FIRE REGIMES IN THE INTERIOR COLUMBIA RIVER BASIN: PAST AND PRESENT

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Coarse-scale classification and mapping of disturbance regimes
in the Columbia River Basin

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ABSTRACT

We mapped and compared historical (circa 1900) and current (circa 1990) fire regimes for the Interior Columbia River Basin. Fiie regime classes were based upon fire frequency (the mean number of years between successive tires) and severity (the fires' effects on the dominant overstory species) of fires. Fiie regimes were assigned to all forest, woodland, shrubland, and grassland vegetation types within the Interior Columbia River Basin. Fire regime classes were assigned based upon dominant vegetation types for each of four different biophysical settings: cold & dry, cold & wet, warm & dry, and warm & wet. One set of decision rules was developed for historical vegetation. A separate set of decision rules was developed for current fire regimes to reflect the influence of fire suppression, invasion of exotic plant species, and other human activities. Decision rules were developed based upon published literature, a fire history data base and expert opinion. The coarse-scale maps (1:250,000 map scale. 1 km^2 resolution) were produced in ARC/INFO format. The maps were judged reasonably accurate when compared to fire history data and when they were evaluated by local experts, but accuracy varied geographically. Current fires occur less frequently and are more severe than historical fires. Nonlethal fires are currently much less common than they were historically (32% vs. 20% of all pixels). Mixed fire regimes were historically less extensive (16% of all pixels) than they are currently (30% of all pixels) extensive. Stand-replacing fires dominate the landscape, both historically (5 1% of all pixels) and currently (48% of all pixels). For all severity classes combined, very frequent fires (those occurring every O-25 years) were more common historically than currently (28% and 6% of all pixels, respectively). Frequent fires (those occurring every 26-75 years) are also less common now than historically (42% and 18% of all pixels, respectively). Fire frequency has not changed where fires occurred very infrequently (every 15 l-300 years), extremely infrequently (every 300 years or more) or rarely, but this occurs on less than 10% of the pixels in the entire Interior Columbia River Basin.

INTRODUCTION

Disturbances, especially fire, are important agents of change in the wildland ecosystems of the Interior Columbia River Basin (ICRB). An assessment of how fire regimes have changed from the past (circa 1900) to the present (circa 1990) provides a spatial and temporal context for evaluating the trends in ecosystem change resulting from human activities, and the corresponding risks and values associated with those changes. This research was conducted as part of the ICRB Scientific Assessment Project.

Our objective was to identify how, where. and to what extent fire regimes have changed in the ICRB. We contrasted two time periods: a) historical, circa 1900, prior to extensive Euro-American settlement, and b) current, circa 1990. We classified fire regimes based upon fire frequency (the interval between successive fires) and fire severity (the effects of fires on the dominant overstory species). Fire regimes were assigned to forest. woodland, shrubland, and grassland vegetation in the Interior Columbia River Basin. Our maps are based upon dominant vegetation, biophysical settings interpreted from potential vegetation types, published literature, a fire history data base. and expert opinion. We produced coarse-scale maps using the ARC/INFO Geographic Information System. Here we report the methods, assumptions, limitations, and general results of our efforts.

METHODS

We developed a classification of fire regimes, and then mapped them based upon vegetation and biophysical settings as identified by potential vegetation types. The fire regime was determined for a particular vegetation type and biophysical setting based upon published literature on fire ecology and fire history. a fire history data base developed by Steve Barrett (1995). and expert opinion. These were summarized as decision rules that were used to map the fire regimes from the GIS vegetation layers.

The ICRB assessment area encompasses more than 80 million hectares (Figure 1). We produced as output a continuous map of fire regimes for the entire ICRB assessment area. The resolution is 1 km^2 (100 hectares or 247 acres) with a map scale of 1:250,000.

Fire Regimes

For a particular ecosystem, fire potential over time can be summarized as the fire regime, the characteristic frequency, severity, return interval, size and pattern of fires (Agee 1993, Heinselman 1978, Kilgore 1978, 1985, Rykiel 1985, White and Pickett 1985). Numerous studies document fire frequency and effects in the Rocky Mountains (e.g. Amo 1980, Stokes and Dieterich 1980). Climate, vegetation type, and topography influence fire regimes (Agee 1993, Clark 1988, 1990; Heinselman 1978, Kessell 1976, Romme and Knight 1981, Swetnam and Betancourt 1990).

The fire regime indicates the effects of typical (but not all) fires. Fire regimes are characterized by the direct (immediate, first-order) effects of fire on the dominant overstory vegetation (trees, or shrubs when no trees are present, or grasses where no shrubs or trees are present), and the typical frequency of fires.

We are constrained by the data available to mapping fire frequency and severity based upon the effect of the fire within relatively small areas. Furthermore, the judgement of fire frequency and severity is based upon the areas that burned. All fires are patchy at some scale because all fires leave patches of unburned vegetation. Our interpretation of fire regimes is based upon the effects of the fires where they actually burned, not upon the interspersion of burned and unburned patches of vegetation.

The fire frequency classes (Table 1) are based upon the mean fire interval (MFI) as interpreted from fire-scarred trees, and forest and shrub age structure. We recognize that fire frequency distributions are often skewed, so that mean intervals between fires are less descriptive of central tendency (Johnson and Gutsell 1994, Johnson 1992), but most of the data available to us consists of MFI. In shrub and herbaceous vegetation types, we are dependent upon the availability of fire scars in adjacent vegetation or the ecology of the dominant plants to determine fire frequency. We have attempted to develop fire frequency classes which are ecologically significant for herbaceous. shrubland, woodland and forest vegetation types. When fire frequency changes. vegetation composition and physiognomy change. For example, Douglas& trees often encroach into adjacent sagebrush and grass communities when fires become less frequent. Following the invasion of exotic annual grasses into some big sagebrush communities, fires are burning much more frequently, contributing to the conversion of many sites once dominated by sagebrush to extensive patches of annual grasses.

The fire severity classes (Table 2) reflect the direct effects of the fire on the dominant vegetation for a given pixel. Interpretation of the fire severity classes is based upon a comparison of burned and unburned vegetation within the first three years following the bum. If within three years the structure and composition of burned vegetation resembles the vegetation prior to burning. the fire is considered nonlethal. Note that stand-replacing fires are not necessarily crown fires. for surface fires may be lethal to fire-sensitive species. The quantitative limits between classes are similar to those used by Agee (1993), Morrison and Swanson (1990). and Morgan and Zack (1994). Following severe fires, it may be many years before plant communities recover to the prebum structure and composition.

We have not included variable fire regimes, those in which the fire effects vary greatly through time, in our classification. Mixed fire regimes are typically also variable fire regimes because even within relatively short time intervals, nonlethal, mixed, and stand-replacement fires occur (Agee 1993, Zack and Morgan 1994).

The fire regime classes (Table 3) are named for both the typical severity (i.e. the resulting effects of fire on the overstory vegetation), and the typical frequency of fires. Note that not all combinations of fire frequency and severity are equally likely to occur. Severe, stand-replacing fires tend to occur relatively infrequently, while frequent fires tend not to be severe (Heinselman 1978, Swetnam 1993).

Decision Rules

We deveioped decision rules to assign fire regimes by vegetation type for each of four different biophysical settings: cool & moist, cool & dry, warm & moist, and warm & dry (Table 4). Decision rules were developed for each vegetation type for each of the 24 geographic sections within the ICRB. One set of decision rules was developed for historical vegetation. A separate set was developed for current fire regimes to reflect the effects of fire suppression, invasion of exotics, and other human influences. Unless there was evidence for differentiation., the decision rules for a given vegetation type and biophysical setting were the same for all of the sections within a given ecoregion.

Data sources

The data layers include biophysical settings, land characterization sections (Figure 1), historical vegetation and existing vegetation. All input data layers were developed by others and supplied to us through the ICRB Scientific Assessment Project. All GIS layers were either developed or resampled to a spatial resolution of one square kilometer.

We generalized from the classification of biophysical settings created by subsection. The layer was developed by a team of ecologists based upon the potential natural vegetation layer type and topography. We generalized the original 16 classes to values of 1 (cool & moist), 2 (cool & dry), 3 (warm & moist). or 4 (warm & dry). The original site codes represent 16 classes in gradients of moisture and temperature for forests (1-16), shrublands (17-32), grasslands (33-48). or barren (49).

The land characterization sections layer contained ecoregions (here used synonymously with province), sections, and subsections based upon similarities in land form, soil, and vegetation (Bailey 1994) (Figure 1). Our decision rules generally did not vary within an ecoregion, but did differ from section to section if it was ecologically appropriate to do so.

The vegetation classification is the same for the historical and existing vegetation layers , although the extent of occurrence of individual classes of vegetation differs for the two time periods (Table 4). The vegetation classes used in both the current and historical data layers are SRM (Shiflet 1994), SAP (SAP 1980), and CRB (developed for the ICRB Scientific Assessment Project, James Menakis and others, personal communication) cover types. The SRM cover types are named for the vascular plant species with the plurality of canopy cover; SAP cover types are named for the tree species with the greatest basal area (the cross-sectional area of tree boles at 1.4 m).

The historical vegetation layer was originally developed to depict vegetation classes just prior to 1900. The sources, including archived maps, government records published from the turn of the century, and other historical documents, varied in scale and quality. This is an approximation of the type and extent of vegetation near the turn of the century. The historic cover type layer was assumed to represent vegetation prior to extensive Euro-American settlement. Native Americans had long influenced the vegetation in parts of the ICRB. No doubt, the degree of their influence varied with both geographic location and vegetation type. By 1900, Euro-Americans had also influenced some areas of the ICRB through grazing, mining, and early timber harvest (Irwin et al. 1994, Johnson et al. 1994, Oliver et al. 1994).

For current vegetation, we used the CRBSUM current cover type data layer. This was developed based primarily upon AVHRR satellite imagery. The classes were initially derived from a land cover characterization generated from AVHRR satellite imagery by EROS (Loveland and Ohlen 1993; Loveland et al. 1991). The resulting maps were then modified by a panel of ecologists to ensure that the vegetation classes represented reality.

GIS Analysis

All GIS operations were performed with the GRID module of ARC/INFO. For each land characterization section, the historical vegetation and biophysical setting layers were combined into one layer, and the existing vegetation **and** the biophysical setting layers were combined into another layer. Each unique combination of vegetation class and biophysical setting received a unique value in an output grid. Decision rules in the form of "Ifvegetation = X AND biophysical' setting = Y, THEN fire regime = Z" were developed for each unique combination were used to "reclassify" the values in the output grid as fire regimes. Any cell for which information was lacking in either the vegetation or biophysical settings layers was assigned NODATA values. These were predominantly cells coded 49 (barren) in the PNV layer.

Fire History Data Base

The fire history data base developed by Barrett (1995) was used to validate the decision rules for historical fire regimes. Nearly all fire history studies conducted in the ICRB are included in the data base.. However, the data base is limited in extent, for most fire history studies have been conducted in relatively dry forests. In addition. some geographic areas within the ICRB such as the Northwest Basin and Range (342B), Owyhee Uplands (342C) and Belt Mountains (M332D) sections are poorly represented within this data base. The data base contains location by latitude and longitude. mean fire interval (for historical. not recent fires), elevation, aspect, and topographic position. The data base includes historical fires only.

Accuracy

The fire regime maps produced from the decision rules were technically evaluated for accuracy in three ways. First. the decision rules were reviewed by Steve Barrett. He drew upon published literature, his expert knowledge, and the data base he developed for historical fires.

Second, we compared the historical fire regime maps to Barrett's (1995) fire history data base. This involved spatially referencing the information from the data base, selecting points from our map and comparing the fire regime classes. Because the decision rules were developed from some of the same literature, the fire regimes we mapped and the fire history data reported in the data bases were not independent. Thus, this step was most revealing if the maps did not agree with the fire history data.

Third, we asked local ecologists and fire managers to review the maps. Each was asked to concentrate on a single section. Their comments were qualitative, but much more geographically-specific evaluations of the maps. These local experts were asked to comment both on overall accuracy and uncertainty in mapped fire regimes.

Assumptions

We made a number of major assumptions which need to be considered when interpreting the results of this study.

1. The 1-km^2 pixels are normally composed of several cover types as well as several potential vegetation types. The fire regime for the pixel was characterized by the fire regime of the vegetation type covering the majority of the pixel. Often this vegetation was present on more than 50% of the pixel. However, in areas with complex topography, the dominant vegetation type may comprise less than 20% of the pixel area.. Vegetation types which usually occur in small patches (e.g. meadows) or narrow linear patches (eg. riparian vegetation) may bum under different fire regimes than the surroundingyegetation types. The scale of these vegetation types is generally too fine to be mapped at the scale of the layers used.

2. We characterized the fire regime for a given 1 km^2 pixei assuming that the fire regime was relatively constant through time.

3. The fire regime was not influenced by adjacent vegetation, fire regime, or topography. This assumption is obviously unrealistic. We are constrained, however by the available data: most fire history studies characterize very small areas and do not describe the surrounding vegetation or fire regimes.

4. We assumed that current vegetation was subject to fire suppression regardless of land ownership and management policies. Thus, we assumed equal effort and equal effectiveness across and within different ownerships. Although this is not

true, even for different areas of land administered by a single government agency, we lacked the data and the time to represent the different fire suppression strategies and effectiveness for different land owners.

5. We did not consider vegetation structure, although the structural stage of vegetation clearly affects fuels and fire behavior, and the probability that fire will change the vegetation.

6. Our description of fire regimes is based upon the degree to which the effects of fires are predominately nonlethal, predominately stand-replacing, or mixed where the fire actually bums. Because all fires include patches of unburned vegetation, the unburned vegetation patches are not considered when assigning fire severity classes.

RESULTS

Fires have generally become less frequent and more severe within the ICRB within the last century (Figures 2.3 and 4). Nonlethal fire regimes have become more often mixed; mixed fire regimes have become increasingly stand-replacement (Figure 2, Tables 3 and 4)). Mixed fire regimes were (16% of all pixels) and are (30% of all pixels) also extensive. Stand-replacing fires dominate the landscapes. both historically (5 1% of all pixels) and currently (49% of all pixels) (Figure 2). Even where the fire severity has not changed, fires typically occur less frequently (Figure 3, Tables 3 and 4). Very frequent fires of all severity classes were once more common (28% or all pixels historically vs. 6% of all pixels currently) (Figure 3). Frequent fires once occurred on 42% of all pixels; they now occur on 18% of all pixels, while infrequent fires that once occurred on 18% now occur on 60% of all pixels (Figure 3). Fiie frequency has not changed where fires occurred very infrequently or rarely, but this occurs on less than 10% of the pixels in the entire ICRB (Figure 3).

Over extensive areas within the Interior Columbia River Basin assessment area, fire regimes have changed (Figures 5). The changes in fire regime differ for different geographic areas within the ICRB (Table 5). The greatest changes occurred where there were extensive conversions in vegetation type. Within a given vegetation type, fire regimes have changed more greatly in the shrublands, grasslands, dry forests, and woodlands than in the mesic forests (Table 4).

A notable exception to the generality that current fires are less frequent and more severe than historical fires is found in southeastern Oregon and southern Idaho (Province 342 in Figure 1). There, the introduction of exotic annual grasses. such as cheatgrass (*Bromus tectorum*, into the big sagebrush vegetation types has greatly changed the fire frequency. There, fires occur much more frequently than they did historically. In many cases the interval between fires is sufficiently brief that the fires are now classified as nonlethal because the sagebrush overstory does not have an opportunity to redevelop between fires, and the annual grasses so rapidly 'reestablish that there is little difference between burned and unburned vegetation within the first three years after the fire. The exotic annual grass and forb vegetation type did not exist historically, but is now extensive (Table 4), reflecting the conversion of other vegetation types to annual grasslands. Because the exotic annuals recover quickly, the fires are described as nonlethal, but they are often lethal to the native species because the tires occur so frequently.

Historical and current fire regimes differ more for some vegetation types than others (Table 4). In many cases, the areal extent of vegetation types have changed, which contributes to the degree to which fire regimes have changed (Table 4). For instance, the areal extent of Interior Douglas-fir has increased by 40% while the areal extent of Interior ponderosa pine has decreased by 23%. This change accentuates the change in fire regime, particularly where Douglas-fir (which often bums in mixed and stand-replacing fire regimes currently) replaced ponderosa pine (which historically burned with nonlethal fire regimes). The fire regime comparisons (Table 3. Figures 2, 3 and 4) represent the combined effect of vegetation cover type changes and the fire regime changes within a given cover type.

Our confidence in assigning fire regime was higher for forests than for woodland, shrublands. and grasslands because little fire history information exists for the latter types. For forests. there is far more published information and expert knowledge for assigning fire regimes to the dry forests at low elevations (e.g. ponderosa pine and Douglas-fir forests) than for high elevation forests (e.g. subalpine fir and alpine larch). As well, our confidence in assigning fire regime classes is lower when fires occur very infrequently or when the fire regime is mixed or stand-replacing, for evidence of past fires is limited for calculating reliable intervals between tires.

DISCUSSION

The extent of changes in fire regimes in the ICRB within the last century is staggering.

The greatest changes in fire regimes are associated with the dry forest vegetation types, such as ponderosa pine and Douglas-fir, and in shrublands, such as mountain big sagebrush and big sagebrush (Table 4). Fire severity has increased in all of them. This is a very significant change because these vegetation types alone account for 40% of the area within the ICRB. Vegetation characterized by the likely occurrence of nonlethal fires has been replaced by vegetation characterized by mixed and lethal fires, although the extent to which thischange occurs varies geographically. Vegetation once characterized by mixed fire regimes has been succeeded by vegetation types likely to support mixed or stand-replacing fires. Even where the vegetation type has not changed, vegetation is often more dense and fuels have accumulated, resulting in increased fire severity. Fire regimes in mesic forest types have not changed greatly, but fires were (and still are) typically mixed and stand-replacing.

The changes in fire regimes are due to active fire suppression, reduction of fine fuels by livestock grazing, and decreased fuel continuity from roads, agriculture and other types of development (Agee 1993, Arno 1980, Pyne 1982). As fire frequency declines, biomass accumulates, and the fires are more severe when they inevitably occur. As fire regimes become more often mixed and stand-replacing, intense crown fires become increasingly likely. As the landscape becomes progressively more dominated by vegetation that will support severe fires, the potential increases for the occurrence of large tires and more homogeneous landscapes. In much of the ICRB, human activity, including fire exclusion efforts, has changed the fire regime to one of large, often uncontrollable fires burning in heavy fuels. In comparison to surface tires, crown fires are far more difficult to suppress, more threatening to human life and property, and where unprecedented, are more damaging.

Changing fire regimes have important implications for the health and function of ecosystems. Forest ecosystems change when fires are less frequent and more severe (Agee 1993; Morgan 1994 and references therein; Huston 1994). The density of trees increases and fuels accumulate. More shade-tolerant, less disease-resistant trees establish., and shrub and herbaceous vegetation becomes less diverse and productive. Organic matter decomposition slows, nitrogen mineralization declines. and nutrient cycles stagnate. Fire size and intensity increases; often these are unprecedented in their behavior and ecological effects. Landscapes become more homogeneous. Many similar changes occur in woodlands and grasslands. There the changes are often more extensive and rapidly manifest.

Limitations

The following limitations apply. Some are the result of project constraints, including the short time frame and the requirement that all input and output data layers be continuous for the entire ICRB. Others will be addressed in future research.

1. The vegetation was not mapped at a consistent spatial scale. The spatial scale for the historical vegetation is variable. and generally broader than the current vegetation. This difference in scale may account for some of the observed changes in fire regime.

2. Fine-scale fire events (i.e. those that bum areas less than 1 km^2 in size) are important ecologically but are not reflected in the coarse-scale maps of fire regimes. When fires bum small areas. they alter fuel structure, abundance, and composition, thus altering the susceptibility and recovery of vegetation from subsequent fires.

3. Spatial extent of fires is not mapped. Our fire regime maps are based on observations and

description of typical fires at points or within small areas, for few data exist on extent or spatial pattern of fires. Therefore, analysis of patch sizes based on our fire regime maps is not appropriate. This remains a very important, and largely unanswered, research question. For instance, we cannot answer the question of whether the risk of very large fires has increased as the vegetation has become more homogeneous.

4. Although fire regimes of a specific cover type are influenced by adjacent vegetation and topography, our classification and maps do not include the effects of the neighborhood on fire frequency and severity. The actual spatial pattern of fire effects are very important in determining the rates of recovery of vegetation and animals, fuels for subsequent fires, and influence of fire on soils and streams.

5. The classes for vegetation cover types are broad. Given the broad cover types used in the both the historical and current vegetation map layers, fire effects often-change within the same cover type as succession occurs. In our analysis, a change in fire regime occurs only when sufficient successional change occurs to result in a change of cover type. In other words, vegetation structure and age may differ greatly within a cover type; these differences affect the available fuels and the effects of fires when they occur, but are not represented here.

6. A pixel is often composed of several cover types with varying fire regimes. However, a single fire regime must characterize the entire pixel. We assigned the fire regime based upon the vegetation cover type occupying the greatest area of the pixel.

7. Fire regimes are a description of the typical frequency and effects of recurring fires. They do not describe the effects of individual fires. the effects of which may differ greatly from the typical fire depicted in the fire regime description.

8. Variation in fire intervals is probably more important than the mean interval between fires in determining fire effects on ecosystem structure, function and composition. Our data are based on mean fire intervals.

9. Our fire regime classification does not reflect the influence of vegetation structural stage on fuels and fire behavior. Thus, the link between our fire regimes and actual fire behavior and fire effects is weak.

Future Research Needs

Fire effects and fire behavior differ greatly with vegetation structure and age, both of which may differ greatly within a cover type. These differences affect the available fuels and the effects of fires when they occur. This is a major limitation that should be addressed in future efforts to map fire regimes, particularly where those are to be projected into the future. As well, the fire regime classification should be extended to include the structural stage of the vegetation as well as the cover type.

In subsequent analysis, we will explore how both fire regime and fire regime change are related to topography (slope, aspect, elevation, and topographic position) and cliiate (precipitation, growing degree days, and solar radiation). In doing so, it is important to incorporate the information on long-term cliiate changes that can be interpreted from tree rings. Such efforts will help us to understand the ecological effects of disturbance over both time and space.

Additional fire history information is needed to fill the gaps in our knowledge. Little information is available on past fire occurrence in most grassland, shrubland. and woodland types. In addition, little is known about the fire regimes in high elevation forests. The current fire history information is also geographically limited. Furthermore, it is very important that the fire history information collected be placed within a spatial context, to capture the spatial extent (where possible) of fires and the variation in fire regime across landscapes.

CONCLUSIONS

Fire is a key process in the forest, woodland, shrublands and grassland ecosystems of the ICRB. Humans have greatly altered the frequency and severity of fires in many vegetation types and most geographical areas within the ICRB.

This comparison of past (circa 1900) to the present (circa 1990) fire regime provides a spatial and temporal context for evaluating ecosystem change. Those changes result from past human activity, as well as other disturbance and success&. The risks and values associated with those changes are great.

The trend is clear. In many vegetation types, fire as an ecological process is now or will soon be functioning outside of the historical range of variability (Morgan et al. 1994; Swanson et al. 1994). In addition to affecting the majority of the land in the ICRB, the changes in fire frequency and severity during the last century are ecologically significant. There are numerous associated risks if these trends continue: increasing risk of large, intense fires that could have unprecedented and undesirable costs in terms of human lives, wildlife habitat, and resource values. Future management decisions must consider the effects that fire suppression, both active and passive, has had on fire frequency and severity over the past century. We currently live with an increasing risk of fires that will have unprecedented and often undesirable effects on the forest, woodland, shrubland, and grassland ecosystems of the ICRB.

GLOSSARY

Biophysical setting	The combination of moisture and temperature that describes the environment for plant growth.
Cover type	The dominant vegetation in an area. For rangelands, the cover type is named for the species with the plurality of canopy cover. In forests, the cover type is named for the tree species with the greatest basal area.
Decision rules	Conditional statements of the form: If [given conditions exist] then [result].
Fire frequency	A description of how often repeated fires occur, usually expressed as mean fire interval (MFI).
Fire history	The past fire occurrence, usually described by frequency of past fifes
Fire regime	A description of the typical occurrence and effects of fires in an area. Our classification of fire regime is based upon the mean interval between recurring fires and the extent of change in the dominant vegetation as a result of the fire.
Fire severity	A description of the degree of change in vegetation as a direct result of fire occurrence, often based upon a comparison of burned and unburned vegetation within the first 3 years following a fire.
Mean fire interval (MFI)	The average number of years between recurring fire events
Potential vegetation type	The climax vegetation that would develop in the absence of disturbance; the endpoint of secondary succession.

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Table 1. Fiie **frequency** classes used for our fire regime classification. The mean fire interval is the average number of years between fires recurring at a point or within a small area.

Class	Symbol	Mean fire interval (MFI)
Very Frequent	VF	Less than 25 years
Frequent	F	26-75 years
Infrequent	I	76- 150 years
Very Infrequent	VI	15 I-300 years
Extremely Infrequent	EI	Greater than 300 years

Table 2. Fire severity classes used for our fire regime classification. Fiie severity is determined based upon the extent of mortality of dominant vegetation (trees, or shrubs if no trees are present, or grasses if no trees or shrubs are present). To produce the maps in this study, we appiied the fire severity classes to 1 km^2 pixels. Note that unburned areas within the fire perimeter are not considered; only burned areas are used as a basis for determining fire severity.

Fire Severity	Symbol	Description
Nonlethal	NL	More than 70% of the basal area or more than 90% of the canopy cover that existed prior to the bum is alive after the bum.
Mixed	M	Fires of intermediate effects, often consisting of fine-grained spatial patterns resulting from a mosaic of varying severity.
Stand-replacement	S R	Less than 20% of the basal area or less than 10% of the canopy cover of the overstory vegetation remains after the fire
Rarely bums .	RB	Fires very seldom occur and are not one of the primary disturbance factors affecting vegetation structure. composition, and succession.

Table 3. Fire regime classes combine the severity and frequency of typical fires. Historical (circa 1900) and current (circa 1990) extent of fires are compared for each severity class across the entire ICRB area. Values are the percent of total area within Interior Columbia River Basin assessment area.

Fire regime class	Symbol	Historical occurrence	Current occurrence
Nonlethal, very frequent	NLVF	27.3	1.4
Nonlethal, frequent	NLF	2.4	4.2
Nonlethal, infrequent	NLI	2.6	14.3
Mixed. very frequent	MVF	0.5	0.0
Mixed. frequent	MF	5.5	13.2
Mixed, infrequent	Ml	9.6	16.9
Mixed, very infrequent	MVI	0.0	0.0
Stand-replacing, very frequent	SRVF	0.0	4.9
Stand-replacing, frequent	SRF	34.1	0.6
Stand-replacing. infrequent	SRI	5.7	29.4
Stand-replacing, very infrequent	SRVI	6.0	9.4
Stand-replacing, extremely infrequent	SREI	5.1	4.3
Rarely bums	RB	1.4	1.5

Table 4. Decision rules for assigning fire regime classes to historical and current vegetation classes. Vegetation classes are named for the dominant cover type. The areal extent (km^2) of the vegetation types by biophysical setting is also shown. Fire regimes are assigned based upon the biophysical settings as interpreted from potential natural vegetation types, and the cover type of the vegetation. Decision rules are based upon published literature, fire history studies, and expert opinion. Bold type designates situations where the current fire regimes differs from the historical fire regime in either frequency or severity.

Vegetation class	Biophysical Setting	Historical fire regime (Circa 1900)		Current fire regime (Circa 1990)		Historical Extent	Current Extent
SHRUBLANDS							
Antelope bitterbrush /	cool/moist	Stand-repl.	Frequent	Stand-repl.	**Infrequent**	239	49
bluebunch wheatgrass	cool/dry	Stand-repl.	Frequent	Stand-repl.	**Infrequent**	245	62
SRM 104	warm/moist	Stand-repl.	Frequent	Stand-repl.	**Infrequent**	352	471
	warm/dry	Stand-repl.	Infrequent	Stand-repl.	Infrequent	1023	713
Big sagebrush	cool/moist	Stand-repl.	Frequent	Stand-repl.[1]	**Infrequent**[2]	12360	5858
CRB S04	cool/dry	Stand-repl.	Frequent	Stand-repl.[1]	**Infrequent**[2]	59940	55113
	warm/moist	Stand-repl.	Frequent	Stand-repl.[1]	**Infrequent**[2]	29064	21373
	warm/dry	Stand-repl.	Frequent	Stand-repl.[1]	**Infrequent**[2]	96201	61746
Chokecherry / rose /	cool/moist	Stand.-repl.	Frequent	Stand-repl.	**Infrequent**	0	33
service berry	cool/dry	Stand-repl.	Frequent	Stand-repl.	**Infrequent**	0	50
SRM 421	warm/moist	Stand-repl.	Frequent	Stand-repl.	**Infrequent**	77	21
	warm/dry	Stand-repl.	Infrequent	Stand-repl.	Infrequent	75	103
Low sage	cool/moist	Stand-repl.	Frequent	Stand-repl.	**Very Infrequent**	770	815
SRM 406	cool/dry	Stand-repl.	Frequent	Stand-repl.	**Very Infrequent**	5286	5795
	warm/moist	Stand-repl.	Frequent	Stand-repl.	**Very Infrequent**	529	319
	warm/dry	Stand-repl.	Frequent	Stand-repl.	**Very Infrequent**	7130	8125

Mountain big sagebrush SRM 402	cool/moist	Stand-repl.	Frequent	Stand-repl.	Inirequent	8773	6538
	cool/dry	Stand-repl.	Frequent	Stand-repl.	Infrequent	20477	18459
	warm/moist	Stand-repl.	Frequent	Stand-repl.	Infrequent	3188	598
	warm/dry	Stand-repl.	Infrequent	Stand-repl.	Infrequent	23928	12983
Mountain mahogany SRM322	cool/moist	Mixed	Frequent	Mixed	Frequent	360	1645
	cool/dry	Stand-repl.	Infrequent	Stand-repl.	Infrequent	48	132
	warm/moist	Stand-repl.	Infrequent	Stand-repl.	Infrequent	6	7
	warm/dry	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	135	463
Salt desert shrub SRM 414	cool/moist	Stand-repl.	Ext. Infrequent	Stand-repl.	Ext. Infrequent	0	0
	cool/dry	Stand-repl.	Ext. Infrequent	Stand-repl.	Ext. Infrequent	5736	5749
	warm/moist	Stand-repl.	Ext. Infrequent	St and-repl.	Ext. Infrequent	20852	18536
	warm/dry	Stand-repl.	Ext. Infrequent	Stand-repl.	Ext. Infrequent	14772	11083
Shrub or herbaceous/tree regeneration CRB 003	cool/moist	Stand-repl.	Frequent	Stand-repl.	Infrequent	7382	6134
	cool/dry	Stand-repl.	Frequent	Stand-repl.	Infrequeni	9354	15360
	warm/moist	Stand-repl.	Frequent	Stand-rep].	Infrequent	4648	3996
	warm/dry	Stand-repl.	Frequent	Stand-repl.	Infrequent	13478	11256
WETLANDS							
Herbaceous wetland CRB 007	cool/moist	Nonlethal	Frequent	Mixed	Infrequent	334	321
	cool/dry	Nonlethal	Frequent	Mixed	Frequent	0	0
	warm/moist	Nonlethal	Frequent	Mixed	Frequent	452	488
	warm/dry	Nonlethal	Frequent	Mixed	Frequent	213	507

Wetland shrub	cool/moist	Mixed	Frequent	Mixed	**Infrequent**	0	51
CRB S05	cool/dry	Mixed	Frequent	Mixed	Frequent	7	0
	warm/moist	Mixed	Frequent	Mixed	Frequent	2475	2598
	warm/dry	Mixed	Frequent	Mixed	Frequent	2685	257
HERBACEOUS							
Exotic Forbs/Annual	cool/moist	Did not exist		**Nonlethal**	**Very Frequent**	0	964
grass	cool/dry	Did not exist		**Nonlethal**	**Very Frequent**	0	2492
CRB S08	warm/moist	Did not exist		**Nonlethal**	**Very Frequent**	0	1827
	warm/dry	Did not exist		**Nonlethal**	**Very Frequent**	0	6095
Native forb	cool/moist	Nonlethal	Infrequent	Nonlethal	Infrequent	0	0
CRB S07	cool/dry	Nonlethal	Infrequent	Nonlethal	Infrequent	8	0
	warm/moist	Nonlethal	Infrequent	Nonlethal	Infrequent	0	0
	warm/dry	Nonlethal	Infrequent	Nonlethal	Infrequent	39	51
GRASSLANDS							
Agropyron bunchgrass	cool/moist	Nonlethal	Very Frequent	Nonlethal	**Frequent**	5897[3]	15386[4]
CRB S06	cool/dry	Nonlethal	Very Frequent	Nonlethal	**Frequent**	2823[3]	1473[4]
	warm/moist	Nonlethal	Very Frequent	Nonlethal	**Frequent**	14251[3]	2520[4]
	warm/dry	Nonlethal	Very Frequent	**Mixed**	**Frequent**	26785[3]	11734[4]
Fescue / bunchgrass	cool/moist	Nonlethal	Very Frequent	Nonlethal	**Frequent**	0[3]	5696[4]
CRB S13	cool/dry	Nonlethal	Very Frequent	Nonlethal	**Frequent**	0[3]	8206[4]
	warm/moist	Nonlethal	Very Frequent	Nonlethal	**Frequent**	0[3]	683[4]
	warm/dry	Nonlethal	Very Frequent	**Mixed**	**Frequent**	0[3]	14255[4]
MESIC FORESTS							

Grand fir / white fir	cool/moist	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	0	4098
CRB SO9	cool/dry	Stand-repl.	Infrequent	Stand-repl.	Infrequent	1984	6622
	warm/moist	Stand-repl.	Infrequent	Stand-repl.	Infrequent	625	6994
	warm/dry	Mixed	Infrequent	Mixed	Infrequent	465	13430
Pacific silver fir /	cool/moist	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	29	591
Mountain hemlock	cool/dry	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	82	969
CRB 008	warm/moist	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	12	195
	warm/dry	Stand-repl.	Infrequent	Stand-repl.	Very Infrequent	0	557
Red fir	cool/moist	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	9	30
CRB S11	cool/dry	Stand-repl.	Infrequent	Stand-repl.	Infrequent	1	6
	warm/moist	Stand-repl.	Infrequent	Stand-repl.	Infrequent	0	0
	warm/dry	Mixed	Infrequent	Mixed	Infrequent	0	0
Western larch	cool/moist	Mixed	Frequent	**Stand-repl.**	**Infrequent**	6952	3705
SAF 212	cool/dry	Mixed	Frequent	Mixed	**Infrequent**	2669	1661
	warm/moist	Mixed	Frequent	**Stand-repl.**	Frequent	7995	5093
	warm/dry	Mixed	Very Frequent	Mixed	**Infrequent**	3722	3246
Western redcedar /	cool/moist	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	113	2004
western hemlock	cool/dry	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	122	313
SAF 227	warm/moist	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	54	1408
	warm/dry	Stand-rep).	Very Infrequent	Stand-repl.	Very Infrequent	115	201
Western white pine	cool/moist	Stand-rep].	Very Infrequent	**Stand-repl.**	**Very Infrequent**	3323	128
SAF 215	cool/dry	Mixed	Infrequent	**Stand-repl.**	**Infrequent**	1395	88
	warm/moist	Stand-repl.	Infrequent	**Stand-repl.**	Infrequent	5679	83
	warm/dry	Mixed	Infrequent	Mixed	**Infrequent**	0	163

DRY FORESTS							
Interior Douglas-fir SAF 210	cool/moist	Mixed	Frequent	**Stand-repl.**	**Infrequent**	7765	10641
	cool/dry	Nonlethal	Frequent	**Mixed**	**Infrequent**	17280	21711
	warm/moist	Mixed	Frequent	**Stand-repl.**	**Infrequent**	3877	8414
	warm/dry	Nonlethal	Infrequent	Nonlethal	Infrequent	20891	29181
Interior ponderosa pine SAF 237	cool/moist	Nonlethal	Very Frequent	**Mixed**	**Infrequent**	5163	5101
	cool/dry	Nonlethal	Very Frequent	**Mixed**	**Frequent**	16683	7839
	warm/moist	Nonlethal	Very Frequent	**Mixed**	**Infrequent**	14614	12154
	warm/dry	Nonlethal	Very Frequent	Nonlethal	**Infrequent**	61508	50729
Pacific ponderosa pine SAF 245	cool/moist	Nonlethal	Very Frequent	**Mixed**	**Infrequent**	452	420
	cool/dry	Nonlethal	Very Frequent	**Mixed**	**Frequent**	202	117
	warm/moist	Nonlethal	Very Frequent	**Mixed**	**Infrequent**	1148	847
	warm/dry	Nonlethal	Very Frequent	Nonlethal	**Infrequent**	737	1285
Sierra Nevada mixed conifer SAF 243	cool/moist	Mixed	Infrequent	**Stand-repl.**	**Very Infrequent**	207	331
	cool/dry	Mixed	Infrequent	Mixed	**Very Infrequent**	95	256
	warm/moist	Mixed	Infrequent	**Stand-repl.**	Infrequent	416	897
	warm/dry	Mixed	Infrequent	Mixed	Infrequent	154	359
WOODLANDS							
Aspen SAF 217	cool/moist	Stand-repl.	Infrequent	Stand-repl.	Infrequent	833	2567
	cool/dry	Stand-repl.	Infrequent	Stand-repl.	Infrequent	1466	6550
	warm/moist	Stand-repl.	Infrequent	Stand-repl.	Infrequent	984	1153
	warm/dry	Stand-repl.	Infrequent	Stand-repl.	Infrequent	5605	6890

Cottonwood / Willow	cool/moist	Mixed Frequent	Mixed **Infrequent**	I	1
SAF 235	cool/dry	Mixed Frequent	Mixed . **Infrequent**	0	8
	warm/moist	Mixed Frequent	Mixed **Infrequent**	49	82
	warm/dry	Mixed Frequent	Mixed **Infrequent**	34	32
Juniper / sagebrush	cool/moist	Mixed Infrequent	Mixed Infrequent	720	**1881**
CRB so3	cool/dry	. . Mixed Infrequent	Mixed Infrequent	852	**1950**
	warm/moist	Mixed Infrequent	Mixed Infrequent	766	2365
	warm/dry	Mixed Infrequent	Mixed Infrequent	4520	9152
Juniper woodland	cool/moist	Mixed Infrequent	Mixed Infrequent	15	16
CRB so1	cool/dry	Mixed Infrequent	Mixed Infrequent	205	206
	warm/moist	Mixed Infrequent	Mixed **Infrequent**	69	69
	warm/dry	Mixed Infrequent	Mixed Infrequent	757	**1005**
Limber pine	cool/moist	Mixed Frequent	Stand-Repl. **Infrequent**	3	**15**
SAF 219	**cool/dry**	Mixed Frequent	Mixed **Infrequent**	128	194
	warm/moist	Mixed Frequent	Stand-Repl. **Infrequent**	**0**	**0**
	warm/dry	Mixed Frequent	Mixed **Infrequent**	**132**	203
Mixed conifer woodland	cool/moist	Mixed Frequent	Stand-Repl. **Infrequent**	1218	35
CRB so2	**cool/dry**	Mixed Frequent	Mixed **Infrequent**	2608	62
	warm/moist	Mixed Frequent	Stand-Repl. **Infrequent**	58	270
	warm/dry	Mixed Frequent	Mixed **Infrequent**	5686	3561
Oregon white oak	cool/moist	Mixed Frequent	Mixed **Infrequent**	33	43
SAF233	cool/dry	Mixed Frequent	Mixed **Infrequent**	4	8
	warm/moist	Mixed Frequent	Mixed **Infrequent**	176	196
	warm/dry	Mixed Frequent	Mixed **Infrequent**	268	411

COLD, HARSH **FORESTS**

Engelmann spruce / subalpine fir SAF 206	cool/moist	Stand-repl.	Very Infrequent	Stand-repl.	'Very Infrequent	8834	7699
	cool/dry	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	18522	25588
	warm/moist	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	1048	383
	warm/dry	Mixed	Infrequent	Mixed	Infrequent	2248	3636
Lodgepole pine SAF 218	cool/moist	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	12937	13897
	cool/dry	Mixed	Infrequent	Mixed	Infrequent	41223	33114
	warm/moist	Stand-repl.	Infrequent	Stand-repl.	Infrequent	4129	4433
	warm/dry	Mixed	Infrequent	Mixed	Infrequent	9056	12689
Mountain hemlock SAF 205	cool/moist	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	322	644
	cool/dry	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	323	599
	warm/moist	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	127	25
	warm/dry	Stand-repl.	Very Infrequent	St and-repl.	Very Infrequent	52	4
Whitebark pine SAF 208	cool/moist	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	1612	1491
	cool/dry	Mixed	Infrequent	Mixed	Infrequent	13439	7704
	warm/moist	Mixed	Infrequent	Mixed	Infrequent	0	0
	warm/dry	Mixed	Infrequent	Mixed	Infrequent	69	157
Whitebark pine / alpine larch CRB S10	cool/moist	Stand-repl.	Very Infrequent	Stand-repl.	Very Infrequent	626	0
	cool/dry	Mixed	Infrequent	**Stand-repl.**	**Very Infrequent**	1482	99
	warm/moist	Mixed	Infrequent	**Stand-rep!.**	**Very Infrequent**	0	0
	warm/dry	Mixed	Infrequent	**Stand-repl.**	**Very Infrequent**	0	0

OTHER

Alpine tundra	cool/moist	Rarely Burns	Rarely Burns		641	641
CRB 005	cool/dry	Rarely Burns	Rarely Burns		2968	2966
	warm/moist	Rarely Burns	Rarely Burns		11	11
	warm/dry	Rarely Burns	Rarely Burns		109	109
Barren	cool/moist	Rarely Burns	Rarely Burns		5	5
CRB 006	cool/dry	Rarely Burns	Rarely Burns		2	2
	warm/moist	Rarely Burns	Rarely Burns		0	0
	warm/dry	Rarely Burns	Rarely Burns		0	0
Crop / hay / pasture	cool/moist	Did not exist	Nonlethal[5]	Infrequent[6]	0	13052
CRB S12	cool/dry	Did not exist	Nonlethal[5]	Infrequent[6]	0	12808
	warm/moist	Did not exist	Nonlethal[5]	Infrequent[6]	0	24162
	warm/dry	Did not exist	Nonlethal[5]	Infrequent[6]	0	68341
Urban	cool/moist	Did not exist	Rarely Burns		0	53
CRB S19	cool/dry	Did not exist	Rarely Burns		0	84
	warm/moist	Did not exist	Rarely Burns		0	275
	warm/dry	Did not exist	Rarely Burns		0	731
Water	cool/moist	Rarely Burns	Rarely Burns		311	311
CRB S20	cool/dry	Rarely Burns	Rarely Burns		0	980
	warm/moist	Rarely Burns	Rarely Burns		0	3222
	warm/dry	Rarely Burns	Rarely Burns		303	3028

[1,2]Fire regime is Stand-replacing Very Frequent where exotic annual grasses are abundant in this vegetation type (Sections 342C and 342I).
[3,4]Fescue / bunchgrass was not identified as a separate class in the historical vegetation layer. Instead, it was called Agropyron bunchgrass.
[5,6]Fire regime is Nonlethal Frequent in Section 331A (Palouse Prairie) and Mixed Frequent where exotic annual grasses are abundant in this

vegetation type (All 5 sections in Ecoregion 342: 3428, 342C, 342D, 342H, and 3421).

Table 5. Fires are typically more severe now (circa 1990) than they were historically (circa 1900), but the degree of change differs among representative ecoregions of the ICRB. Each ecoregion includes from 1 to 7 sections. The alphanumeric codes for ecoregions and sections (in italic type) are shown in Figure 1.

Ecoregion and sections	**Area (km²)**	**Fire severity**	**Historical (%)**	**Current (%)**
M242 : Cascade *(Section M242C)*	44,572	Nonlethal	49	20
		Mixed	29	42
		Stand-replacing	20	36
		Rarely bums	2	2
M332G: Middle Rocky Mountains *(Sections M332A, B, C, D, E, F, and G)*	218,533	Nonlethal	54	37
		Mixed	18	29
		Stand-replacing	28	37
		Rarely bums	0	0
M333: Northern Rocky Mountains *(Sections M333A, B, C, and D)*	96,146	Nonlethal	33	21
		Mixed	33	24
		Stand-replacing	31	53
		Rarely bums	2	2
M342: Intermountain Semi-Desert *(Sections M342B, C, D, H and I)*	288.25 1	Nonlethal	13	6
		Mixed	3	33
		Stand-replacing	83	60
		Rarely bums	1	1
33 I : Great Plains-Palouse Dry Steppe *(Section 331A)*	18,445	Nonlethal	97	7
		Mixed	2	10
		Stand-replacing’	0	4
		Rarely bums	0	1
M33 1: Southern Rocky Mountains *(Sections M33 1A, D and J)*	71,036	Nonlethal	16	18
		Mixed	38	39
		Stand-replacing	41	38
		Rarely burns	5	5

M26 1: Sierran *(Sections D and G)*	48.3 16	Nonlethal	55	39
		Mixed	10	32
		Stand-replacing	32	30
		Rarely bums	3	3
34 1 :and Desert *(S* Intermountain **Semi-** Desert ***ection*** *E)*	*33,924*	Nonlethal	3	3
		Mixed	2	3
		Stand-replacing	96	94
		Rarely bums	0	0

Figure 1. The ICRB area, for which historical and current fire regimes are mapped, is divided into 8 ecoregions and 24 sections (Bailey 1994). The alphanumeric codes indicate both ecoregion (3 digits and the preceding letter) and section (last letter in code).

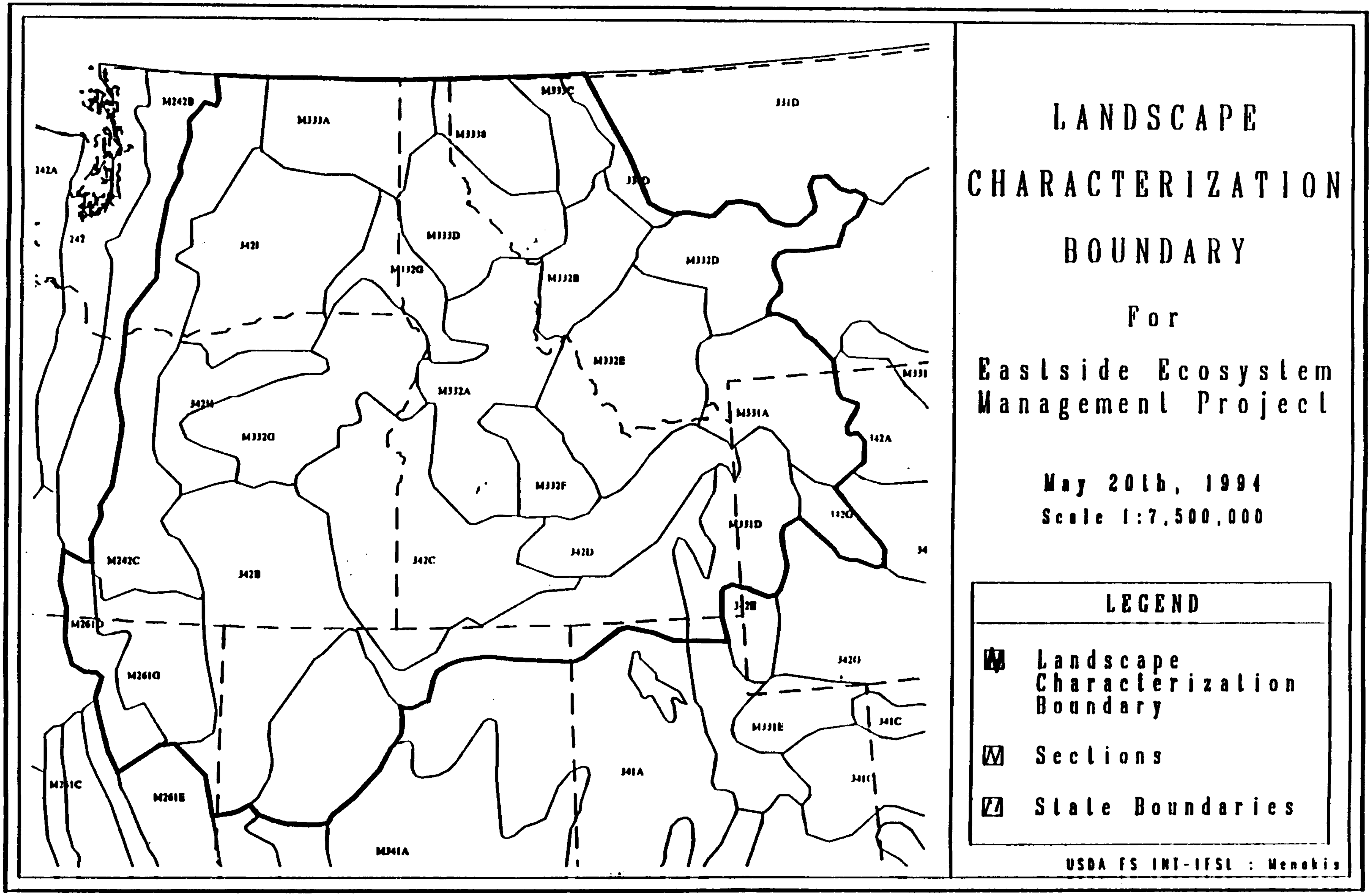
Figure 2. Changing fire severity in the ICRB. See Table 1 for a description of the fire severity classes and their symbols.

Figure 3. Changing fire frequency in the ICRB. See Table 2 for a description of the fire frequency classes and their symbols.

Figure 4. Changing fire regimes in the ICRB. See Tables 1 and 2 for a description of the fire regime classes and their symbols.

Figure 5. Past (circa 1900) and present (circa 1990) fire regimes in the ICRB. Fire regime changes incorporate changes due to both'changes in fire regime within a given type of vegetation and the changing areal extent of the vegetation types.

Figure 1. The ICRB area, for which historical and current fire regimes are mapped, is divided into 8 ecoregions and 24 sections (Bailey 1994). The alphanumeric codes indicate both ecoregion (3 digits and the preceding letter) and section (last letter in code).



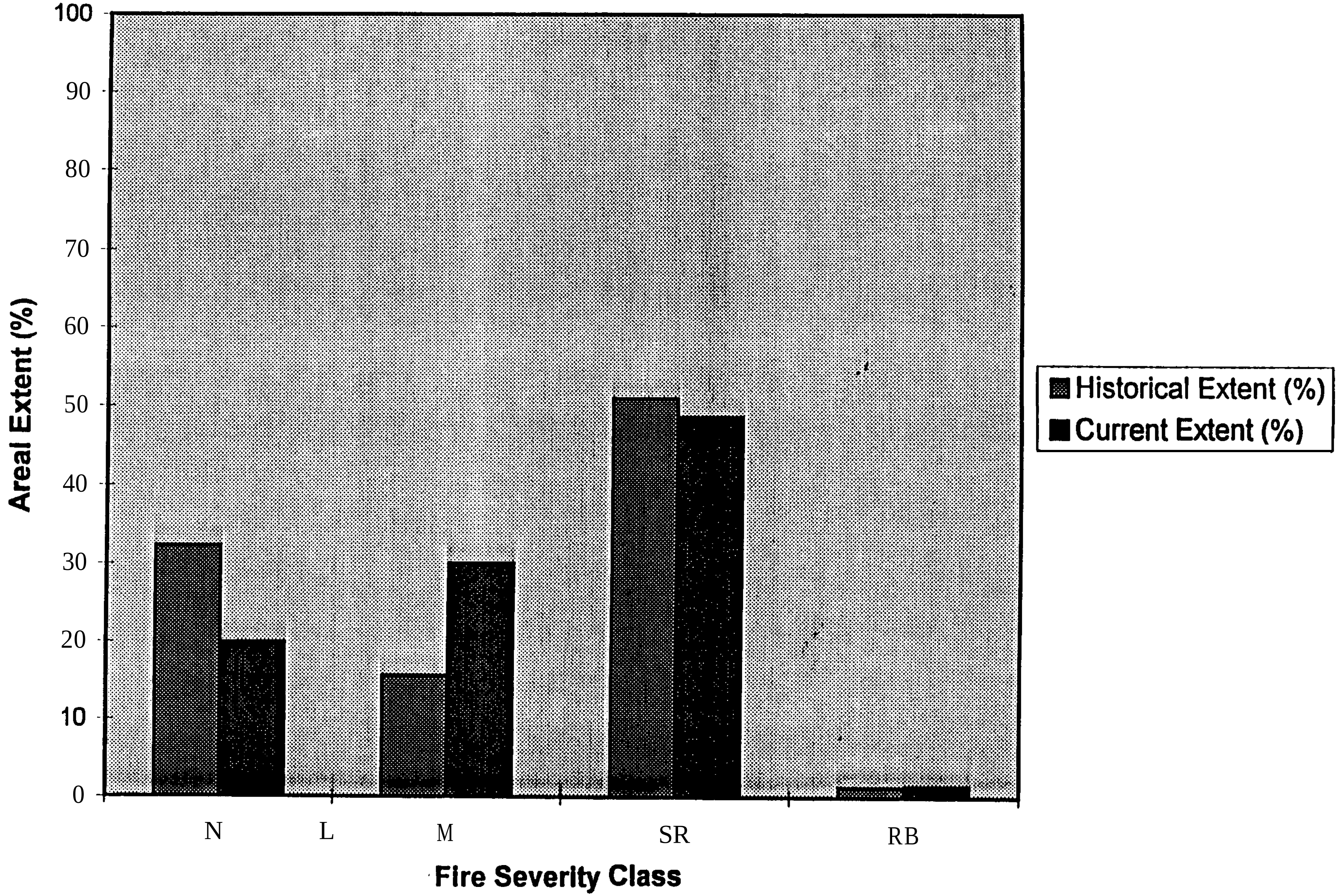


Figure 2. Changing fire severity in the ICRB. See Table I for a description of the fire severity classes and their symbols.

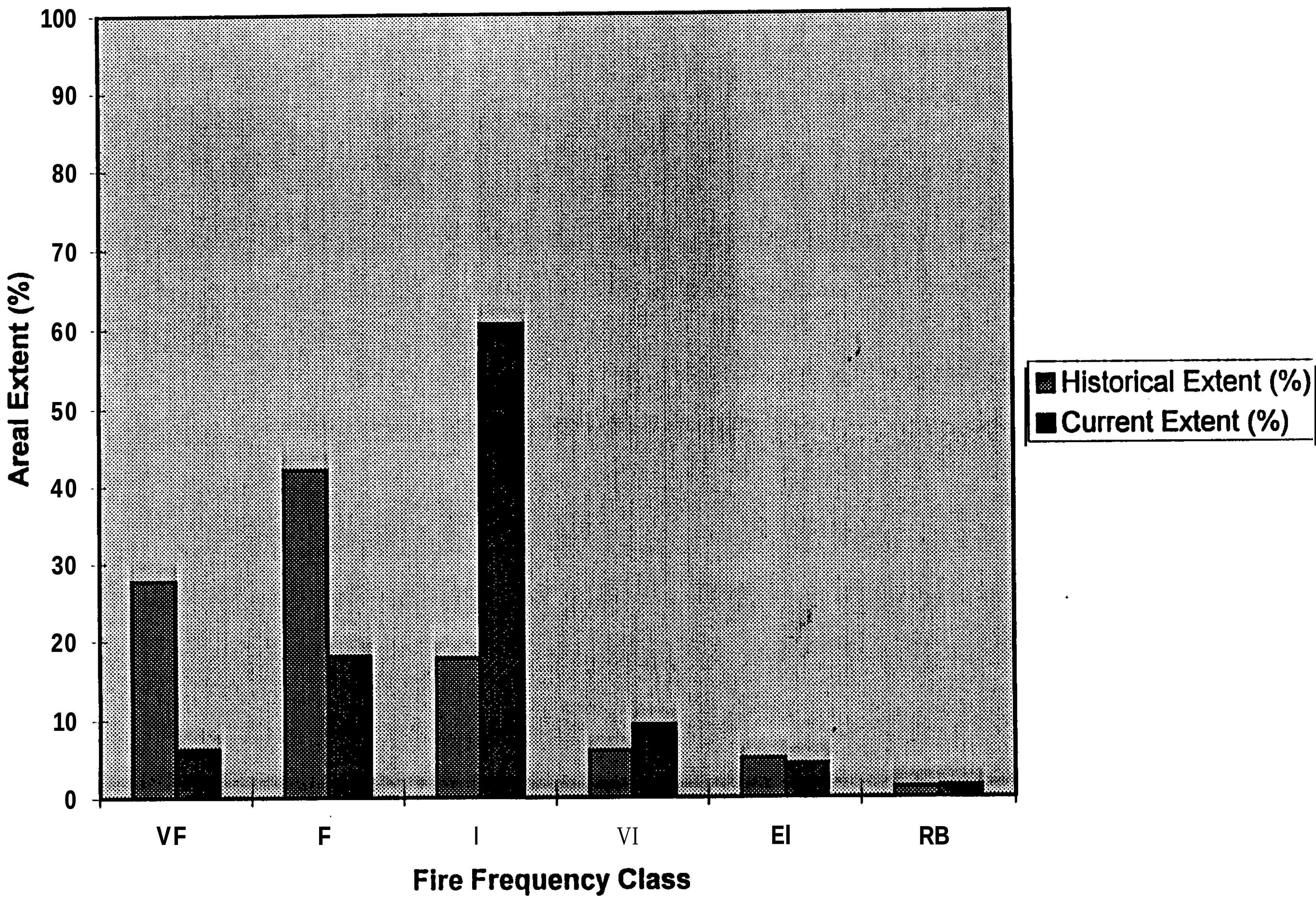


Figure 3. Changing **fire** frequency in the ICRB. See Table 2 for a description of the fire frequency classes and their symbols.

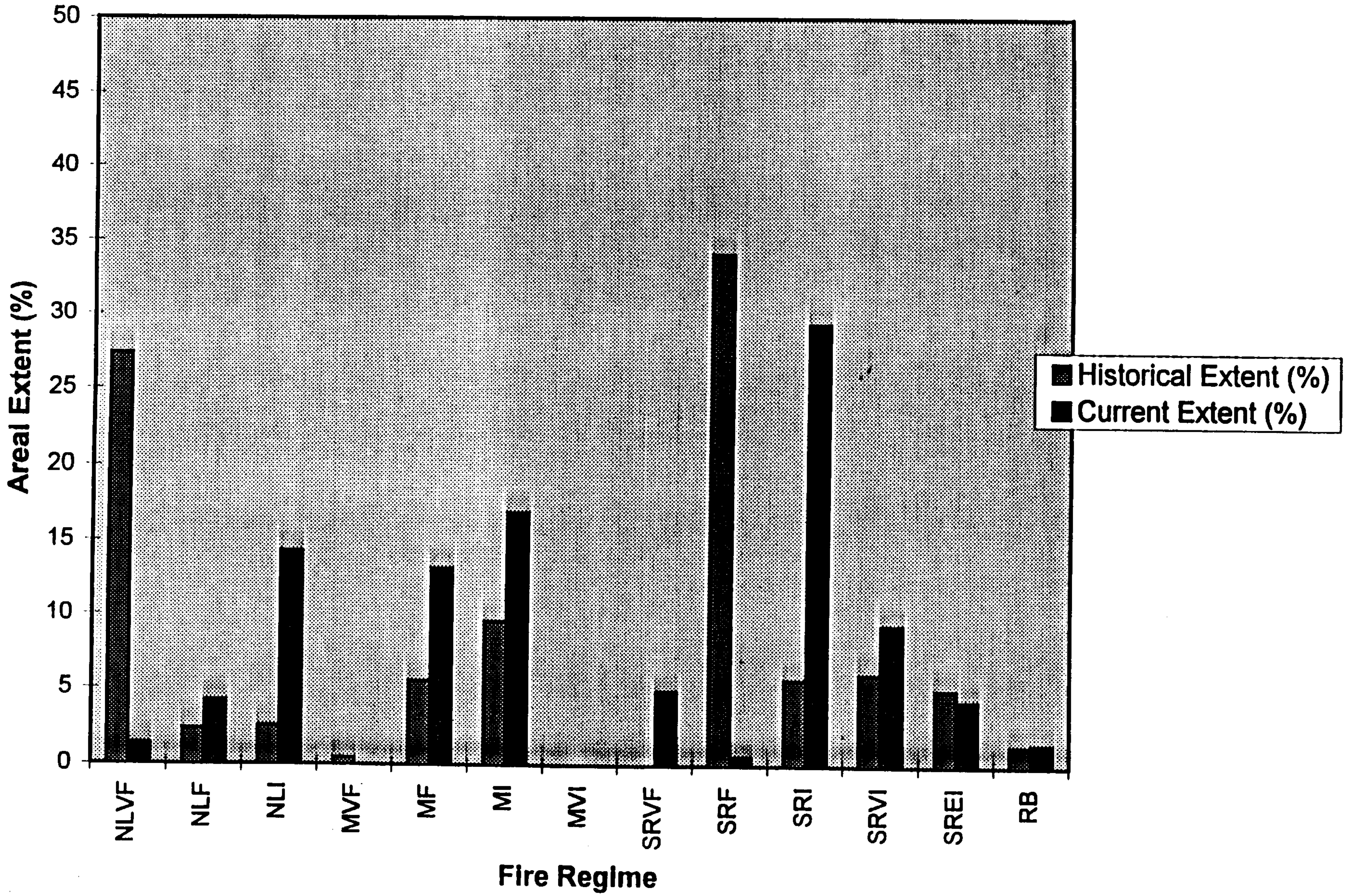
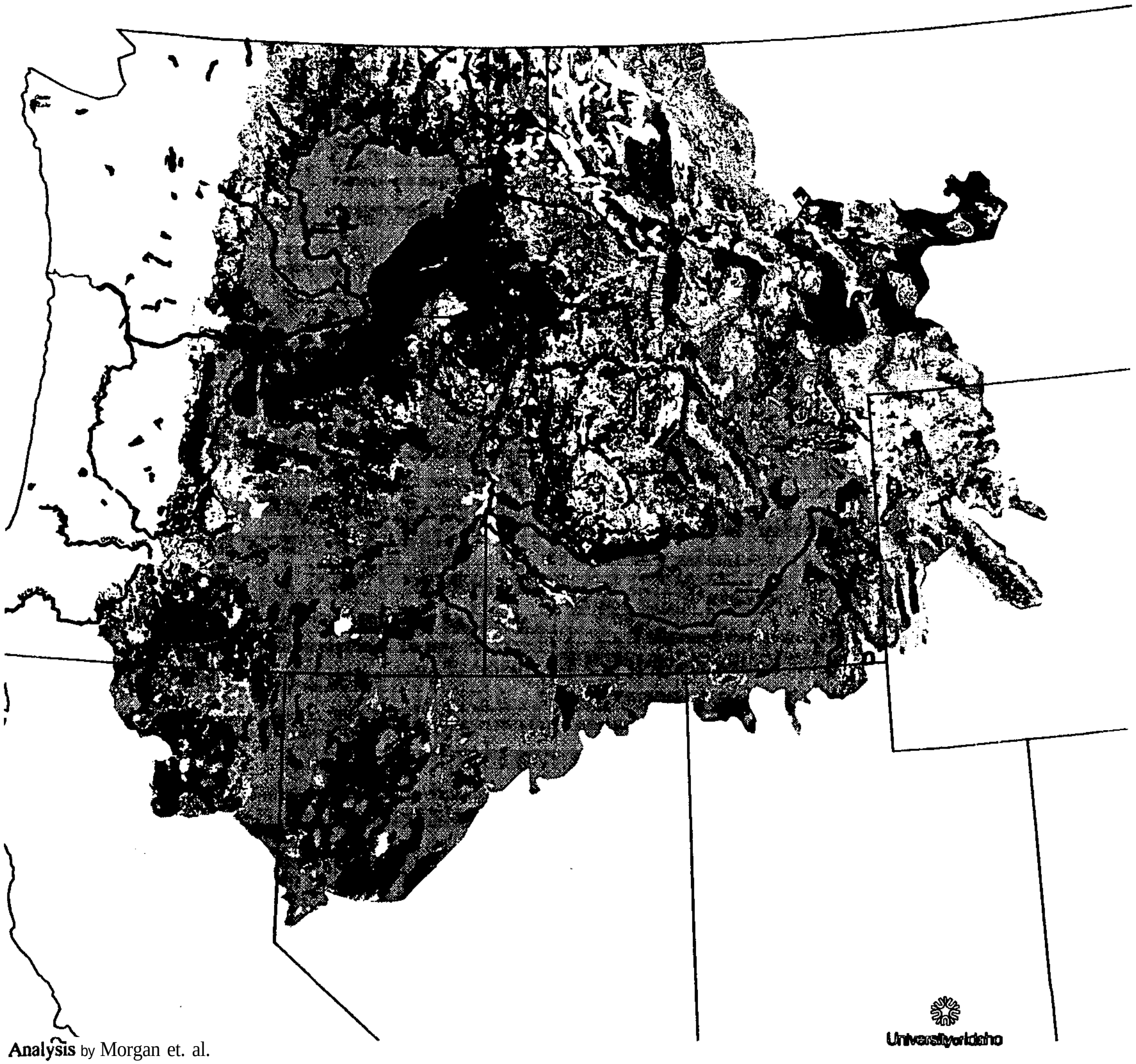


Figure 4. Changing fire regimes in the ICRB. See Tables 1 and 2 for a description of the fire regime classes and their symbols.

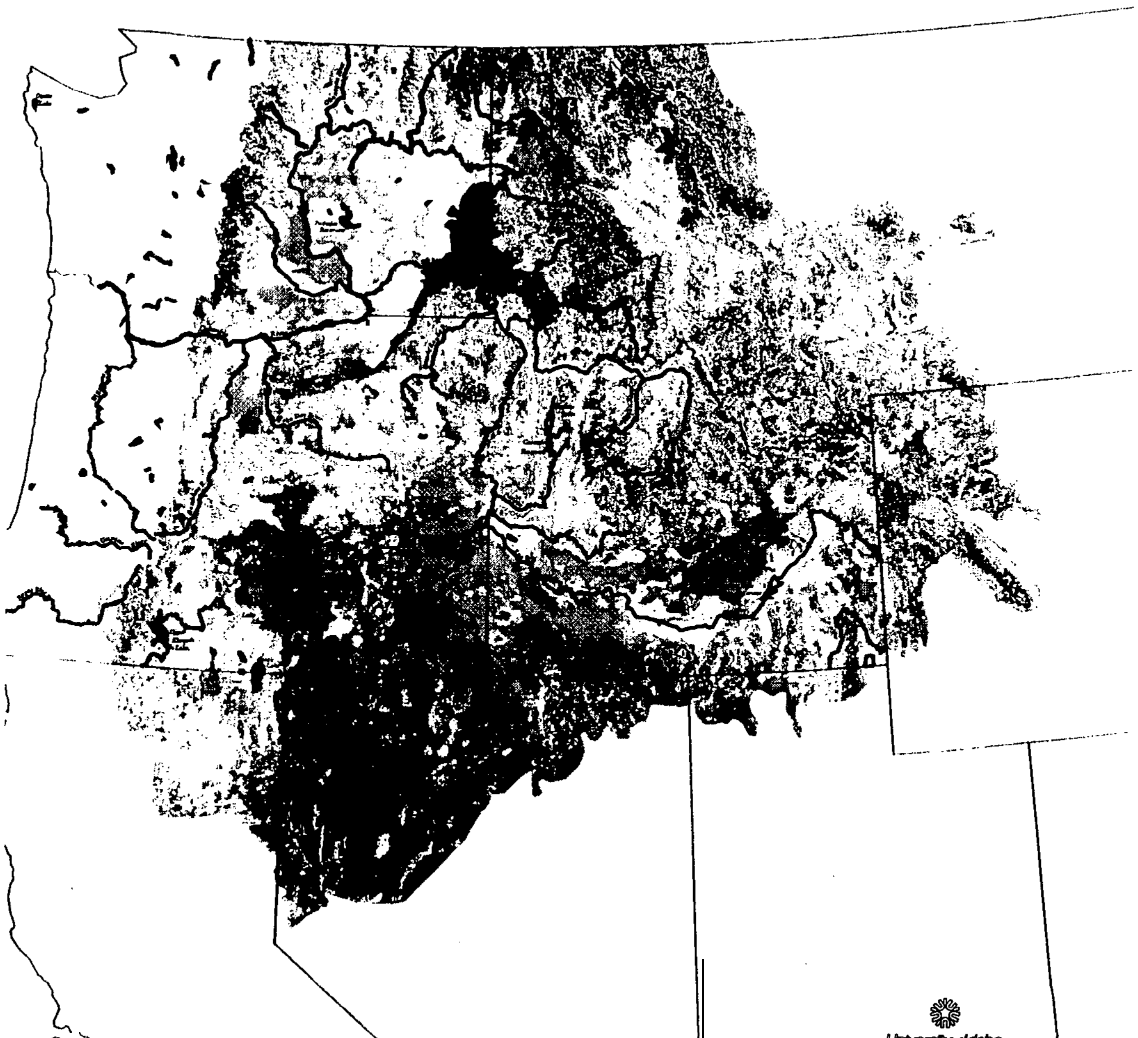
HISTORICAL FIRE REGIMES OF THE INTERIOR COLUMBIA RIVER BASIN



Analysis by Morgan et. al.

- Nonlethal Very Frequent
- Nonlethal Frequent
- Nonlethal Infrequent
- Mixed Very Frequent
- Mixed Frequent
- Mixed Infrequent
- Mixed Very Infrequent
- Stand-replacing Very Frequent
- Stand-replacing Frequent
- Stand-replacing Infrequent
- Stand-replacing Very Infrequent
- Stand-replacing Extremely Infrequent
- Rarely Bums

Interior Columbia River Basin



Analysis by Morgan et. al.

CURRENT FIRE REGIMES OF THE INTERIOR COLUMBIA RIVER BASIN

- Nonlethal Very Frequent
- Nonlethal Frequent
- Nonlethal Infrequent
- Mixed Very Frequent
- Mixed Frequent
- Mixed Infrequent
- Mixed Very Infrequent
- Stand-replacing Very Frequent
- Stand-replacing Frequent
- Stand-replacing Infrequent
- Stand-replacing Very Infrequent
- Stand-replacing Extremely Infrequent
- Rarely Bums

Interior Columbia River Basin