 Keane et al. 1996 www.icbemp.gov
Modeled historical range of variation	Historical/1 km	931 BGBLTVEG	CRBSUM long-term historical vegetation	Findings proxied to SDR, BDBLVP, BDBLMP, BDBPVGPT	Hann et al. 1997 Keane et al. 1996 www.icbemp.gov
Ecosystem plot data	Current/fine scale	817 BDBECOD	Ecodata plot inventory database (1940s-1994)	Findings proxied to SDR, BDBLVP, BDBLMP, BDBPVGPT	Hann et al. 1997 Keane et al. 2002 www.icbemp.gov
Vegetation dynamics models	Mid and fine scale	883 CMBVDDTS	Management scenario data files for VDDT	Findings proxied to SDR, BDBLVP, BDBLMP, BDBPVGPT	Hann et al. 1997 Hemstrom et al. 2001 Keane et al. 1996 www.icbemp.cgov
Current/ historical/ aerial photo fragmentation index findings	Mid scale	677, 896, 897, 900, 901, 790, 902-905	Vegetation-current mid-scale subsample (Pt 1-5), vegetation-historical mid-scale subsample (Pt 1-5)	Findings proxied to SDR, BDBLMP, BDBLVP, BDBPVGPT	Hessburg et al. 1999 www.icbemp.gov
Current to historical similarity on selected HUC6	Mid scale	HUC6	BDBPVGPT	Findings proxied to SDR,	Hann unpublished findings

Table 3—Variables related to the disturbance departure and fragmentation index developed for the Interior Columbia Basin Ecosystem Management Project (ICBEMP) (continued)

Variable	Time period/scale	ICBEMP theme ID export name	ICBEMP theme name	Relation to disturbance departure and fragmentation index	Source and related publication(s)
Current/ historical/ oblique photo data	Fine scale			Findings proxied to input variable	Hann et al. 1997 Hann unpublished findings Losensky 1995
Historical range of variability composite departure	Current/HUC6	932 BDBHRVD, SDEIS variable 16 (VB16)	Current year historical range of variability composite departure (SDEIS)	Main variable used to characterize the index	Hemstrom et al. 2001 www.icbemp.gov

[a] Hydrologic unit code; a sixth-code HUC is a subwatershed.
[b] Historical range of variability.

Appendix 2

Coarse-, mid-, and fine-scale data used in cluster and ordination analysis to develop rationale to assign a similarity index to the 299 unique combinations of the three input variables (landscape management pattern, landscape vegetation pattern, and potential vegetation group pattern; see table 2) are listed. A detailed list of data and findings used in the analysis is provided in appendix 1.

Coarse scale: Land ownership, forest health vulnerability, rangeland health vulnerability, exotic plant invasion vulnerability, hydrologic impacts index, similarity of succession/disturbance, similarity of fire regime, and similarity of composition/structure.

Mid scale: Patch (stand) fragmentation of mosaic pattern, patch (stand) homogenization of mosaic pattern, similarity of succession/disturbance, similarity of composition/structure, and similarity of landscape patterns.

Fine scale: Plot data on surface fuels, plot data on composition and structure of vegetation, plot data on density of large trees, plot data on density of large snags, historical fire interval, historical fire severity, and basal native vegetation cover/ground cover.

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