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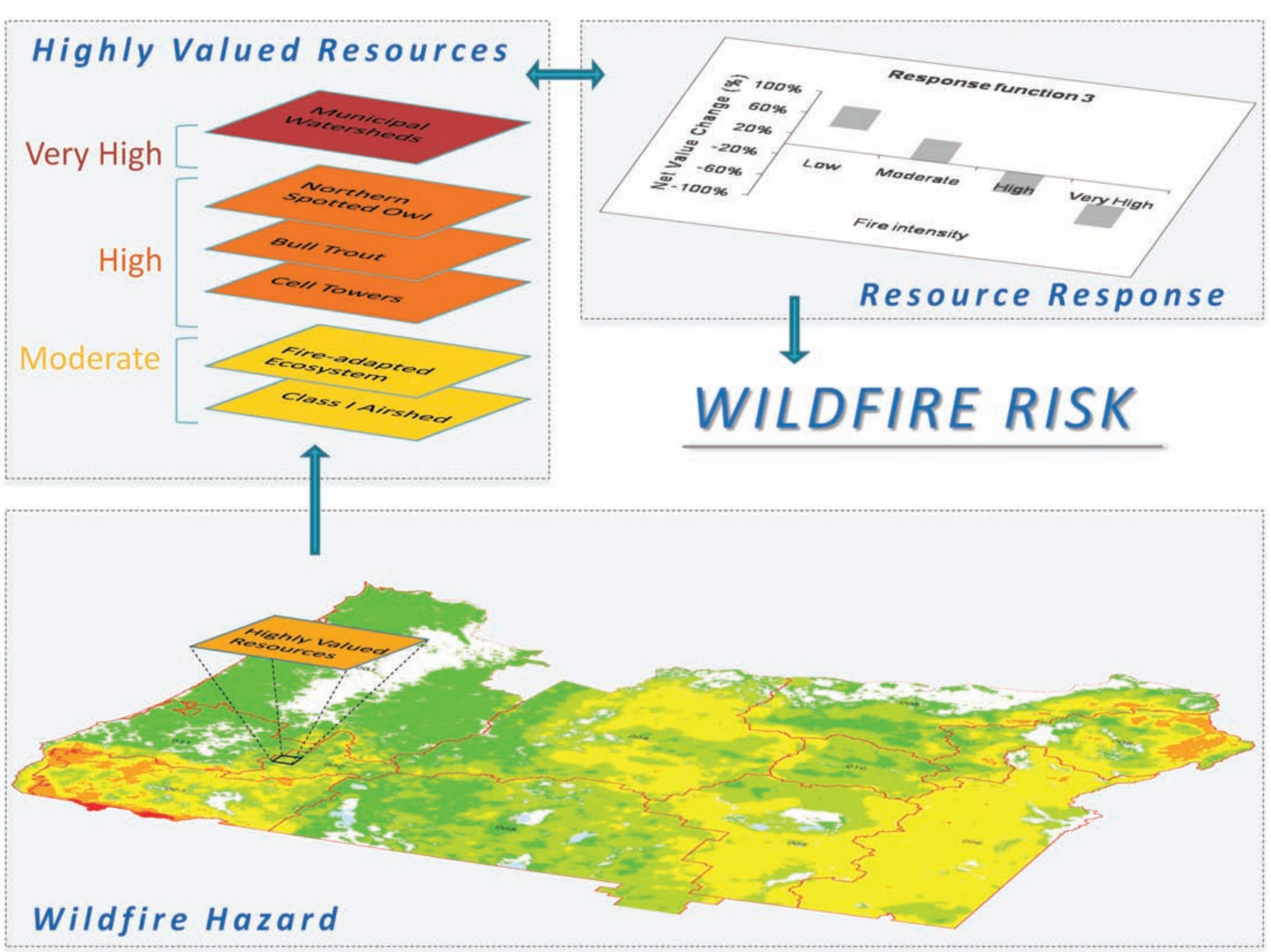
Wildfire Risk and Hazard: Procedures for the First Approximation



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Abstract

This report was designed to meet three broad goals: (1) evaluate wildfire hazard on Federal lands; (2) develop information useful in prioritizing where fuels treatments and mitigation measures might be proposed to address significant fire hazard and risk; and (3) develop risk-based performance measures to document the effectiveness of fire management programs. The research effort described in this report is designed to develop, from a strategic view, a first approximation of how fire likelihood and fire intensity influence risk to social, economic, and ecological values at the national scale. The approach uses a quantitative risk framework that approximates expected losses and benefits to highly valued resources from wildfire. Specifically, burn probabilities and intensities are estimated with a fire simulation model and are coupled with spatially explicit data on human and ecological values and fire-effects response functions to estimate the percent loss or benefit. This report describes the main components of the risk framework, including the burn probability models, highly valued resource data, and development of response functions, and illustrates the application to the State of Oregon. The State of Oregon was selected for prototype due to the wide range of variability in ecoregions represented in the state. All of the highly valued resource themes were represented in the mix of developed and natural resources present in the state. National risk and hazard approximation results for the Continental United States are available at the following location: www.fs.fed.us/wwetac/wflc/.

Keywords: wildland fire, risk management, wildfire hazard, highly valued resources, net value change

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Contents

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Introduction

Reviews have been conducted by Federal oversight agencies and blue ribbon panels to identify causal factors of the unprecedented fire suppression costs and to suggest possible modifications to Federal fire management policy and strategies (USDOI, USDA 2004; USDAOIG 2006; GAO 2007, 2009). Agency and panel member reviews have found that Federal agencies with wildland fire responsibilities are not able to quantify the value of fire management activities in terms of reducing wildfire risk to social, economic, and ecological values. In response, the Wildland Fire Leadership Council's (WFLC) monitoring strategy asked: What are the trends and changes in fire hazard on Federal lands? Fire risk assessment requires an understanding of the likelihood of wildfire by intensity level and the potential beneficial and negative effects to valued resources from fire at different intensity levels.

This monitoring study was conducted to meet three broad goals: (1) address the WFLC monitoring question regarding fire hazard on Federal lands; (2) develop information useful in prioritizing where fuels treatments and mitigation measures might be proposed to address significant fire hazard and risk; and (3) respond to critiques by Office of Management and Budget, General Accounting Office, and Congress that call for risk-based performance measures to document the effectiveness of fire management programs. The results of this monitoring study are useful for project planning to quantify the potential effects of proposed actions in terms of reducing risk to specific resources of concern.

Developing decision support tools that utilize an appropriate risk management framework would address many of the issues identified within government oversight reports. Specifically, the Office of Inspector General (USDAOIG 2006) reviewed USDA Forest Service (FS) large fire costs and directed that the "FS must determine what types of data it needs to track in order to evaluate its cost effectiveness in relationship to its accomplishments. At a minimum, FS needs to quantify and track the number and type of isolated residences and other privately owned structures affected by the fire, the number and type of natural/cultural resources threatened, and the communities and critical infrastructure placed at risk."

The application of fire risk and fire hazard analyses has been demonstrated at the watershed and National Forest scales (Ager and others 2007). There, specific details regarding probabilities of fire and fire intensity are linked with specific resource benefit and loss functions (Ager and others 2007). Expanding these detailed analyses to regional and national scales to provide consistent risk assessment processes is complicated by the required data specificity and difficulty in developing loss-benefit functions for the range of human and ecological values. The research effort described in this report is designed to develop, from a strategic view, a first approximation of how both fire likelihood and intensity influence risk to social, economic, and ecological values at the national scale. The approach uses a quantitative risk framework that approximates expected losses and benefits from wildfire to highly valued resources (HVR).

The information gathered in this study can be summarized in tabular and map formats at many different scales using administrative boundaries or delineations of HVR such as built structure density. The overall purpose of the analysis is to provide a base line of current conditions for monitoring trends in wildfire risk over time. Future analyses would be used to determine trends and changes in response to fuel reduction investments, climate shifts, and natural disturbance events (e.g., bark beetles) between the timeframes analyzed. Monitoring data could be used to address national and regional questions regarding changes in fire risk and hazard as a result of investment strategies or changing conditions. While similar analyses could be conducted for alternative scenarios, this work is designed to develop the base line hazard and risk situation.

Relationship to Other Fire Management Planning Efforts

This study is closely related to two large interagency national fire management planning and decision support efforts: Fire Program Analysis (FPA) and the Wildland Fire Decision Support System (WFDSS).

The FPA system is a common interagency strategic decision support tool for wildland fire planning and budgeting (www.fpa.nifc.gov). The research described in this report uses wildfire simulation outputs from FPA to quantify wildfire likelihood and intensity. FPA wildfire simulations include geospatial data, which provide the means to map levels of wildfire risk on analyzed lands within the United States. FPA provides managers with tradeoff analysis tools for strategic planning and budgeting to support comprehensive, interagency fire management programs. FPA is tasked to evaluate the effectiveness of fire management strategies for meeting fire and land management goals based on the following five performance metrics:

1. Reducing the probability of costly fires
2. Reducing the probability of costly fires within the Wildland-Urban Interface
3. Increasing the proportion of land meeting or trending toward attaining fire and fuels management objectives
4. Protecting HVR areas from unwanted fire
5. Maintaining a high initial attack success rate

The initial FPA model used a weighting system called Expert Opinion Weighted Elicitation Process (EOWEP) to guide resource allocation decisions (Rideout and Ziesler 2004). However, the EOWEP value process was dropped and subsequent efforts on understanding the effects of fire management resource allocation on the protection of HVR have been limited.

This first approximation is designed to offer data and preliminary categorical ranking of HVR for evaluation of FPA's performance metric (4): *Protecting HVR areas from unwanted fire*. Additionally, this effort may provide a more accurate spatial representation of human population and development than available in the Silvis WUI layer (http://silvis.forest.wisc.edu/projects/WUI_Main.asp) currently used to evaluate FPA's metric (2): *Reducing the probability of costly fires within the Wildland-Urban Interface*.

The National Fire and Aviation Executive Board chartered the WFDSS project in June of 2005 "to develop a scalable decision support system for agency administrators that utilizes appropriate fire behavior modeling, economic principles and information technology to support effective wildland fire decisions consistent with Resource and Fire Management Plans."

The economic effects module of WFDSS is known as the Rapid Assessment of Values At Risk (RAVAR) (www.fs.fed.us/rm/wfdss_ravar/). Critical infrastructure (residential structures, major power lines, communication towers, etc.) and highly valued natural and cultural resources (endangered species habitat, critical watersheds, etc.) are spatially identified and linked to output from the Fire Spread Probability (FSPro) model that identifies the probability of a fire reaching a given point on the landscape over a period of time (typically 7 to 14 days) in the absence of fire suppression. Because RAVAR was developed to respond to the individual event, national data consistency is desirable but not required. A primary data set within the critical infrastructure is the Structures layer, which is developed from county level cadastre data. The Structures layer was developed in coordination with the Federal Geographic Data Committee's National Cadastral Subcommittee. Committee members intended to acquire spatial tax record data from each county in the western United States. To date, approximately three-quarters of those counties have provided data to the WFDSS team. However, full national coverage does not yet exist because many counties, some of which are rural and have low total county income, have not defined their tax records in geospatial format. In the absence of these records, structure data for RAVAR are acquired in real time for a given event from remotely sensed image interpretation conducted by the U.S. Geological Survey's Rocky Mountain Geographic Science Center.

Fire intensity, an important predictor of fire effects, is currently calculated within FSPro; however, due to the stochastic nature of the model, interpretation is not obvious and appropriate use of these data is being studied. Within RAVAR, only resource presence is identified, not information regarding potential benefits or losses. Therefore, the effect of wildfire on the identified resources is left to local interpretation.

Methods

Overview

Three main components were combined to generate wildfire risk outputs, namely (1) burn probability generated from wildfire simulations, (2) spatially identified HVR, and (3) response functions that describe the impact of fire on the HVR. The components were combined in a risk framework modified from Finney 2005[1] to calculate *Expected Net Value Change:*

$$E[\text{nvc}] = \sum_{i=1}^{N}\sum_{j=1}^{n} p(F_i)[RF_{ij}] \qquad \text{[formula 1]}$$

where

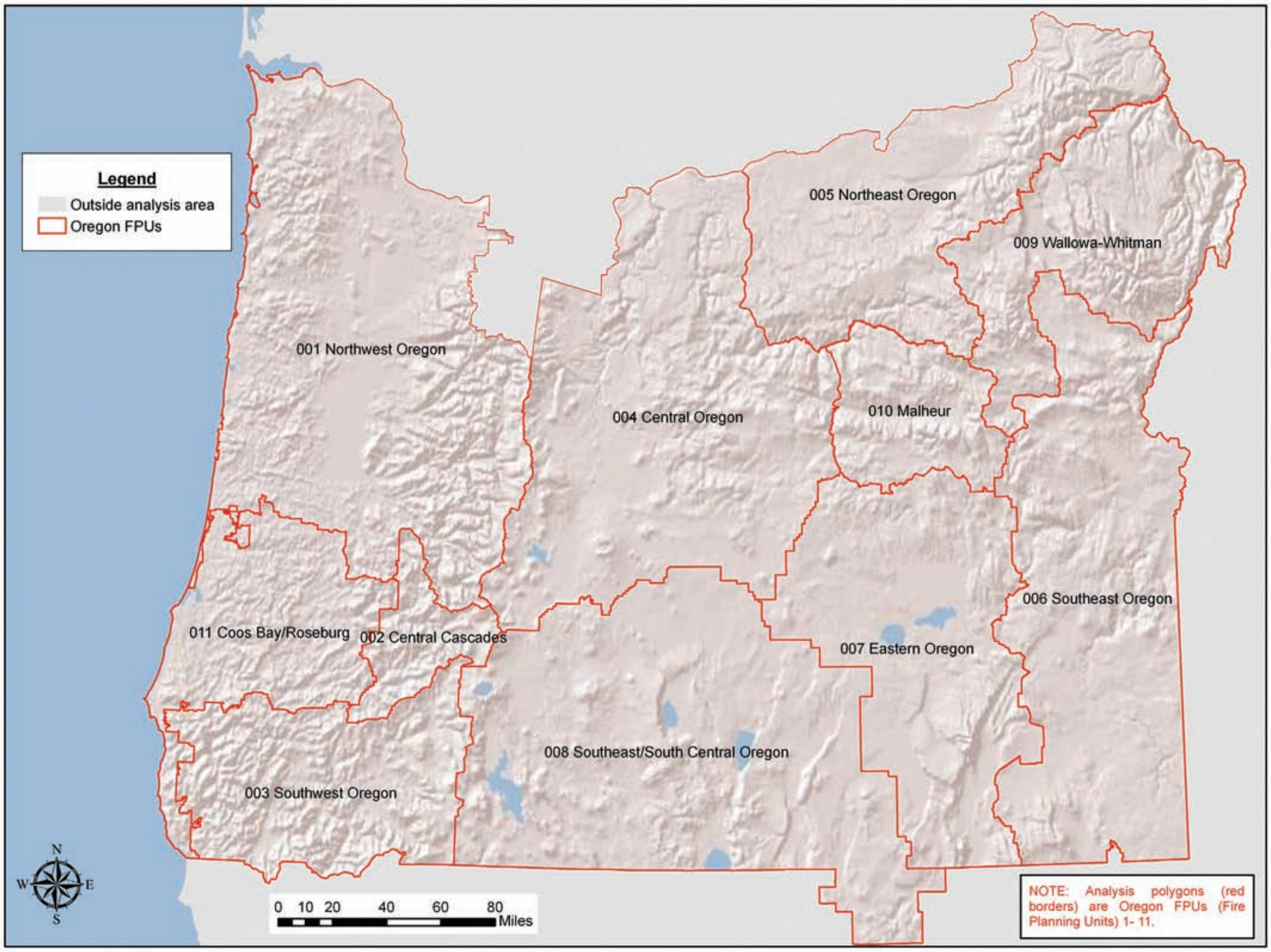
$p(F_i)$ = probability of a fire at intensity i, and

RF_{ij} = "response function" measuring the net change to value j from fire intensity i.

Thus, risk is the product of the burn probability at a given fire intensity ($p(F_i)$) and the resulting change in value (RF_{ij}) summed over all possible fire intensities and values. Calculating risk at a given location (according to formula 1) requires spatially defined estimates of the likelihood and intensity of fire interacted with identified values. This interaction is quantified through the use of response functions that estimate expected benefits and losses to resources at the specified intensities. This monitoring study has been designed for analysis on a national scale; however, protocols were tested and reported here as a prototype only for the State of Oregon. Oregon was selected because of its wide range of variability in ecoregions and diversity of HVR.

Estimating Wildfire Likelihood and Intensity

The risk assessment was conducted on a pixilated landscape made up of 886- by 886-ft (approx. 270- by 270-m) pixels, consistent with methodology developed for the FPA project. Analyses were conducted at the individual Fire Planning Unit (FPU) and results were developed for the 11 FPUs contained in Oregon (figure 1).



NOTE: Analysis polygons (red borders) are Oregon FPUs (Fire Planning Units) 1- 11.

Figure 1—Map of FPUs in Oregon and adjacent states. This study covers only FPUs that are assigned to Oregon, as denoted in the FPU numeric codes.

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[1] The original specification developed by Finney represented benefits and losses separately at individual flame lengths to the specified resource values; whereas we evaluate net change in aggregate using a "response function" RF_{ij}.

Fire simulation was used to produce estimates of burn probabilities and fire intensity distributions (the first component of this hazard and risk model) following methods developed for the FPA project. Specifically, the wildfire simulation model FSim (Finney 2007) was used to estimate annual burn probability for each 886- by 886-ft (or approx. 18-acre) pixel. The FSim program features:

1. sensitivity to seasonal and daily weather and ignition variability by geographic area;
2. effect of fuels and topography on large fire spread, which are the primary drivers of wildfire threat in much of the United States;
3. spatial effects of fuel treatments on local and offsite values; and
4. fire intensity distributions that reflect both weather and fire spread variations from multiple ignition sources, which are essential to estimating fire effects.

Results can be compared to historical average burn probabilities and fire size distributions. Such comparisons provide a means to check that simulation outputs are realistic.

Fire simulations with FSim were performed individually for each of the 139 FPUs within the United States. Simulations for each FPU were parameterized to reflect differences in historical fire management activities as well as climatic and ignition variability. The FSim simulation process was conducted as follows (Finney 2007):

1. A representative Remote Automated Weather Station (RAWS) was selected for each FPU. Daily historical weather was processed to obtain Energy Release Component (ERC) as implemented in the National Fire Danger Rating System. Selected weather stations had a minimum of 20 years of weather records and were judged to best reflect fire weather and seasonal and daily climatology for the FPU. We recognize there is considerable heterogeneity in weather conditions within many FPUs, and more robust modeling results would probably be obtained if the larger FPUs were further subdivided or if multiple weather stations were incorporated into the wildfire modeling. Neither of these options was feasible in this study.
2. Weather data were analyzed to generate 20,000 to 50,000 artificial fire seasons (more artificial seasons were required for FPUs with historically smaller fires or lower fire frequency). Specifically, daily ERC values for 20 years of weather data were subjected to a Time Series Analysis that derived estimates of the seasonal trends, the auto correlation (dependency of a day's ERC value on previous days), and the daily standard deviation. Wind data (speed by direction) were also derived and tabulated by month as a joint probability distribution, which was used to stochastically assign wind data to each day in each of the simulated fire seasons.
3. A logistic regression was developed for each FPU that predicted the probability of a large fire based on the historical ERC-large fire relationship.
4. The daily occurrence of large fires was then simulated using ERC-large fire relationship and the simulated fire season data (step (2)). We assumed random ignition location. While wildfire ignitions are not a random spatial process, in general there is a weak relationship between burn probability and ignition location, mostly because the bulk of the area burned is by relatively few large fires that spread over long distances.
5. A fire suppression model was developed and employed to determine containment probability based on historic large fires and their recorded sequence of daily activity (Finney and others 2009). This model was developed by analyzing change in daily fire size from 306 fires occurring from 2001 to 2005. The analysis identified intervals of high spread and low spread for each fire. The containment probability model was found to be positively related to periods of low fire spread. The model was tested against independent data from 140 fires in 2006 (Finney and others 2009).
6. Each fire's growth and behavior was simulated from its ignition day through the remainder of the season or until containment was achieved as predicted by the suppression model (step (5)).
7. Each pixel's annual burn probability and the marginal probability of a fire at specific flame length categories were then calculated. The flame length categories were 0 to 2, greater than 2 to 6, greater than 6 to 12, and greater than 12 ft.

The FSim program uses the minimum travel time fire spread algorithm (Finney 2002), which is optimized for processing large numbers of fires. Simulations were completed on a bank of computers located at the EROS Data Center in Sioux Falls, SD. Results were assembled by FPU and by geographic area (aggregates of FPUs).

A number of validation exercises were completed as part of the FPA project, including a comparison of predicted fire size distributions with historic data from selected FPUs (Finney 2009). Initial outputs revealed sharp transitions between burn probabilities on the boundaries of adjacent FPUs, which were possibly caused by limitations of this initial attempt to generate FPU-specific fire size distributions from historic weather and perhaps also from highly variable RAWS data among adjacent FPUs. To smooth inter-FPU differences, the burn probability estimates were normalized using historic burn probability data for each FPU calculated from historic fire size data. The normalization involved multiplying the simulated burn probability by the ratio of the simulated to historical burn probability.

The FSim probability and flame length model results were then used in risk calculations (formula 1) to calculate the expected net value change to HVR.

Highly Valued Resource Data Layers Acquisition

The second component of the risk assessment model involved identification of highly valued resource (HVR) data layers. Five HVR categories were originally proposed by the FPA Executive Oversight Group, including natural and cultural resources and critical infrastructure. These categories were initially critical habitat (refined to fire-susceptible species), Federal recreation infrastructure, energy infrastructure, air quality, and municipal watersheds. Within these categories, data layers were chosen based on availability at a national scale and HVR representation upon which fire management decisions are made. The categories proposed were not intended to represent the full suite of resource layers considered to be of high value. Instead, categories were chosen based on available data to make a first attempt at approximating national HVR data sets. Fire-adapted ecosystems and built structures were later identified as nationally consistent data sets and were included as two additional data categories, making seven total for this exercise.

Despite wide interest in these specific data for many other wildland fire assessment projects, there remain significant challenges to acquire, assemble, and reconcile these data for national wildfire risk analyses. The "Discussion" section (p. 29) of this study addresses the challenges and issues associated with HVR data acquisition at the national scale.

Initial efforts to locate data sets included exploring national Internet portals such as Geospatial One Stop and the National Atlas project (www.nationalatlas.gov). However, many of the data layers requested or proposed as HVR themes were not available from these and other enterprise sources. Generally, this was either because the data release required a measure of security not offered in a Web portal or because data are managed by a Federal land management agency that has not mapped the resource to a national extent.

Much of the available enterprise data lacks the attribution necessary to distinguish between resources of high value in relative scarcity versus those of low value found in abundance. This issue is particularly common among such data sets as recreation infrastructure and Federal structures. For example, highly developed campgrounds on Federal lands hold value both in their developed infrastructure and in their attraction to visitors, thereby providing recreation income to the managing agency and neighboring communities. In the data sets acquired for these resources, attribution was limited or did not exist to help distinguish between lightly used primitive backcountry campsites and those with high visitation and significant infrastructure investments.

Attribution and data completion consistency often vary geographically. For example, within the National Park Service (NPS) Visitor Services data, Federal buildings and visitor centers are missing from certain National Parks where they are known to exist. However, other Parks appear to have complete representation. Additionally, in the Visitor Services data set, some Parks distinguish between developed and primitive campsites, while others do not. The National Scenic and Historic Trails data set available from the NPS GIS Data Store is not a complete representation of all trails designated National Scenic or National Historic (www.nps.gov/nts/nts_trails.html) because many are missing from the available GIS data set. Multiple data contacts, including the publishers of these maps and brochures documenting the complete National Trails System, indicated that some mapped trails are cartographic renderings that do not exist in geospatial form.

Some data sources became available only after we obtained additional access and security clearance. Databases such as the Homeland Security Infrastructure Program (HSIP), a large database of national infrastructure GIS data sets, are available only by granted access. Some additional data sources not accessible through Web sites and Web portals are the NPS Facility Maintenance Software System that contains NPS building information and locations, the Natural Resources Conservation Service that provides access to sixth order Hydrologic Unit Codes, and the National Pipeline Mapping System that contains national oil and gas pipelines information.

Despite the challenges of using national enterprise data sets, this remains the best approach for a first approximation of a national monitoring exercise. Data collected for this exercise were obtained from a combination of sources, including enterprise databases, data clearinghouses and servers, and local data aggregated to the national scale. Many of the data sets required augmentation from other sources, while others appeared to require relatively little, if any, processing.

Table 1 displays the list of HVR layers included in this monitoring exercise, and the following discussion addresses data set sources and any known errors or limitations for using the data in a project of this nature.

Energy Infrastructure

The energy infrastructure category is made up of four data layers: power lines, oil and gas pipelines, power plants, and cell communication towers. Each sub-category is reviewed in detail below.

Power Transmission Lines—This layer is comprised of power line data from both the HSIP database and the Cartographic Feature Files (CFF) from the FSGeodata Clearinghouse. Global Energy Decisions created the power transmission line data set from HSIP for use by agencies, offices, and contractors of the Federal government. The FSGeodata Clearinghouse (http://svinetfc4.fs.fed.us/clearinghouse/index.html) provides access to CFF line files, from which records labeled "power lines" were extracted. The CFF are point and line features digitized from FS Primary Base Series maps. Their coverage is primarily limited to FS lands.

Table 1—Data layers acquired for first approximation of HVR.

HVR theme	Sub-layer within theme	Source
Energy Infrastructure	Power Transmission Lines	Homeland Security Infrastructure Program
	Oil and Gas Pipelines	National Pipeline Mapping System
	Power Plant Locations	Homeland Security Infrastructure Program
	Cellular Tower Point Locations	Federal Communication Commission http://wireless.fcc.gov/geographic/index.htm
Federal Recreation and Recreation Infrastructure	FS Campgrounds	USDA Forest Service (FS), FSGeodata Clearinghouse-Vector Data Gateway http://svinetfc4.fs.fed.us/vectorgateway/index.html
	Ranger Stations	ESRI Data and Maps 9.3
	BLM Recreation Sites and Campgrounds	GeoCommunicator http://www.geocommunicator.gov/GeoComm/index.shtm
	NPS Visitor Services and Campgrounds	National Park Service (NPS) Data Store http://www.nps.gov/gis/data_info
	FWS Recreation Assets	USDI Fish and Wildlife Service (FWS)
	National Scenic and Historic Trails	NPS Data Store http://www.nps.gov/gis/data_info
	National Alpine Ski Area Locations	National Operational Hydrologic Remote Sensing Center http://www.nohrsc.noaa.gov/gisdatasets/
Fire-Susceptible Species	Designated Critical Habitat	U.S. Fish and Wildlife Service Critical Habitat Portal http://crithab.fws.gov/
	National Sage-Grouse Key Habitat	Bureau of Land Management (BLM)
Air Quality	Class I Airsheds	NPS Air Resources Division http://www.nature.nps.gov/air/maps/receptors/index.cfm
	Non-Attainment Areas for PM 2.5 and Ozone	Environmental Protection Agency downloaded from www.myfirecommunity.net
Municipal Watersheds	Sixth Order Hydrologic Unit Codes	Natural Resource Conservation Service
Fire-Adapted Ecosystems	Fire-Adapted Regimes	LANDFIRE map products http://www.landfire.gov/
Residential Structure Location	Pixels Identified as Containing Built Structures	LandScan USA

Because the CFF layer contained power lines on Federal lands that were not mapped in the HSIP data layer, both data sets were included in the final HVR data layer. Proposed power lines were eliminated from the HSIP data layer.

Oil and Gas Pipelines—Oil and gas pipelines are mapped by the National Pipeline Mapping System (NPMS). This data layer was obtained from the Defense Threat Reduction Agency's Incident Command Water Modeling Tool (ICWater) database. The NPMS is a GIS data layer created by the U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration Office of Pipeline Safety in cooperation with other Federal and State governmental agencies and the pipeline industry (USDOT 2007). The pipeline layer consists of line segments representing hazardous liquid transmission, liquefied natural gas plants, and hazardous liquid breakout tanks under the jurisdiction of the Pipeline and Hazardous Materials Safety Administration.

Power Plant Locations—Power plant locations were obtained from the HSIP database, and records for proposed plants were eliminated from the final HVR data set. This data set was created by Global Energy Decisions (for HSIP) for use by agencies, offices, and contractors of the Federal government. Records detailed generating stations and power plants producing hydroelectricity, geothermal, solar, and nuclear energy.

Cellular Tower Point Locations—Tower locations were obtained from the Federal Communication Commission's Geographic Information Systems Web site (http://wireless.fcc.gov/geographic/index.htm, accessed March 31, 2009) for all towers for which the Commission collects information.

Federal Recreation and Recreation Infrastructure

The Federal Recreation and Recreation Infrastructure data layer consists of six sub-category data layers: FS Campgrounds and Ranger Stations, BLM Recreation Sites and Campgrounds, NPS Campgrounds and Visitor Centers, FWS Campgrounds, National Scenic and Historic Trails, and National Ski Areas. Each sub-category is reviewed in detail below.

United States Forest Service Campgrounds—These data were downloaded from the Geospatial Service and Technology Center, FSGeodata Clearinghouse's Vector Data Gateway. The Miscellaneous Points layer was downloaded from this clearinghouse, and using the Cartographic Feature File metadata, points labeled with the FS campground feature number were extracted. Attribute records for FS campgrounds do not distinguish between developed and primitive campgrounds; therefore, all campground records are included in this HVR layer.

Ranger Stations—Though a national GIS data set of primarily FS ranger stations was desired as one sub-layer of the Federal Recreation HVR data layer, this data set could not be acquired from FS at the national extent. Yet the Environmental Systems Research Institute (ESRI) Data and Maps 9.3 database contains a data layer titled "glocale," from which records containing the text "ranger stations" were extracted and added to the final Federal Recreation HVR layer. This data set contains ranger stations located primarily on NPS and FS lands. Records indicate both operational ranger stations and historic stations no longer in use.

Bureau of Land Management (BLM) Recreation Sites and Campgrounds—These data were obtained from GeoCommunicator's National Integrated Land System (NILS) GIS Web service (www.geocommunicator.gov, accessed August 1, 2008). Recreation Sites and Campgrounds are two separate data layers that were combined to create the BLM Recreation HVR layer. Attribute records defined certain BLM campgrounds as being unimproved, developed, or semi-developed. Because this attribution is absent from some agencies' data sets, all records in the BLM Recreation Sites and Campgrounds data layers were included in the final HVR layer for consistency.

National Park Service Visitor Services and Campgrounds—NPS data were downloaded from the NPS Data Store (www.nps.gov/gis/data_info, accessed August 1, 2008). Selected HVR attributes from this data layer include Campgrounds, Headquarters, Lodges, Museums, Ranger Stations, and Visitor Centers. For this study, it was desired that campgrounds be limited to front country and developed campsites only. The attribution was not available in all Parks and Units; therefore, all records for the themes listed above are included in the final HVR data layer.

Additional limitations of this data layer occur in areas where resources are known to exist but are not included in the data set. For example, Glacier National Park lodges were not included in the original Visitor Services data layer. To address this issue, hotels and lodges were extracted from a separate data set provided by the NPS. The NPS Facility Maintenance Software System contains NPS building locations, facility names, and assigned dollar values. Using building names, all hotels and lodges were extracted and then matched with the original NPS Visitor Services data layer to identify hotels and lodges missing from the HVR data set. This data augmentation enabled a more accurate value category placement.

FWS Recreation Assets—USDI Fish and Wildlife Service (FWS) provided recreation asset data for all its Regions. Campgrounds were extracted from the data set provided, but there was no distinction between developed and undeveloped campgrounds. All records labeled campgrounds were included in the final HVR layer. Additional latitude and longitude points were provided for known FWS Visitor Centers and Environmental Education Centers in existence in 2007. According to data documentation, the coordinates approximate the location of the Visitor Center parking lot visible in Google Earth. FWS assumes no liability or responsibility for the accuracy of this data as these data sets are still in development. An estimated 50 percent of the data set approximates structure location (within approx. 0.5 miles) visible from Google Earth imagery; however, the authors were unable to assess the completeness of the data set.

National Scenic and Historic Trails—A spatial trails data set was acquired from the NPS Data Store (http://science.nature.nps.gov/nrdata, accessed August 1, 2008). This data set contains 12 trails of National Scenic and Historic designation: the Appalachian Trail, Trail of Tears, Pony Express, Oregon Trail, Mormon Pioneer, Lewis and Clark Trail, El Camino Real de Tierra Adentro, California Trail, Iditarod Trail, North Country Trail, Ice Age Trail, and the Juan Bautista De Anza. According to the associated metadata, the intended use of these data is to "support diverse planning activities including planning, management, maintenance, research, and interpretation." However, this data set is not a full representation of all National Scenic and Historic trails. Compared to the National Trails System Web site (www.nps.gov/nts/nts_trails.html), which provides a comprehensive list of all National and Historic Trails, the NPS Data Store data set contains only 12 of the 26 trails with National Scenic or Historic designation. An additional four data sets have been located to represent trails not included in the NPS Data Store layer: Continental Divide Trail, Pacific Crest Trail, Florida Trail, and Natchez Trace Trail. Although the data set has known gaps, this final layer contains 16 of the 26 trails included in the National Trails system.

National Alpine Ski Area Locations—A complete spatial data set of national alpine ski areas could not be located for this study. However, the National Operational Hydrologic Remote Sensing Center (NOHRSC) hosts access to a data set of "Skiing Locations" in the lower 48 states (www.nohrsc.noaa.gov/gisdatasets, accessed October 20, 2008). Disclaimers on the site indicate that inclusion of a ski location does not imply endorsement and the locations included are those that were known in 2007, at the time of publication.

After performing an attribute selection of "ski area" and "ski basin" on the NOHRSC data set and removing any records labeled "cross country," 499 records remained. According to the National Ski Area Association (www.nsaa.org/nsaa/press/sa-per-state.pdf), the total number of ski areas is 481. Using a combination of visual confirmation in Google Earth, comparison with a Google Earth .kml file titled "Geotagged Ski Areas U.S." and Web searches on the status of specific ski areas, the NOHRSC data set was modified to eliminate ski areas that no longer exist and those whose locations were incorrectly reported to NOHRSC. The final data layer in the Recreation HVR layer includes 469 downhill ski area points approximating the ski area's main lodge—three-quarters of which was edited to correct original latitude and longitude assignment. In order to represent more of the ski area features potentially at risk of wildfire, these points were buffered by 1 mile.

Fire-Susceptible Species

The HVR layer representing fire-susceptible species is made up of two data sets discussed below. One data set represents Federally designated critical plant and wildlife habitat, and the other represents greater sage-grouse (*Centrocercus urophasianus)* key habitat as defined by the BLM.

Designated Critical Habitat—Designated critical habitat data were obtained from the Conservation Biology Institute, and the national layer was built by combining several hundred individual layers downloaded from the U.S. Fish and Wildlife Service Critical Habitat Portal (http://crithab.fws.gov) with nine newer data sets from agency staff. The Federal database contains 1,357 endangered species. Of these, 485 have had designated critical habitat mapped as part of their recovery plans. Jack Waide (Research Coordinator for Conservation Science, National Wetlands Research Center, USGS) identified 64 vertebrate, invertebrate, and plant species as fire-susceptible species (or species most likely to be negatively impacted by fire) through review of many recovery plans and critical habitat designations. This included 23 species of vertebrates (four mammals, eight birds, three reptiles, five amphibians, and three fishes), seven species of invertebrates, and 34 species of plants. Many listed species have very small geographic distributions but are scattered across the country with concentrations in several biological hotspots (e.g., southern California and the Florida panhandle). The 64 species included in the model broadly represented the general geographic distribution of listed taxa. Eight of the 64 fire-susceptible species were located in Oregon and were included in the prototype run. These species are bull trout (*Salvelinus confluentus*), Fender's blue butterfly (*Icaricia icarioides fender*), greater sage-grouse (*Centrocercus urophasianus*), Kincaid's lupine (*Lupinus sulphureus*), marbled murrelet (*Brachyramphus marmoratus*), northern spotted owl (*Strix occidentalis caurina*), Oregon silverspot butterfly (*Speyeria zerene hippolyta*), and Willamette daisy (*Erigeron decumbens* var. *decumbens*).

National Sage-Grouse Key Habitat—Although the sage-grouse is not a Federally listed threatened or endangered species (USFWS 2009), a National Sage-Grouse Key Habitat layer is included in the Fire-Susceptible Species HVR layer. The key habitat layer was compiled by the BLM National Sage-Grouse Mapping Team and was provided to this group for the purpose of informing wildfire decisionmaking.

Air Quality

Air quality data from the Environmental Protection Agency (EPA) was recommended for use by the wildland fire community and was acquired from www.myfirecommunity.net. Data sets consist of nonattainment areas for particulate matter (PM) 2.5 and Ozone. Class I Airsheds data were downloaded from the NPS Air Resources Division (www.nature.nps.gov/air/maps/receptors/index.cfm, accessed October 23, 2008). Class I Airshed data delineate 215 airsheds representing NPS, FWS, and FS jurisdiction. Bureau of Indian Affairs (BIA) and Tribal land are not represented. According to Western Regional Air Partnership (www.wrapair.org/tribal/index.htm), Class I designation on Tribal land is not mandatory but is encouraged in 309 Tribal Implementation Plans under the Regional Haze Rule. The EPA states, "Mandatory Class I Federal areas include international parks, national wilderness areas, and national memorial parks greater than five thousand acres in size, and national parks greater than six thousand acres in size, as described in section 162(a)" (www.epa.gov/EPA-AIR/1997/January/Day-16/1043.htm). Under the Clean Air Act (PL 108-201), Federal land managers are required to protect the air quality and associated values (including visibility) of areas designated as Class I lands.

Municipal Watersheds

A comprehensive national GIS data set for municipal watersheds was not available for this study. A spatial data layer was developed for this resource by obtaining the Hydrologic Unit Code (HUC) level six watersheds from the Natural Resource Conservation Service and selecting watersheds that contain water supply intakes. An additional buffer was applied to the watersheds to further obscure the location of the water supply intakes for national security purposes. Water intake sources were obtained from the ICWater database (http://eh2o.saic.com/SectionProjects/Transport/Surface/ICWater/ICWater.aspx).

Fire-Adapted Ecosystems

Many of the concepts regarding a first approximation of the layer labeled "Fire-Adapted Ecosystem" for use in fire risk analysis came from Robert Keane (Research Ecologist, Rocky Mountain Research Station, FS). The data represents fire-adapted ecosystems where the management goal is to re-introduce fire. The intent was to obtain a layer that would represent landscapes where fire historically played an important role in a non-lethal way to maintain the ecosystem. The data are derived using fire regime and fire return interval data products from LANDFIRE (www.landfire.org). LANDFIRE is an interagency (USDA, USDI) project that has generated consistent spatial data describing vegetation, wildland fuel, and fire regimes across the United States at an approximately 98-ft (30-m) grid spatial resolution.

The LANDFIRE fire regime data products were resampled to 0.62-mile (1-km) data sets. Fire-Adapted Ecosystems were defined as cells that had fire regime groups 1 or 3 (fire return interval of less than 200 years and low to mixed severity) and the percent of low severity fire was greater than 50 percent (codes 11 to 61).

Residential Structure Location

National-level building or structure location data sets do not exist, although the U.S. Department of Homeland Security (DHS) is working with various local, State, Federal, and Tribal government agencies to initiate development of these data (DHS 2008). Because of inconsistent spatial data for structures, recent studies have used alternatives such as parcel data (USDAFS 2008) and census population data (Dobson and others 2000; Radeloff and others 2005; Theobald and Romme 2007) to estimate potential wildland fire impacts.

Studies that employ the U.S. census data compute housing density by dividing the total number of people counted within each census block by the area of the respective census block to identify where housing density exceeds one housing unit per 40 acres (Stewart and others 2009). Generally, census blocks are small in area; however, blocks in sparsely settled areas may contain many square miles of territory (Census 2001). This can result in large census blocks with a small cluster of homes in one area but with large uninhabited regions in the remaining area. This can either create an average density too low to meet the Wildland-Urban Interface (WUI) criteria set forth in the Federal Register (Stewart and others 2009), or it can result in the designation of an entire large census block as WUI where only a small portion of the block contains housing units (Leonard 2007). To work around this problem, studies have used ancillary data in dasymetric (or thematic) mapping to modify the boundaries of census blocks omitting areas where people typically do not reside, such as public lands. However, extensive private inholdings, typical in eastern U.S. forests, would not be accounted for by masking public lands (Stewart and others 2009).

Researchers at the U.S. Department of Energy's Oak Ridge National Laboratory have used geographic information systems and remote sensing to develop, refine, and update a U.S. population database known as LandScan USA. LandScan produces a high-resolution (approx. 295-ft^2 [90-m^2] cell) assessment of the number of people present in a given area during the night (also known as residential population) and the day (Krause 2002). The database was derived from the best available census counts that were redistributed to spatial cells from probability coefficients related to slope, road proximity, land cover, nighttime lights, and other information including an urban density factor (Dobson and others 2000).

Although LandScan does not attempt to represent structure location, a strong positive correlation is expected to exist between population count and structure location. In the absence of a national structure location data set, LandScan USA population estimates were categorized to represent built structure locations. Incorporating the LandScan USA data with the output from the fire simulation model required aligning the geographic coordinate systems, including the datum, projection, and raster cell-size, while assuring cell alignment. The LandScan data was transformed to conform to the FSim burn probability grid of approximately 886- by 886-ft (270- by 270-m) cells. In order to do this, we needed to categorize the population density to represent built structures. Therefore, it was determined for the prototype that nighttime population density should be separated into two categories: (1) low density (cells with two or fewer occupants approximating at least one structure per 18-acre pixel), and (2) moderate or high density (cells with three or more occupants approximating more than one structure per 18-acre pixel).

Other Biological Values Considered for Inclusion

We evaluated numerous other spatial data sets for describing biological values in the wildfire risk model (Appendix A). These included data from a wide range of biological assessments and other studies. While future risk assessments could leverage these data for wildfire risk assessments, they were excluded from this study for the following reasons: (1) the spatial resolution was too coarse relative to other data sets; (2) the spatial extent was incomplete (did not include the entire nation); or (3) response function assignment was not possible given the framework used in this study (table 2). A subset of the data sets would best be described by a fourth category as potentially valuable for future assessments given more time and resources to modify the data to fit the assessment approach.

Additional information for each data set considered, including description, citation, Web site, and sample map(s), are provided in Appendix A. Of the biological value data sets examined, 12 fell into the category of being too coarse for inclusion in the risk model, four showed some promise but did not cover the entire country, and three data sets were inappropriate as their relationships with wildfire were part of their inherent value.

An aggregation of the Natural Heritage data sets maintained at the state level would potentially improve this risk model. These data contain thousands of records for hundreds of species; however, the data sets (usually a combination of points and polygons) would need to be purchased and standardized. Secondly, the data sets would need to be reviewed and fire-susceptible species extracted for meaningful response functions to be assigned—not all fire-susceptible species respond to fire the same way. It may be possible to "bundle" species into response function groups (e.g., group six species that share the same response to fire); however, doing so would require an additional post-processing step. See Appendix A for more detail.

We examined the Conservation Biology Institute Protected Areas Database (version 4.5) with the idea of identifying specific protected areas as biological values that might be negatively impacted by fire. We also considered looking at Gap Analysis Program (GAP) Status 1 and 2 lands, but this proved problematic (Appendix A). For example, GAP Status 1 lands are defined as "lands

Table 2—List of biological data sets considered, accompanied by their sources and reason for exclusion.

Name	Source
1. Resolution too coarse	
International Biological Hotspots	Conservation International
Global 200 Most Biologically Valuable Ecoregions	World Wildlife Fund
Global Wetlands	UNEP-WCMC
Ecoregions of High Species Richness	World Wildlife Fund
Ecoregions of High Species Endemism	World Wildlife Fund
Ecoregions of High Species Rarity	World Wildlife Fund
Centers of High Plant Diversity	World Wildlife Fund / UNEP
Forest Intactness	Conservation Biology Institute
Critical Watersheds for Conserving Biodiversity	NatureServe
Watersheds of High Crayfish Rarity	NatureServe
Watersheds of High Mussel Rarity	NatureServe
Imperiled Species by Equal Area Hexagons	U.S. Environmental Protection Agency
2. Map extent incomplete	
Priority Conservation Areas	The Nature Conservancy
National Wetlands Inventory	U.S. Fish and Wildlife Service
GAP Species Richness	U.S. Geological Survey
Underrepresented GAP Plant Communities	U.S. Geological Survey
3. Inappropriate to assign loss functions	
Frontier Forests	World Resources Institute
Last of the Wild	Wildlife Conservation Society
Top 1 Percent Wild Areas	Wildlife Conservation Society

having permanent protection from conversion of natural land cover and mandated management plans to maintain a natural state and maintenance of natural disturbance events," which makes these lands difficult to include in the model. However, regardless of the protection status, the fact that these lands are protected does not easily translate into specific response functions in a wildfire risk model. Risk is a function of what is on-the-ground, not of its particular management designation. This data set may provide some information about rare or vulnerable ecological values (e.g., Botanic Areas and Research Natural Areas), but these designated places are small and difficult to assess without additional information. Not all Botanic Areas, for example, contain the same plant communities characterized by the same response functions.

The new United States Protected Areas Database (PAD-US) will likely expand its attribute table to describe more than just management intent expressed through GAP codes. Discussions are underway to provide additional information about various ecological values contained in each mapped polygon. In the not too distant future, the new PAD-US database may provide important inputs to future wildfire risk modeling.

We considered including data on ecological systems mapping for the country (a joint LANDFIRE-NatureServe effort) in the fire risk model. Ecological systems are medium resolution vegetation community types comprised of several association/alliance level communities. The associations (more than 400 types) that comprise each system are fully described, but their locations are not mapped; therefore, the detailed spatial extent of each system is unknown. Those ecological systems that are most rare in the country (as defined by covering less than 0.05 percent of the United States land cover) might provide a starting point for mapping these communities, but these data must be more refined before they can be logically incorporated into the fire risk model (Appendix A).

Categorizing Highly Valued Resources

Integrating multiple assets and resource values into a general risk assessment framework is facilitated by quantifying values in a common unit of measurement (formula 1). Venn and Calkin (2009) reviewed the state of economic research in regard to the monetary quantification of value change to non-market natural resource values due to wildfire. They found that the ability to assign monetary value change to natural resources due to wildfire was constrained by the following challenges: (1) gaps in scientific understanding about how the spatial and temporal provision of non-market values are affected by wildfire; (2) a lack of studies that have estimated marginal willingness-to-pay

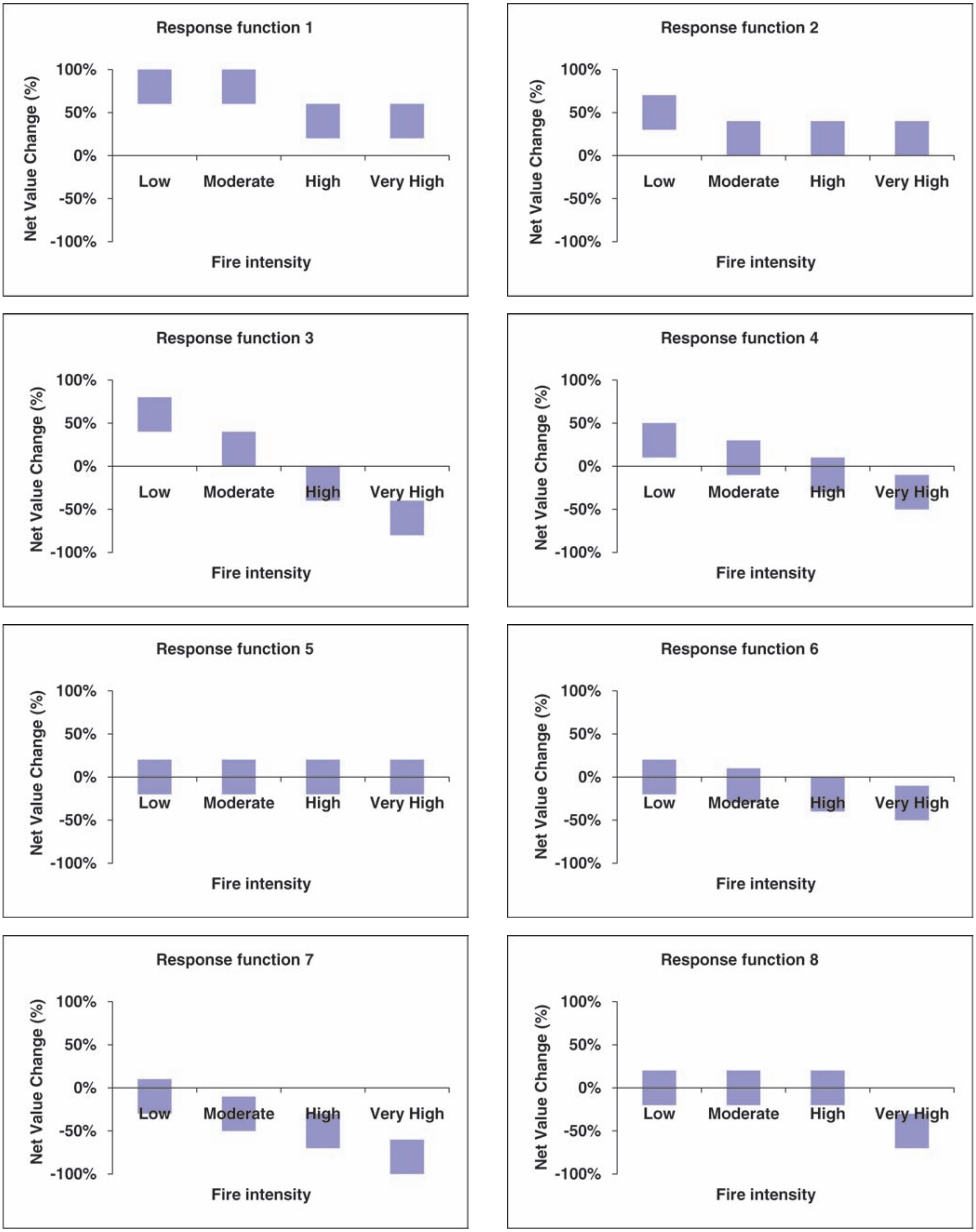
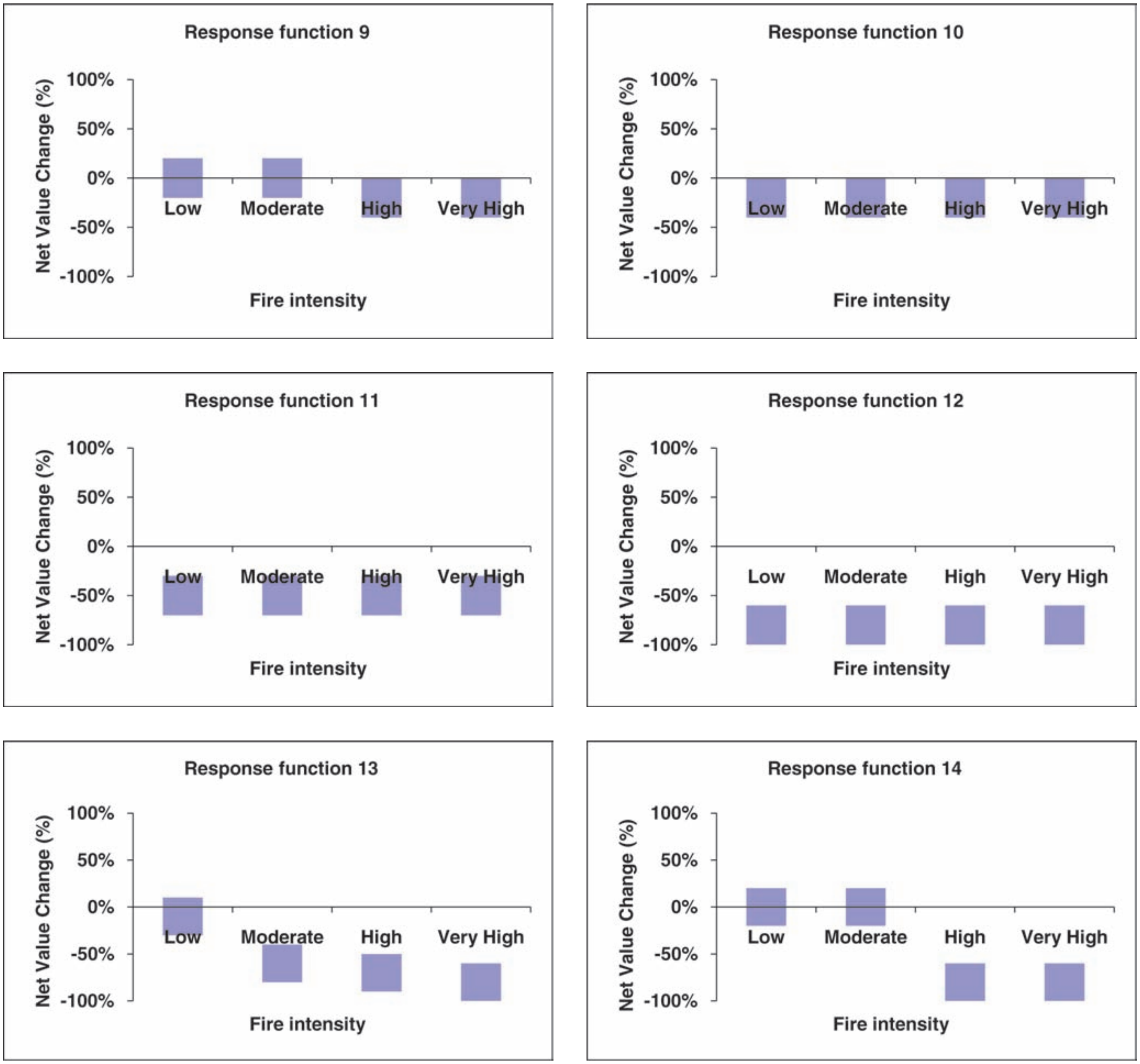


Figure 2—Graphic depiction of the response functions 1 through 14 used in this first approximation. Bars indicate a range of relative net value change; however, only the midpoint of the bar (table 4) is used in the calculations.

Figure 2 (CONTINUED)



to conserve non-market values; (3) violation of consumer budget constraints; and (4) the infeasibility of valuing indigenous cultural heritage. Given these challenges, Boyd (2004) recommended evaluating important natural resource values in their natural units rather than by using a common unit of measurement.

Despite the difficulties in quantifying net fire-caused change in value across multiple HVR, a general aggregation of HVR may be informative. To that end, we classified each HVR by initial value—Moderate, High, and Very High. Because this project addresses only *highly valued* resources, a "low value" category was not included, thereby excluding all areas not identified as having an HVR. Categorizing the HVR themes implies that HVR in the same category presumably have values of a similar magnitude. Therefore, the relative risk values are additive within each value category. However, we made no attempt to weight the relative value or importance of the three value categories to produce an overall weighted wildfire risk. As a result, formula 1 must be calculated separately for each HVR category. Estimation of formula 1 across all values would require that each HVR category be given a relative weight. Efforts to integrate the separate wildfire risk values or value categories into a common unit for tradeoff assessment provides potential opportunities; however, caution is recommended given the challenges of non-market valuation.

We consulted fire and fuels program management officials from the Federal agencies with fuels and fire management responsibility before assigning HVR value categories. Discussions were held with 10 national leaders from the FS, NPS, BLM, FWS, and BIA. Though support was not unanimous on all initial value assignments, there was considerable agreement. Most disagreement was centered on the need to assign a single initial value to national level data when there was desire to assign a different value to assets within a national aggregate class. For instance, there was a desire to assign well-developed campground sites in major National Parks a High initial value compared to small campgrounds with few amenities that would be assigned a Moderate initial value. However, as discussed above, the attribution for all Federal campgrounds was not equally descriptive, and further separation by value classes is not feasible at this time.

Response Functions—Response functions are the third component in the risk framework employed in this study. These functions translate fire effects into net value change (NVC) to the described resource. In each response function, NVC is based on the flame length of the fire and represents both beneficial and adverse effects to the resource. The approach used here quantified NVC to a given resource as the percentage change in the initial resource value resulting from a fire at a given flame length. Specifically, risk was quantified as the expected annual relative NVC on a pixel-by-pixel basis. The value of the resource represents the value derived from the resource in this and all future periods; therefore, NVC was inclusive of future resource value changes including potential recovery or deterioration over time. For example, if a low flame length fire occurred in an area that reduced the immediate values of critical habitat but resulted in less adverse affects (or even positive effects) in subsequent years, the overall response may be less adverse than the initial response because it integrates the future outcomes of the fire.

The response functions are mathematical or tabular relationships between fire characteristic and fire outcome. Although fire outcomes could be related to any fire characteristic, response is typically related to some measure of fire intensity (e.g., flame length) (Ager and others 2007; Finney 2005). Fire intensity is a robust fire characteristic because it integrates two important fire characteristics—fuel consumption and spread rate. In this first approximation, we related relative NVC to flame length. The fire modeling results described in the previous section produced burn probability by flame length class for each 886- by 886-ft (approx. 270- by 270-m) pixel. Accordingly, we developed response functions to correspond to these same flame length classes: Low = 0 to 2 ft, Moderate = greater than 2 to 6 ft, High = greater than 6 to 12 ft, and Very High = greater than 12 ft.

In detailed risk analyses conducted at smaller scales, tradeoffs may be thoroughly evaluated using a weighted prioritization model such as Analytical Hierarchical Process (Schmoldt and others 2001). In some cases, it may be possible for outcomes to be expressed as absolute benefits and losses in a common currency, such as dollars. However, such detail is not possible in this large-scale first approximation. Rather than developing response functions that directly address absolute change in resource or asset value, this first approximation of fire risk relies on generalized, relative response functions that can be applied to any number of resources or assets. The generalized response functions indicate a range of relative NVC as a percentage of initial resource value for the four flame length classes. Although response range is shown for the response functions (figure 2), only the midpoint value is used in calculations.

The stylized response functions used in the first approximation of fire risk are shown in figure 2 and described in table 3. The 14 functions (RF1 to RF14) were developed after considering the different ways in which the various HVR under consideration might respond to fire of different intensities. The response functions were selected in an attempt to adequately cover the range of responses expected for the resources and assets analyzed in this project. However, these functions do not necessarily represent the complete set that could be applied in other risk assessment projects.

As was the case when assigning HVR value categories, although national leaders were mostly in agreement, opinions differed on assigning response functions to non-attainment areas, Class I airsheds, and fire-adapted ecosystems. Differences largely centered on the desire to alter the response function through different time horizons. For example, smoke from current wildfires is initially harmful; however, smoke from future fires in the area will likely be lessened due to the reduction in fuels. The authors rectified any disagreements among managers and selected a single response function for each HVR after carefully considering the managers' rationale.

Table 3—Summary characteristics of the 14 response functions used in the first approximation. Values indicate the midpoint (+/– 20 percent) expected net value change (percent of initial value) for the four flame length classes.

Response function	Description	Midpoint of relative net value change by flame length class (percent)			
		L	M	H	VH
1	All fire is beneficial; strong benefit at low and moderate fire intensities and moderate benefit at high and very high intensity.	+80	+80	+40	+40
2	All fire is beneficial; moderate benefit at low fire intensity and mild benefit at higher intensity.	+50	+20	+20	+20
3	Strong benefit at low fire intensity decreasing to a strong loss at very high fire intensity.	+60	+20	–20	–60
4	Moderate benefit at low fire intensity decreasing to a moderate loss at very high fire intensity.	+30	+10	–10	–30
5	Slight benefit or loss at all fire intensities.	0	0	0	0
6	Mild increasing loss from slight benefit or loss at low intensity to a moderate loss at very high intensity.	0	–10	–20	–30
7	Moderate increasing loss from mild loss at low intensity to a strong loss at very high intensity.	–10	–30	–50	–80
8	Slight benefit or loss at all fire intensities except a moderate loss at very high intensity.	0	0	0	–50
9	Slight benefit or loss at low and moderate fire intensities and a mild loss at high and very high intensities.	0	0	–20	–20
10	Mild loss at all fire intensities.	–20	–20	–20	–20
11	Moderate loss from fire at all fire intensities.	–50	–50	–50	–50
12	Strong loss from fire at all fire intensities.	–80	–80	–80	–80
13	Loss increases from slight loss at low intensity to strong loss at very high intensity.	–10	–60	–70	–80
14	Slight benefit or loss from fire at low and moderate intensities and a strong loss from fire at high and very high intensities.	0	0	–80	–80

Generating Risk Maps and Calculating Outputs

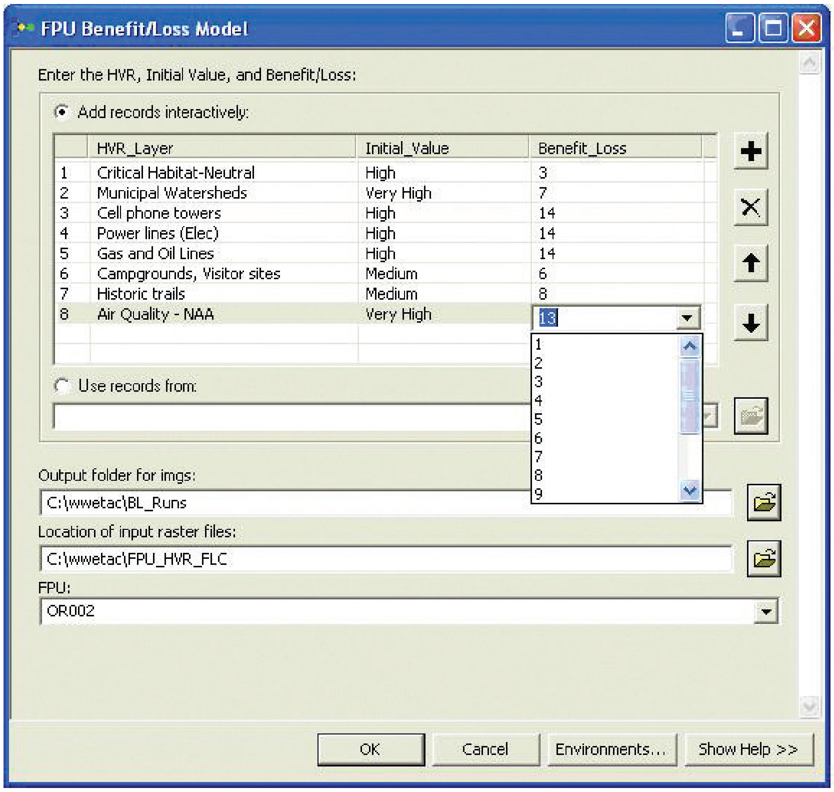
The following simple example illustrates the risk calculation. Assume hypothetical burn probabilities by flame length class for a single pixel illustrated in table 4. These burn probabilities describe the likelihood of a fire at a given flame length. The pixel of interest contains one HVR that has been assigned response function 4 (RF4).

The total annual burn probability for the pixel is 0.01 (1 percent), and the expected fire behavior leans toward the lower flame length classes (that is, the probabilities of the lower flame length classes are greater than the higher flame length classes). The percentage change in initial value for RF4 is displayed on the second row of the table. Note that RF4 exhibits moderate benefit at low intensity, moderate loss at very high intensity, and mostly neutral effects at moderate and high intensities. Multiplying the burn probability by the percent value change for each flame length class and then adding those four values generates the risk output—the annual average percent change—for the pixel. In this example, the result is +0.001 percent, or an expected net increase in value of one-thousandth percent per year.

The computations for calculating risk from the fire simulation flame length probability files, the HVR layers, and the response functions were automated in Python programming language within ArcMap^{TM}. The process was written in three sequential modules that batch-process the data for each FPU. All processing was conducted on a PC with ESRI ArcGIS 9.3 software with Spatial Analyst extension. The first two modules, *Import FPA 2 Raster* and *FLC_HVR,* prepare the data for processing by the third module, *BL_Calc*, which calculates the percent change in value for each HVR pixel (figures 3 and 4). All input data were in the Albers USGS NAD83 projection. Appendix B summarizes the function of each module.

Table 4—Example burn calculation of value change to a hypothetical pixel. The example uses response function RF4.

	Flame length class				
	L	**M**	**H**	**VH**	**Total**
Annual burn probability	0.004	0.003	0.002	0.001	0.010
Response (RF4), percent value change	+30	+10	–10	–30	0
Annual average percent change (APC)	+0.0012	+0.0003	–0.0002	–0.0003	+0.001



Enter the HVR, Initial Value, and Benefit/Loss:

● Add records interactively:

	HVR_Layer	Initial_Value	Benefit_Loss
1	Critical Habitat-Neutral	High	3
2	Municipal Watersheds	Very High	7
3	Cell phone towers	High	14
4	Power lines (Elec)	High	14
5	Gas and Oil Lines	High	14
6	Campgrounds, Visitor sites	Medium	6
7	Historic trails	Medium	8
8	Air Quality - NAA	Very High	13

○ Use records from:

Output folder for imgs: C:\wwetac\BL_Runs

Location of input raster files: C:\wwetac\FPU_HVR_FLC

FPU: OR002

Figure 3—Screen capture of the BL_Calc python script modules for calculating wildfire risk using FPA wildfire simulation data (FSim), HVR, and loss/benefit (response) functions.

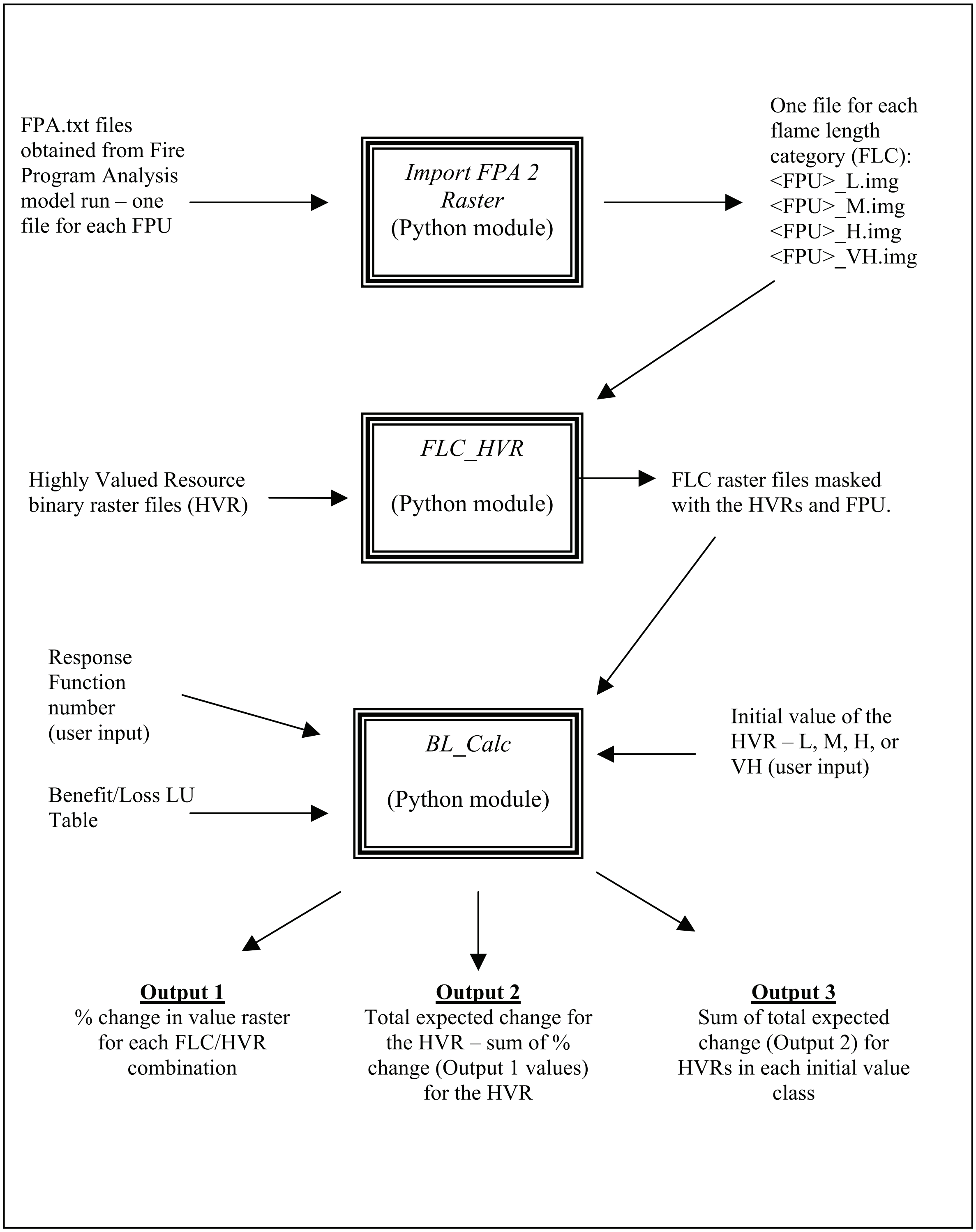


Figure 4—Analysis flow for calculating risk.

Results

Area of Highly Valued Resources by FPU in Oregon

Highly valued resources (HVR) are described by area and FPU, recognizing that some themes have layers in multiple HVR value categories (e.g., Air Quality—Class I Airsheds (Moderate value) and NAA (Very High value)). Fire-susceptible species comprised the largest area (15.7 million acres) among the HVR themes, primarily due to sage-grouse habitat within FPUs 006, 007, and 008 and because of northern spotted owl and marbled murrelet habitat in FPU 001 (tables 5 and 5a). Fire-adapted ecosystems comprised 9.4 million acres, mostly distributed east of the Cascade Mountains. Municipal watersheds and built structure density were next largest at 5 and 2.1 million acres, respectively. The air quality theme made up 1.6 million acres, energy related utilities covered more than 1.2 million acres, and the recreation theme comprised the lowest total area at approximately 217,000 acres. It should be noted that all HVR were represented as 886- by 886-ft (approx. 270- by 270-m) pixels so the area of linear features like trails and transmission lines were represented by a buffer and probably cover less area than estimated. Ski area locations were represented as 1-mile (1.6-km) buffered points because actual area polygons were unavailable.

Burnable Area by FPU

Variation existed in the burnable area among the FPUs due to different proportions of non-burnable fuels (table 6). Non-burnable fuels resulted in burn probabilities of zero in the FSim data. In particular, large areas of the Northwest Oregon FPU are considered urban and non-burnable (27 percent) in a wildfire context. Non-burnable area covered 25 percent of the Northeast Oregon FPU and 29 percent of the Coos Bay-Roseburg FPU because each contained large agricultural areas, rock, and other non-burnable land types.

Area in HVR Categories by FPU

The percent area covered by at least one HVR on burnable area varied from 19 to 91 percent among the 11 FPUs and averaged 58 percent over the entire study area (table 7). Southeast and Eastern Oregon FPUs had the highest percentage of HVR within their boundaries primarily due to sage-grouse key habitat. The Coos Bay/Roseburg and Northwest Oregon FPUs had the highest percentage of area in the Very High category (17 and 21 percent, respectively) primarily due to human population as indicated by the built structure data. It is important to note that there is considerable overlap among the HVR value categories (figures 5a and 5b). The majority of the overlap exists between two initial value categories, while relatively little overlap occurs among all three initial value categories.

Response Functions Assignment and Initial Value Categories

The assignment of each HVR to a response function and HVR initial value category is described by table 8.

All critical plant and wildlife habitat layers were placed in the High value category due to the rarity of critical habitat and the inability or length of time required to replace them if lost or damaged by fire. Critical habitat of fire-susceptible species was assigned to RF13 based on the assumption that low flame length fire results in mild loss, but greater flame length fire results in substantial net reduction of habitat value.

Municipal watersheds were placed in the Very High value category due to the direct implication to human health and welfare. It was assumed that low flame length fire generally corresponds to lower fuel consumption and lower severity and would, therefore, have a less adverse impact on the watershed and water quality value. This was assigned to RF7, indicating a small value reduction at low flame length, which would increase to substantial reduction of value at high flame length.

All energy infrastructure HVR were placed in the High value category because of their importance to the function of modern society. Although these assets are replaceable if damaged or destroyed, loss can cause significant disruption over the short- and medium-term. All energy infrastructure HVR were assigned to RF14 based on the assumption that only high to very high flame length causes damage to these assets, but that damage, when it occurs, is generally substantial.

For recreation infrastructure, the recreation sites and national trails HVR were placed in the Moderate value category (the lowest value category used in this project, which addresses only *highly valued* resources). Ski areas were placed in the High value category due to their relative scarcity and to the difficulty of replacing them because of site requirements. Recreation sites were assigned to RF6 on the assumption that their value reduction is proportional to flame length; however, sites may remain functional even after high severity fire. Ski areas were assigned to RF4 on the assumption that low flame length fire may confer a net benefit by accomplishing routine vegetation management and reducing the likelihood of a future, more

Table 5—HVR area by Oregon FPU, including all burnable and non-burnable acres.

	FPU	Energy (Plants)	Energy (Gas)	Energy (ElecTrans)	Energy (Cell)	Rec (Camp)	Rec (Trails)	Rec (Ski)	Fire-sus. species [a]	NAA	Class I Airsheds	Watershed	Fire ecos.	Built structures
1	Northwest Oregon	685	104,283	318,181	1,873	2,918	51,592	3,170	2,543,574	13,024	318,487	2,595,995	189,021	1,284,271
2	Central Coast Range	144	0	11,367	36	793	3,152	0	269,886	0	5,927	117,235	42,765	2,702
3	Southwest Oregon	216	8,809	74,182	432	2,450	27,021	1,225	1,309,220	0	181,293	333,745	59,140	178,519
4	Central Oregon	252	28,984	174,249	739	4,053	24,643	2,882	863,698	0	175,024	392,056	1,985,231	195,812
5	Northeast Oregon	234	33,956	84,792	612	721	27,327	3,999	0	0	0	287,629	1,039,407	111,471
6	Southeast Oregon	108	21,473	41,306	288	955	17,798	0	4,322,888	0	0	92,214	2,439,742	61,590
7	Eastern Oregon	0	0	47,323	54	576	0	0	3,188,061	0	0	0	1,414,494	15,150
8	Southeast/South	126	21,653	122,207	414	1,549	15,258	2,054	2,442,750	63,607	219,987	0	1,587,789	79,298
9	Wallowa-Whitman	54	5,728	50,908	144	1,279	4,936	2,000	7,494	0	571,187	254,466	397,911	46,908
10	Malheur	18	0	15,294	72	468	0	0	4,918	0	68,543	73,317	204,909	11,997
11	Coos Bay/Roseburg	54	10,034	86,089	630	883	13,312	0	790,021	0	18	901,204	33,830	163,657
	Total	1,891	234,920	1,025,898	5,294	16,645	185,039	15,330	15,742,510	76,631	1,540,466	5,047,861	9,394,239	2,151,374

[a] Fire-susceptible species acres are for all species represented in the Oregon prototype. Table 5a presents acres by FPU for individual species.

Table 5a—Area of fire-susceptible species by Oregon FPU, including all burnable and non-burnable acres.

	FPU	Bull Trout	Fenders Blue Bfly	Sage-Grouse	Kincaids Lupine	Marbled Murrelet	N. Spotted Owl	Oregon Silverspot Bfly	Willamette Daisy
1	Northwest Oregon	15,726	2,954	0	504	891,494	1,647,739	180	703
2	Central Coast Range	0	0	0	0	0	269,886	0	0
3	Southwest Oregon	0	0	0	0	420,014	889,206	0	0
4	Central Oregon	9,295	0	765,180	0	0	95,888	0	0
5	Northeast Oregon	38,262	0	0	0	0	0	0	0
6	Southeast Oregon	8,881	0	4,322,888	0	0	0	0	0
7	Eastern Oregon	3,585	0	3,188,061	0	0	0	0	0
8	Southeast/South	31,777	0	2,333,784	0	0	84,287	0	0
9	Wallowa-Whitman	61,067	0	7,494	0	0	0	0	0
10	Malheur	1,261	0	4,918	0	0	0	0	0
11	Coos Bay/Roseburg	0	0	0	0	226,652	563,369	0	0
	Total	169,854	2,954	10,622,324	504	1,538,160	3,550,376	180	703

Table 6—Area by FPU classified as burnable for Oregon.

	FPU	Acres Burnable	Acres Non-burnable	Total	Percent burnable
1	Northwest Oregon	7,377,573	2,767,921	10,145,494	73
2	Central Coast Range	1,024,816	15,438	1,040,254	99
3	Southwest Oregon	3,775,911	164,828	3,940,739	96
4	Central Oregon	8,355,444	553,047	8,908,491	94
5	Northeast Oregon	4,273,782	1,455,224	5,729,005	75
6	Southeast Oregon	7,201,991	382,455	7,584,446	95
7	Eastern Oregon	5,476,575	409,998	5,886,574	93
8	Southeast/South	8,992,274	803,009	9,795,284	92
9	Wallowa-Whitman	3,916,078	271,543	4,187,621	94
10	Malheur	1,917,426	11,493	1,928,919	99
11	Coos Bay/Roseburg	2,337,945	969,567	3,307,512	71
	Total	54,649,814	7,804,523	62,454,337	87

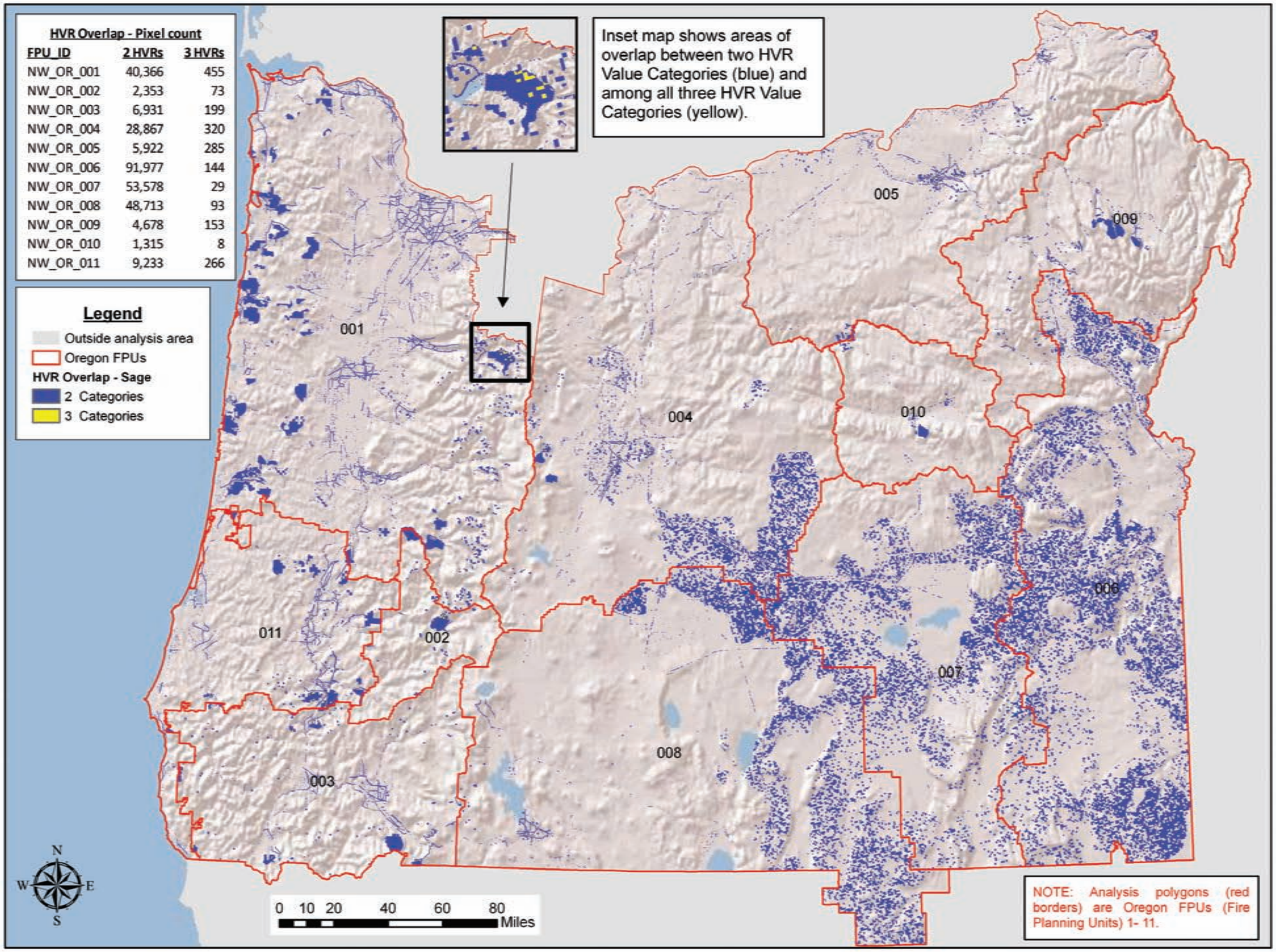
Table 7—Area by HVR category for the 11 Oregon FPUs. M = moderate, H w/ SG = high with sage-grouse habitat, H w/o SG = high without sage-grouse habitat, and VH = very high. Only burnable lands were included in the calculations and area reported includes all HVR present in a pixel (i.e., acres reported account for overlapping HVR within a value category).

		HVR category				Percent of total FPU			
	FPU	M	H w/ SG	H w/o SG	VH	M	H w/ SG	H w/o SG	VH
1	Northwest Oregon	479,496	2,809,515	2,809,515	2,120,228	5	28	28	21
2	Central Coast Range	52,241	282,603	282,603	119,072	5	27	27	11
3	Southwest Oregon	262,464	1,407,397	1,407,397	357,560	7	36	36	9
4	Central Oregon	2,033,473	1,108,833	344,175	439,865	23	12	4	5
5	Northeast Oregon	686,675	96,375	96,375	163,153	12	2	2	3
6	Southeast Oregon	2,393,572	4,385,306	71,660	24,301	32	58	1	0
7	Eastern Oregon	1,325,289	3,209,029	52,565	2,828	23	55	1	0
8	Southeast/South	1,726,280	2,597,779	265,184	52,475	18	27	3	1
9	Wallowa-Whitman	919,416	119,451	111,957	240,433	22	3	3	6
10	Malheur	270,408	26,589	21,671	78,001	14	1	1	4
11	Coos Bay/Roseburg	31,020	738,699	738,699	575,295	1	22	22	17

damaging fire. We also assumed that high flame length fire would significantly, but not completely, reduce the value of the ski area. National trails were assigned to RF8 on the assumption that only very high fire severity would adversely affect the value of these trails; lower flame length fires would have little effect on trail value. Furthermore, the net value reduction at the highest fire flame length class is not 100 percent because these trails can typically be reconstructed as needed.

Non-attainment areas were placed in the Very High value category due to the direct implication to human health and welfare. Non-attainment areas were assigned to RF13 because they have the potential for slight loss from low flame length fires, but would likely experience substantial loss at all flame lengths above low. Class I Airsheds were assigned to RF6 and the Moderate value category, which assumes that fires of increasing flame length class would be increasingly damaging to the visibility and air quality within the airshed.

Fire-adapted ecosystems were placed in the Moderate value category because fire is important in these ecosystems and is necessary to maintain healthy and functioning environments. Fire-adapted ecosystems were assigned to RF3 on the assumption that low flame length fire would confer a substantial net benefit, but higher flame length fires would result in increasing loss.



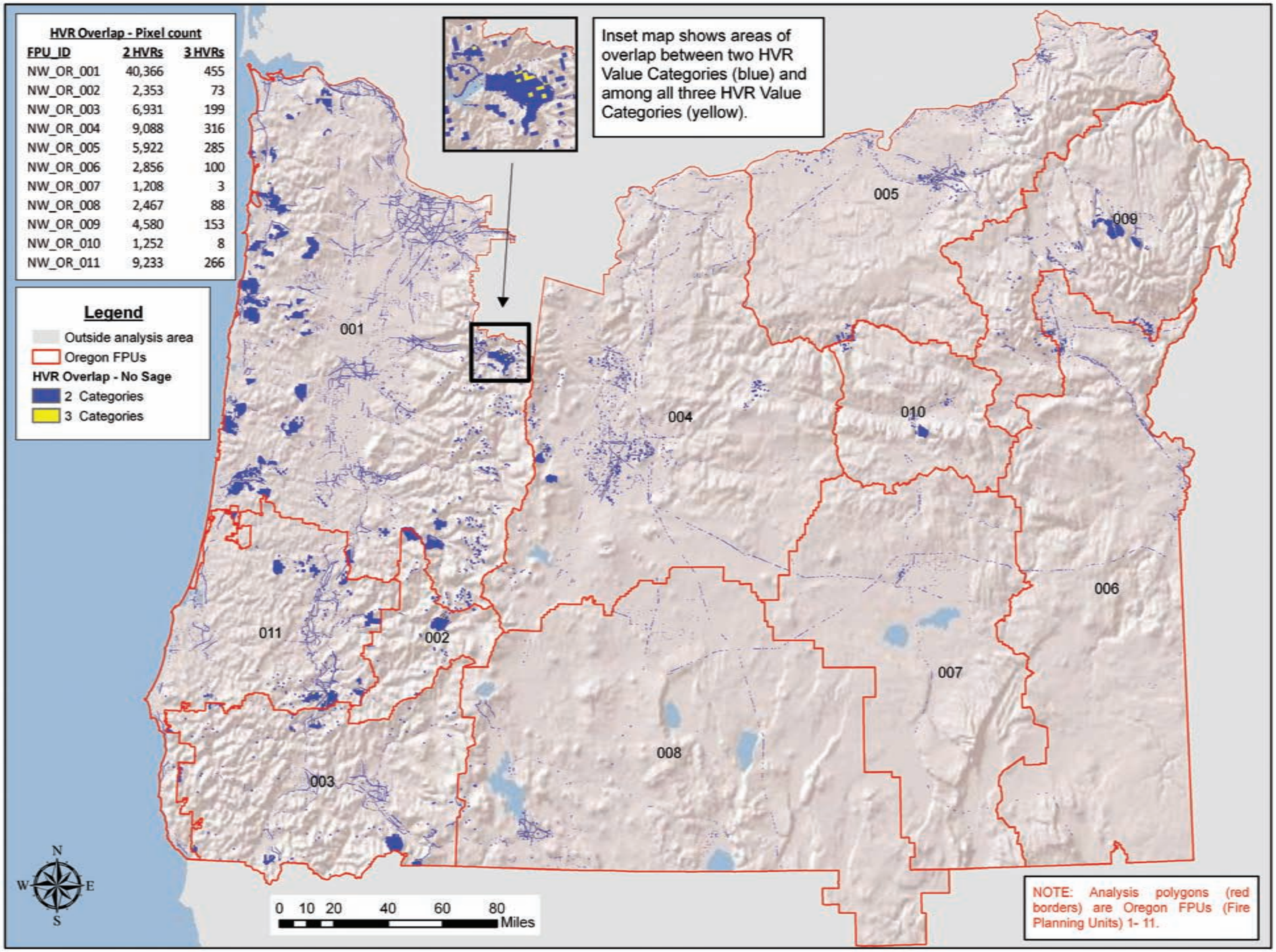
HVR Overlap - Pixel count

FPU_ID	2 HVRs	3 HVRs
NW_OR_001	40,366	455
NW_OR_002	2,353	73
NW_OR_003	6,931	199
NW_OR_004	28,867	320
NW_OR_005	5,922	285
NW_OR_006	91,977	144
NW_OR_007	53,578	29
NW_OR_008	48,713	93
NW_OR_009	4,678	153
NW_OR_010	1,315	8
NW_OR_011	9,233	266

Inset map shows areas of overlap between two HVR Value Categories (blue) and among all three HVR Value Categories (yellow).

NOTE: Analysis polygons (red borders) are Oregon FPUs (Fire Planning Units) 1- 11.

Figure 5a—Map of Oregon FPUs that demonstrate overlapping pixels among HVR categories, *with* sage-grouse habitat. Blue pixels represent areas of overlap between two HVR value categories, and yellow pixels represent overlapping pixels among three HVR categories. The black box and inset map highlight an area of high overlap (among three HVR categories). Counts of overlapping pixels by FPU are shown in the table inset above.



HVR Overlap - Pixel count

FPU_ID	2 HVRs	3 HVRs
NW_OR_001	40,366	455
NW_OR_002	2,353	73
NW_OR_003	6,931	199
NW_OR_004	9,088	316
NW_OR_005	5,922	285
NW_OR_006	2,856	100
NW_OR_007	1,208	3
NW_OR_008	2,467	88
NW_OR_009	4,580	153
NW_OR_010	1,252	8
NW_OR_011	9,233	266

Figure 5b—Map of Oregon FPUs that demonstrate overlapping pixels among HVR categories, *without* sage-grouse habitat. Blue pixels represent areas of overlap between two HVR value categories, and yellow pixels represent overlapping pixels among HVR categories. The black box and inset map highlight an area of high overlap (among three categories). Counts of overlapping pixels by FPU are shown in the table inset above.

Table 8—Assignment of response functions to the HVR included in the study and the initial value category assigned to each HVR.

HVR type	HVR	Response function (% value change by intensity)	Initial HVR category
Fire-susceptible species	Bull trout	13 (–10,–60,–70,–80)	H
	Fender’s blue butterfly	13 (–10,–60,–70,–80)	H
	Greater sage-grouse	13 (–10,–60,–70,–80)	H
	Kincaid’s lupine	13 (–10,–60,–70,–80)	H
	Marbled murrelet	13 (–10,–60,–70,–80)	H
	Northern spotted owl	13 (–10,–60,–70,–80)	H
	Oregon silverspot butterfly	13 (–10,–60,–70,–80)	H
	Willamette daisy	13 (–10,–60,–70,–80)	H
Watershed	Municipal watershed	7 (–10,–30,–50,–80)	VH
Energy infrastructure	Communication towers	14 (0, 0,–80,–80)	H
	Electric transmission lines	14 (0, 0,–80,–80)	H
	Power plants	14 (0, 0,–80,–80)	H
	Oil and gas transmission	14 (0, 0,–80,–80)	H
Recreation infrastructure	Rec. sites and campgrounds	6 (0,–10,–20,–30)	M
	Ski areas	4 (+30,+10,–10,–30)	H
	National trails	8 (0, 0, 0, –50)	M
Air quality	Non-attainment areas	13 (–10,–60,–70,–80)	VH
	Class I Airsheds	6 (0, –10,–20,–30)	M
Ecosystem	Fire-adapted ecosystems	3 (+60,+20,–20,–60)	M
Built structures	Low density	12 (–80,–80,–80,–80)	H
	Moderate and high density	12 (–80,–80,–80,–80)	VH

Finally, pixels identified as containing built structures were assigned to one of two categories: (1) High initial value for low density cells that were estimated to contain only one built structure (1 or 2 projected persons per cell), and (2) Very High for cells that were estimated to contain more than one built structure (3 or more persons per cell). Both built structure categories were assigned to RF12, assuming that any fire had the potential to result in a substantial loss.

Burn Probability Outputs from Wildfire Modeling

Burn probability (BP) varied both among and within FPUs (tables 9 and 10, figures 6 and 7). Burn probabilities were arbitrarily categorized for tabular and display purposes only as noted in table 9. The highest BP values were observed for the Southwest FPU (3 percent in burn probability class 5). In contrast, BP for the Northwest, and to a lesser extent, Coos Bay/Roseburg FPUs exhibited the lowest burn probabilities, and values for the Northwest Oregon FPU were almost entirely within BP class 1. On both a percentage and absolute basis, burn probabilities for the Southeast Oregon FPU were concentrated in BP class 3.

Wildfire Hazard

Wildfire hazard was defined in this report as the average flame length of all simulated fires that burned a given pixel. Hazard was calculated as the probability weighted flame length among the flame length intervals output from the FSim program. The outputs were then placed into categories corresponding with the response function flame length categories of Low (L), Moderate (M), High (H), and Very High (VH). Variation in flame length among simulated fires is caused by a number of factors, including wind speed, fuel moisture, and the direction of fire arrival relative to the maximum spread direction.

Table 9—Area in BP classes by FPU, excluding non-burnable land types.

		Area in burn probability classes (acres)					
		1	2	3	4	5	
FPU		0.000019 - 0.0024	0.0024 - 0.0055	0.0055 - 0.0097	0.0097 - 0.019	0.019 - 0.041	Total
1	Northwest Oregon	7,006,035	299,897	80,180	6,017	0	7,392,128
2	Central Coast Range	232,182	525,630	263,653	14,898	0	1,036,362
3	Southwest Oregon	165,783	1,071,418	1,658,980	768,423	112,155	3,776,758
4	Central Oregon	1,886,659	3,512,619	2,951,159	6,161	0	8,356,597
5	Northeast Oregon	1,724,893	1,659,772	788,472	105,580	0	4,278,717
6	Southeast Oregon	60,455	833,561	6,271,208	40,117	0	7,205,341
7	Eastern Oregon	154,506	2,015,368	3,303,747	3,765	0	5,477,386
8	Southeast/South	3,002,589	5,318,431	712,345	198	0	9,033,562
9	Wallowa-Whitman	485,315	1,542,664	1,408,639	483,711	0	3,920,329
10	Malheur	304,202	1,364,001	249,350	108	0	1,917,661
11	Coos Bay/Roseburg	1,823,898	355,254	374,529	192,660	919	2,747,259

Table 10—Percent area in BP classes by FPU, excluding non-burnable land types.

		Percent area in burn probability classes				
		1	2	3	4	5
FPU		0.000019 - 0.0024	0.0024 - 0.0055	0.0055 - 0.0097	0.0097 - 0.019	0.019 - 0.041
1	Northwest Oregon	95	4	1	0	0
2	Central Coast Range	22	51	25	1	0
3	Southwest Oregon	4	28	44	20	3
4	Central Oregon	23	42	35	0	0
5	Northeast Oregon	40	39	18	2	0
6	Southeast Oregon	1	12	87	1	0
7	Eastern Oregon	3	37	60	0	0
8	Southeast/South	33	59	8	0	0
9	Wallowa-Whitman	12	39	36	12	0
10	Malheur	16	71	13	0	0
11	Coos Bay/Roseburg	66	13	14	7	0

In general, high hazard values were observed within all FPUs and were associated with higher elevation mixed conifer forests distributed among the various mountain ranges in Oregon (figure 8). Averaged across all FPUs, 13 percent of the total burnable area was assigned to the H hazard category (greater than 6 to 12 ft flame length), 62 percent to the M category, and 24 percent to the L category. None of the burnable area in Oregon was in the VH hazard category. The Southwest Oregon FPU contained the largest area on both a percentage and total area basis in the H category (47 percent, table 11). The Central Oregon and Southeast/South FPUs show relatively minor area within the H hazard category (4 and 2 percent, respectively). Nearly all the burnable area in the Southwest, Southeast, and Eastern Oregon FPUs were in the M and H categories (table 11). The Northwest and Central Coast FPUs had the largest percentage of area in the L hazard category, reflecting relatively moderate weather and fuel moisture conditions.

Wildfire Risk Calculations

Within each HVR value category, the annual change in area (table 4) was calculated by combining the burn probabilities and response functions for each HVR category. The resulting risk estimates are represented by the Total Change Equivalent (TCE) and Average Percent Change

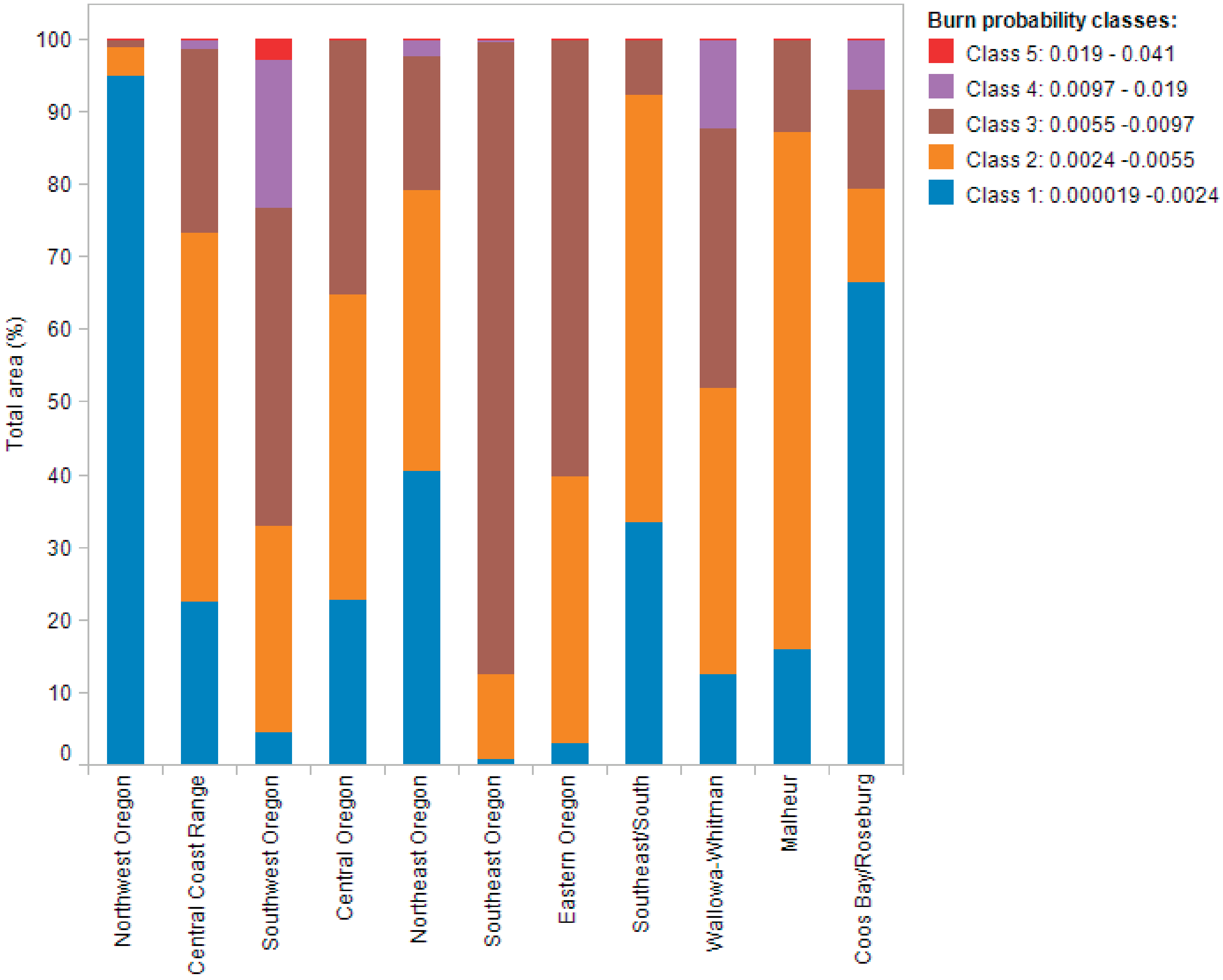


Figure 6—Percent area in burn probability classes by FPU. Calculations include burnable land types only.

(APC, table 12). TCE is the *equivalent* area lost, or gained, assuming 100 percent loss, or gain, for a particular HVR as measured in acres. APC is TCE divided by the sum of burnable area of HVR in a given value category.

These area measures aggregate marginal responses to the HVR in order to arrive at a unitary proxy for decisionmaking. The proxy sums over all affected area in each HVR class, conditioned on the probability of burning and fire intensity. For example, assume that a given 18-acre pixel of critical habitat (RF13) had a probability of burning of 0.5 percent with a high fire intensity (70 percent loss in value) and a 1 percent chance of burning with a very high fire intensity (80 percent loss in value). The contribution of this pixel to TCE would equal 0.207 acres [(0.005 * 0.7 * 18 acres) + (0.01 * 0.8 * 18 acres)].

In general, APC estimates were relatively low, reflecting low burn probabilities for individual pixels (table 12). Large differences in TCE and APC among the FPUs were projected, especially between the coastal and interior FPUs. The APCs averaged across all FPUs were 0.097 (M), –0.258 (H, with sage-grouse), –0.163 (H, without sage-grouse), and –0.063 (VH) of the total HVR area (table 12, figure 9a). Projected loss was largest for the H category whether sage-grouse was included or not (figures 9a and 9b). The total HVR area by category had a strong influence on the APC and TCE estimates—the more HVR area within an FPU the higher the loss estimate for TCE given a constant burn probability, flame length, and RF (table 7). Spatial patterns in the APC largely reflected the distribution of HVR (figures 10, 11a, 11b, and 12). The largest negative APC was observed for the Southwest Oregon FPU for the H category at –0.582 percent, which equated to a TCE of –8,192 acres.

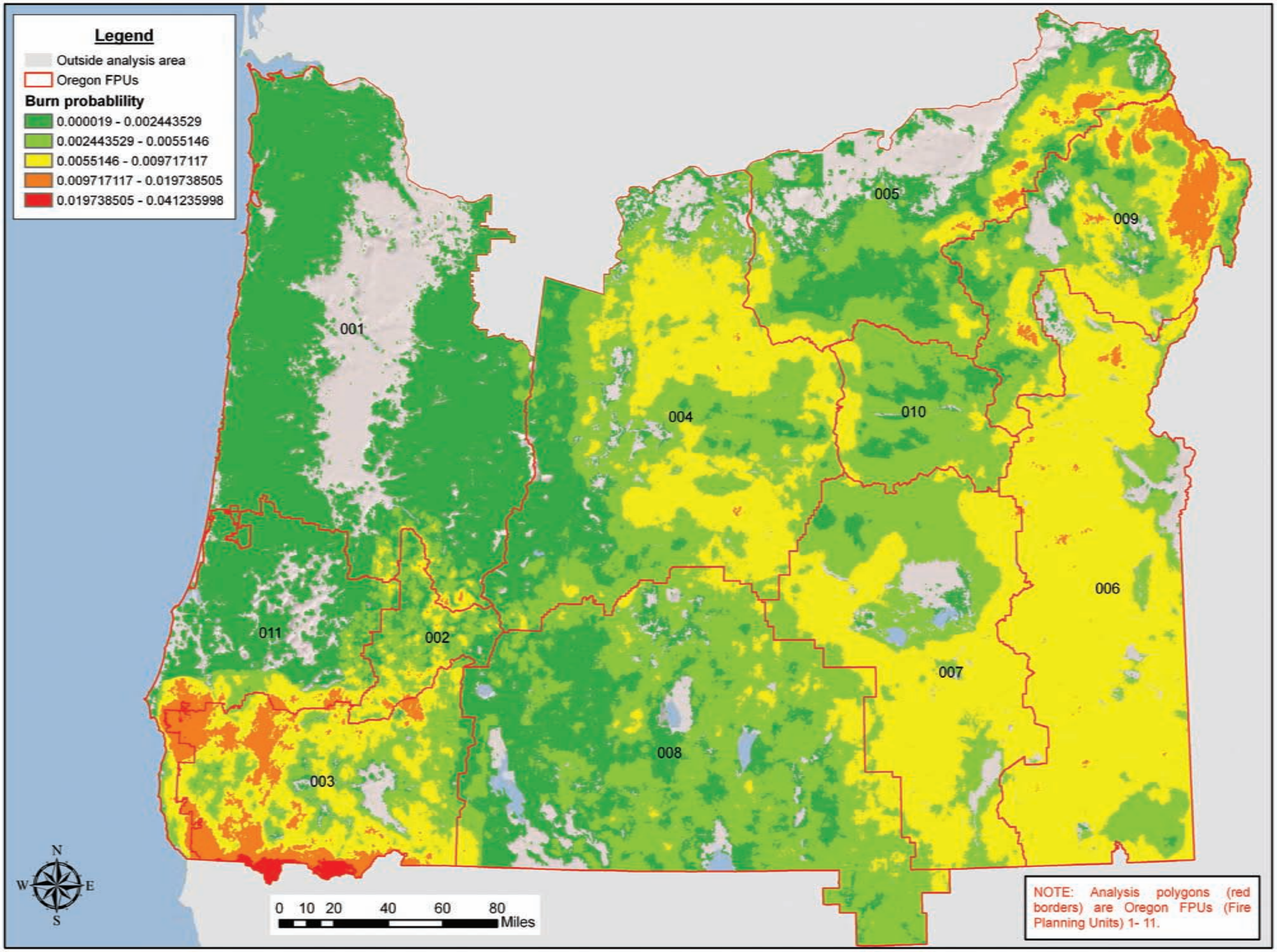
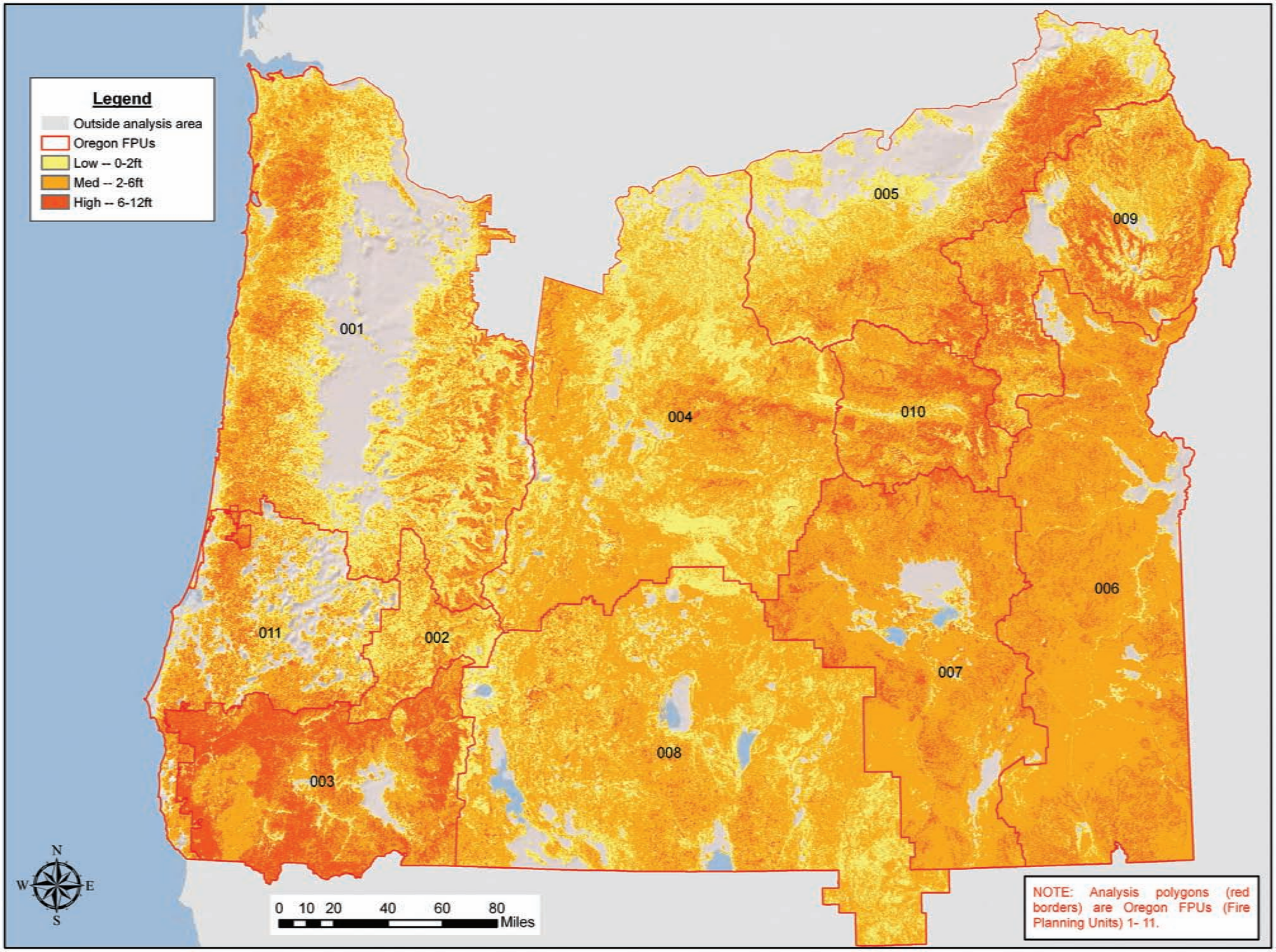


Figure 7—Map of Oregon FPUs showing burn probability outputs from the FSim model. Values represent estimates of annual burn probability.



NOTE: Analysis polygons (red borders) are Oregon FPUs (Fire Planning Units) 1- 11.

Figure 8—Map of Oregon FPUs showing wildland fire hazard results from the FSim program. Fire hazard is defined as the average flame length of the fire.

Table 11—Area in the L, M, H, and VH Wildfire hazard categories. Categories defined as L = 0 to 2 ft, M = greater than 2 to 6 ft, H = greater than 6 to 12 ft, VH = greater than 12 ft. Hazard is defined as the average flame length of the simulated fires.

		Wildfire hazard categories (acres)				Wildfire hazard categories (percent of area)			
	FPU	L	M	H	VH	L	M	H	VH
1	Northwest Oregon	3,022,981	3,553,763	800,830	0	41	48	11	0
2	Central Coast Range	445,017	480,523	99,275	0	43	47	10	0
3	Southwest Oregon	281,270	1,705,582	1,789,059	0	7	45	47	0
4	Central Oregon	2,999,671	5,010,427	345,346	0	36	60	4	0
5	Northeast Oregon	1,492,891	2,043,416	737,474	0	35	48	17	0
6	Southeast Oregon	327,818	6,084,241	789,985	0	5	84	11	0
7	Eastern Oregon	295,609	4,411,408	769,557	0	5	81	14	0
8	Southeast/South	2,535,216	6,241,737	215,321	0	28	69	2	0
9	Wallowa-Whitman	891,350	2,135,378	889,350	0	23	55	23	0
10	Malheur	235,101	1,164,838	517,488	0	12	61	27	0
11	Coos Bay/Roseburg	746,878	1,222,177	368,890	0	32	52	16	0
	Average					24	62	13	0

Table 12—Estimates of Average Percent Change (APC) and Total Change Equivalent (TCE) by FPU and HVR category. Values represent annual change. The M category contains both positive and negative values because some FPUs had beneficial effects from fire that outweighed the negative effects—principally due to the response function for fire-adapted ecosystems. Results for the H value category are shown with and without sage-grouse habitat for comparison.

		TCE (acres)				APC			
	FPU	M	H (w/ SG)	H (w/o SG)	VH	M	H (w/ SG)	H (w/o SG)	VH
1	Northwest Oregon	–2	–500	–500	–161	–0.001	–0.018	–0.018	–0.008
2	Central Coast Range	35	–504	–504	–106	0.066	–0.178	–0.178	–0.089
3	Southwest Oregon	–173	–8192	–8192	–1,026	–0.066	–0.582	–0.582	–0.287
4	Central Oregon	3,075	–2105	–224	–510	0.151	–0.190	–0.065	–0.116
5	Northeast Oregon	392	–55	–55	–132	0.057	–0.057	–0.057	–0.081
6	Southeast Oregon	3,507	–16922	–76	–52	0.147	–0.386	–0.106	–0.214
7	Eastern Oregon	1,261	–10120	–56	–11	0.095	–0.315	–0.106	–0.372
8	Southeast/South	1,569	–4492	–158	–40	0.091	–0.173	–0.059	–0.076
9	Wallowa-Whitman	80	–194	–175	–424	0.009	–0.162	–0.156	–0.176
10	Malheur	108	–23	–18	–93	0.040	–0.086	–0.084	–0.119
11	Coos Bay/Roseburg	2	–155	–155	–73	0.008	–0.021	–0.021	–0.013
	Total	9,854	–43263	–10113	–2,627				
	Average	896	–3933	–919	–239	0.097	–0.258	–0.163	–0.063

Eastern Oregon and Southwest Oregon FPUs exhibited the largest negative APCs for the VH category. The large negative TCEs for the H (with sage-grouse) category in the Eastern Oregon and Southeastern Oregon FPUs resulted from a combination of high burn probabilities and large areas of key sage-grouse habitat. The large negative TCE in the H category in the Southwestern FPU resulted from large areas of northern spotted owl and marbled murrelet critical habitat combined with high burn probabilities. Including sage-grouse habitat in the risk model did not affect the Southwestern FPU results.

Positive TCE and APC were realized in the Moderate category in many of the FPUs due to the positive benefits realized from RF3 for low and moderate intensity fires in fire-adapted ecosystems. The Central and Southeast FPUs have the largest projected benefit from wildfire at 0.151 and 0.147 percent, respectively, followed by the Eastern Oregon FPU at 0.095 percent. Risk results are mapped in figures 10, 11a, 11b, and 12 for the Moderate, High with sage-grouse, High without sage-grouse, and Very High HVR categories, respectively.

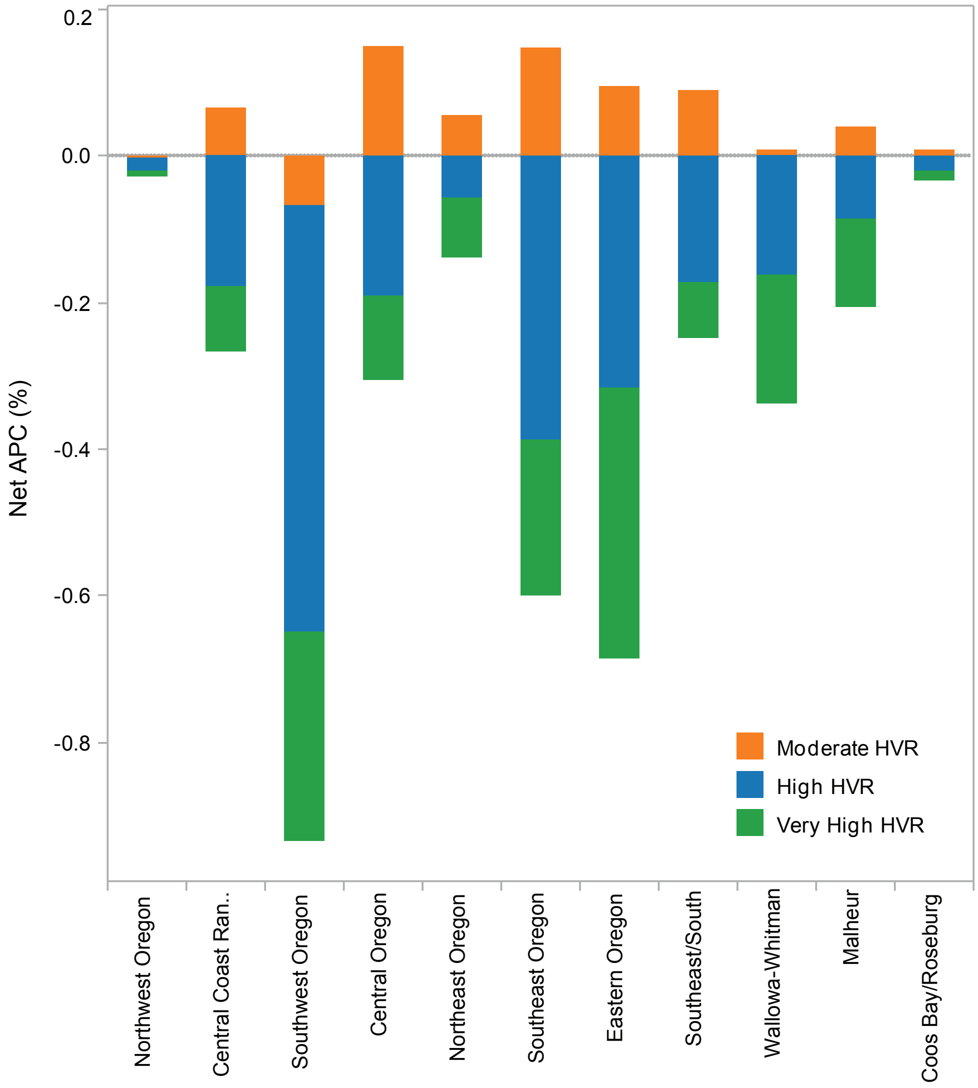


Figure 9a—Annual Average Percent Change (APC) by HVR value category for the Oregon FPUs. The High HVR category shown here includes sage-grouse key habitat.

Risk Calculations Without Sage-Grouse

The inclusion of the sage-grouse key habitat layer significantly impacted risk calculations in those FPUs where habitat is abundant. A full analysis was completed comparing the TCE and APC results for all HVR in the High value category with and without sage-grouse. The results confirm that this layer drives risk results in the Southeastern, Eastern, Central, and Southeast/Southern FPUs where APC is significantly reduced by removing sage-grouse from the calculations (figure 9b). The risk was reduced by 0.280 (–0.386 to –0.106 percent), 0.209 (–0.315 to –0.106 percent), 0.125 (–0.190 to –0.065 percent), and 0.114 (–0.173 to –0.059 percent), respectively, in these FPUs (table 12).

Discussion

Wildfire Hazard

Wildfire hazard represents the intensity with which an area is likely to burn if fire does occur there. If wildfire hazard, not risk, was the main concern, areas of highest hazard within individual Fire Planning Units (FPUs) could be further refined using map products from this analysis. It is important to recognize the difference between the hazard values calculated here and various indices of fire behavior reported in other publications. Typically fire behavior models like FlamMap (Finney 2006) and Behave are used to model flame length or fire intensity for individual pixels or stands assuming a heading fire.

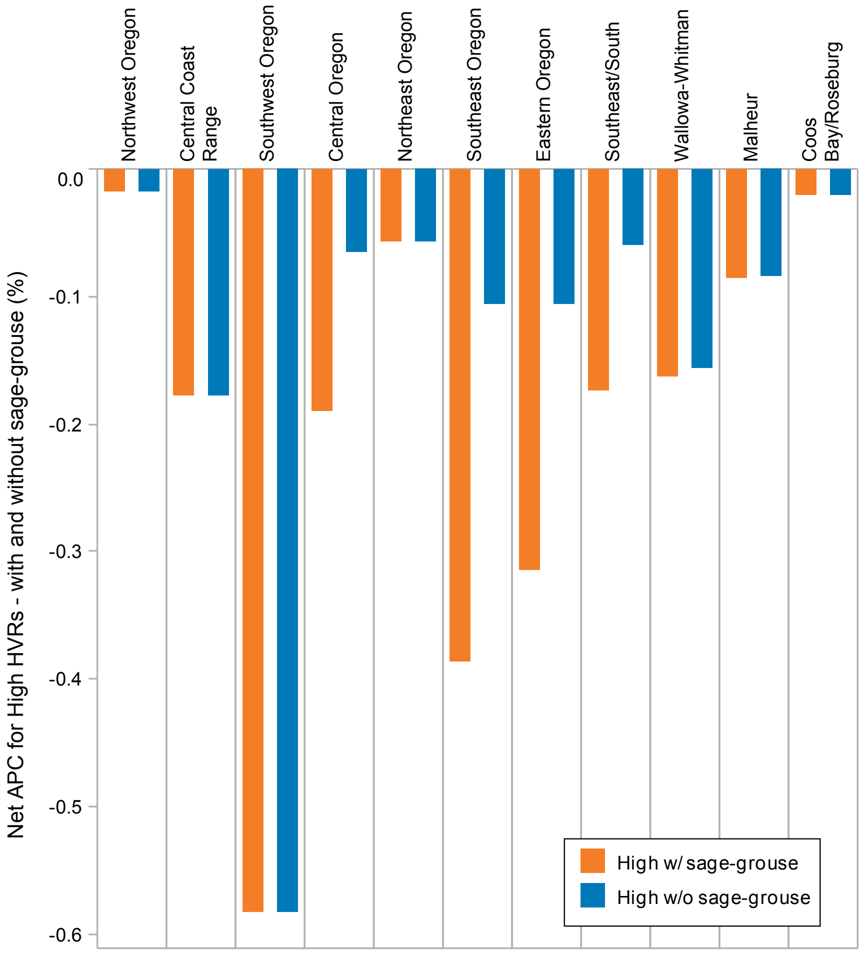


Figure 9b—Side-by-side comparison of annual APC for the High HVR category with sage-grouse and for the High HVR category without sage-grouse for the Oregon FPUs.

A spreading fire front will have variable intensity depending on the arrival direction relating to the spreading front. Flanking and backing fires have a lower intensity than a heading fire. The relative frequency of fires arriving from different directions and the resulting intensity is not accounted for in analyses that measure fire behavior at the pixel or stand level. Thus, the measure of hazard in this report represents a more robust estimate of potential fire behavior by accounting for these characteristics.

Wildfire Risk

We demonstrated a wildfire risk modeling system that incorporates important interactions among wildfire spread, flame length, and relative change to highly valued resources (HVR). The core wildfire simulation models used in this work are being applied daily for operational problems throughout the United States and the world (www.fpa.nifc.gov/). The USDA Forest Service also applies the same core wildfire spread model on a daily basis to support wildland fire incidents throughout the United States (McDaniel 2007; USGS 2009b). Burn probability modeling is implemented in the operational version of FlamMap (Finney 2006) that is widely used for fuel planning in Federal land management agencies. The modeling framework is well-suited for analyzing a wide variety of wildfire risk problems at a range of spatial scales ranging from project development (Ager and others 2007), watershed analyses, National Forest assessments (Ager and Finney 2009), to national scales as in this report. While some of the methods used in this work remain in the research domain, we envision the suite of tools we used being made operationally available within the next year or two. To accomplish this study, we relied on high performance, 64-bit 32 processor computers housed at Fire Program Analysis (FPA). Each FPU simulation required 3 to 5 hours, depending on the number of fires and the size of the FPU. Thus, similar resources will be required for implementation at field units.

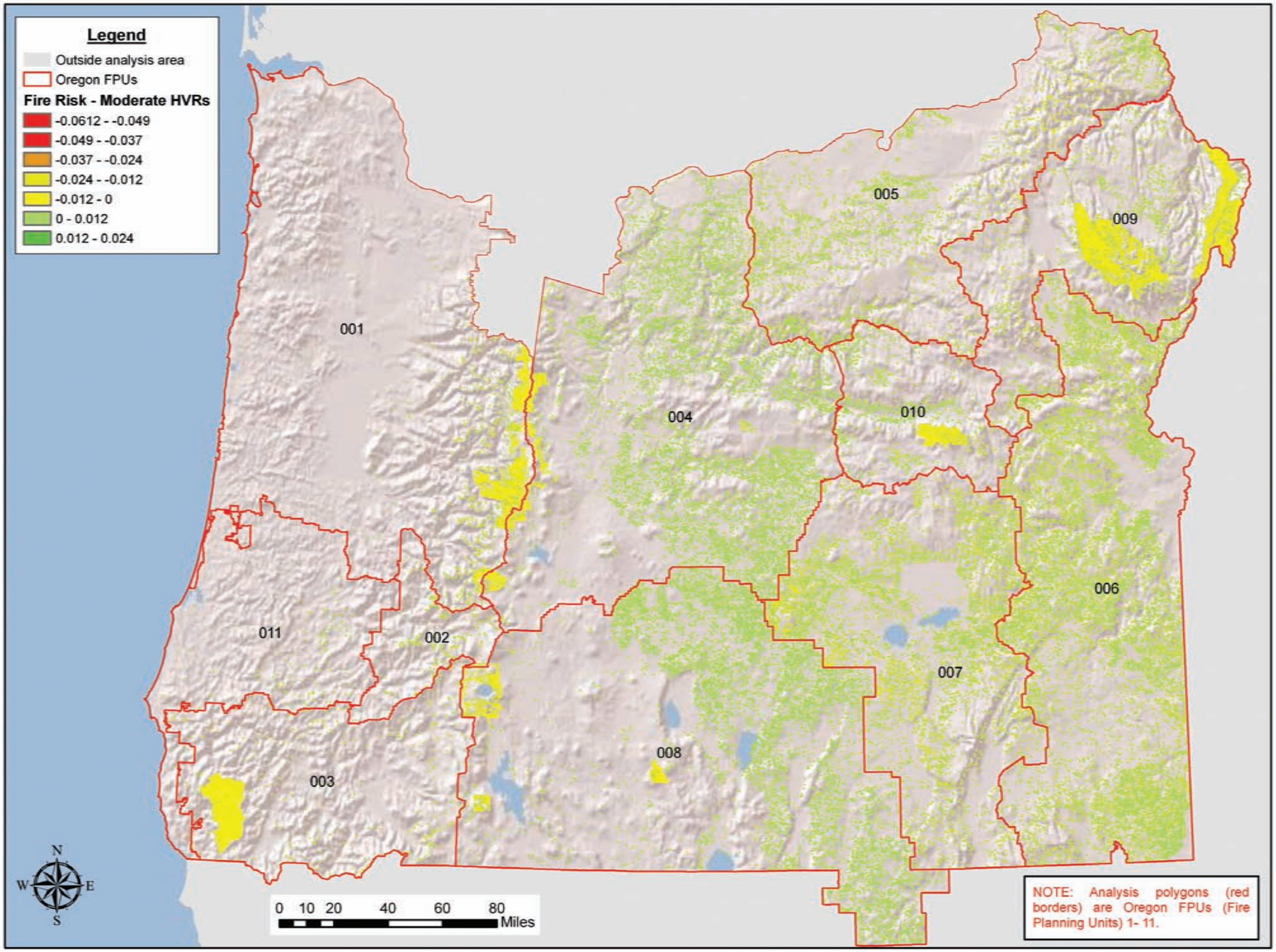


Figure 10—APC of HVR in the Moderate category for the Oregon FPUs.

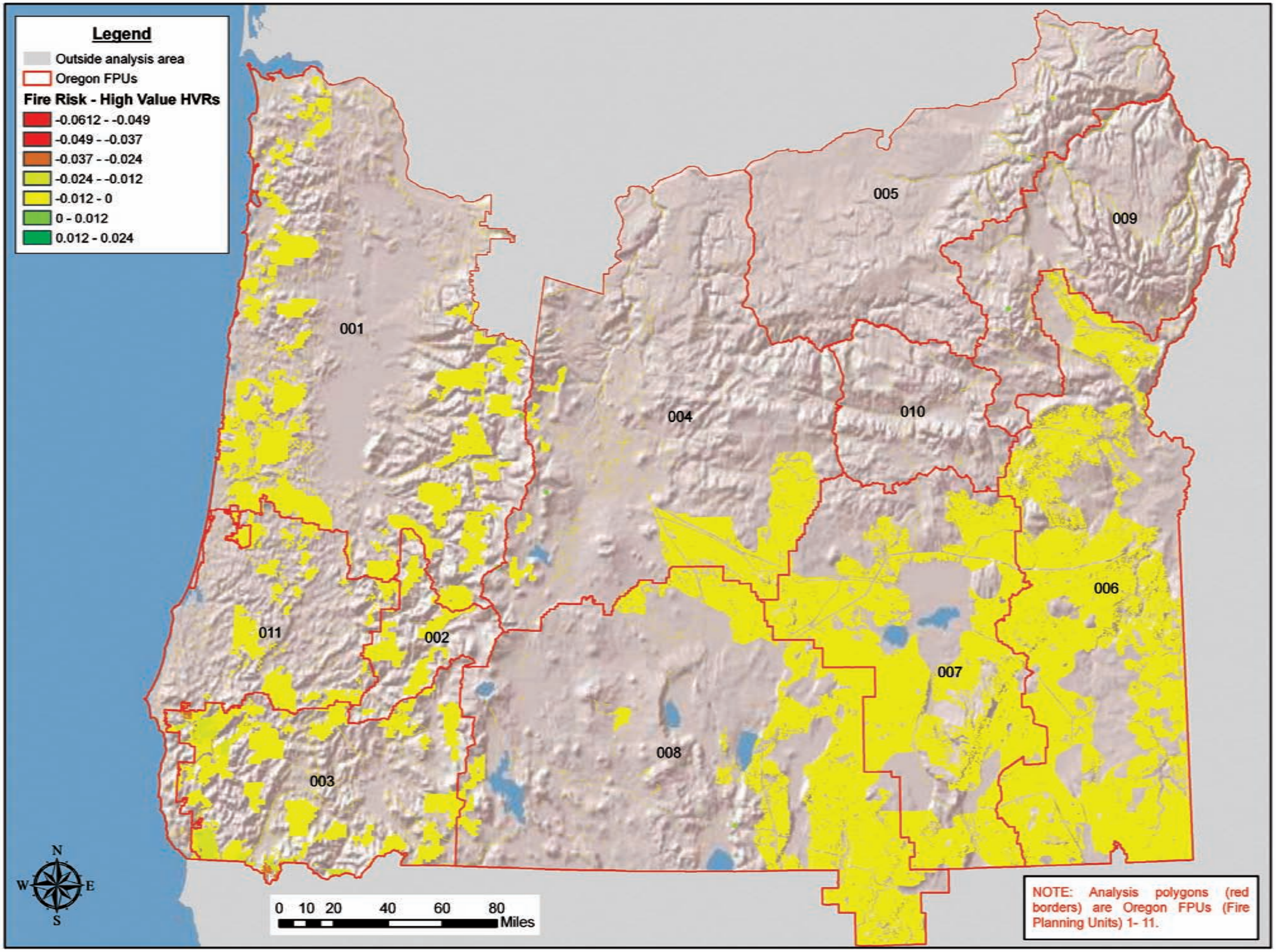


Figure 11a—APC of HVR in the High category for the Oregon FPUs with sage-grouse.

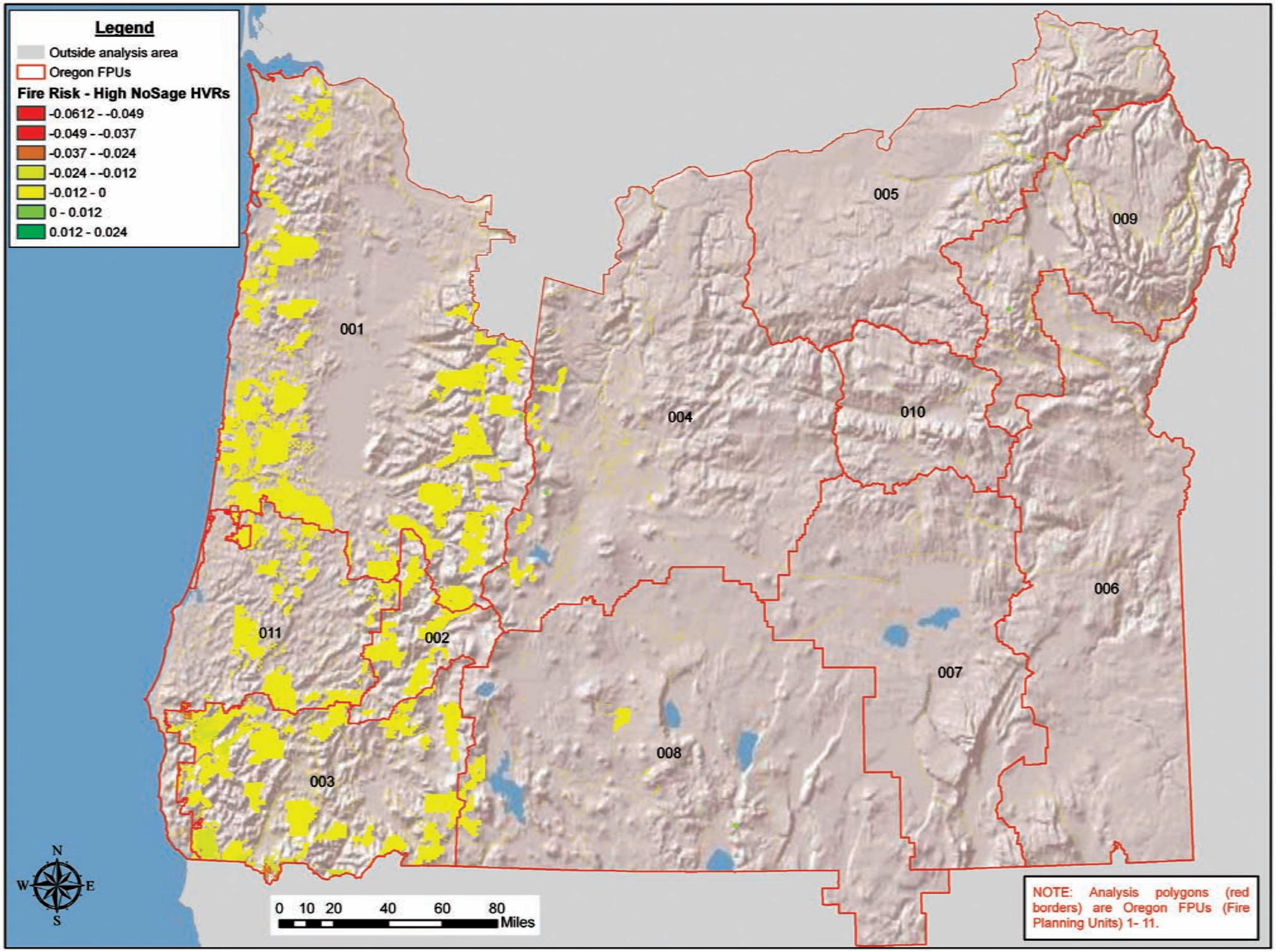


Figure 11b—APC of HVR in the High category for the Oregon FPUs without sage-grouse.

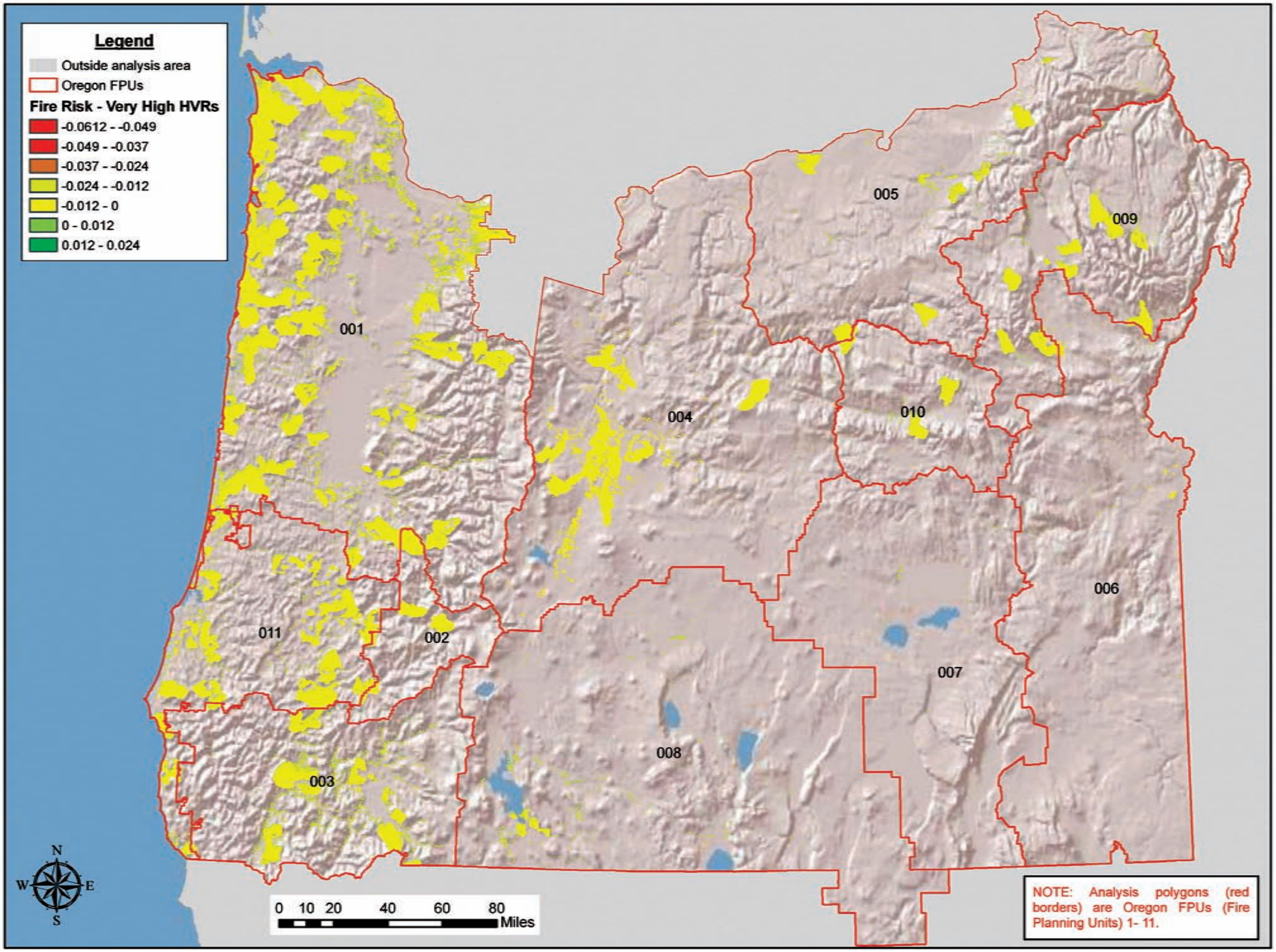


Figure 12—APC of HVR in the Very High category for the Oregon FPUs.

This approximation quantifies wildfire risk using a formal quantitative definition that incorporates wildfire likelihood, intensity, and fire effects. Numerous other wildfire risk measures have been proposed and published, most of which lack one or more of the key components of risk. The importance of incorporating wildfire spread into risk measures is especially important in the western United States where the bulk of the total area burned is from a few large fires that spread over large distances. As average fire size increases, the utility of risk indices that only incorporate local fire behavior diminish, since the latter indices do not consider fire spread over large distance.

We summarized wildfire risk as net value change (NVC) for individual HVR categories (Very High, High, and Moderate). Multiple data layers contributed to each of the HVR categories. The bulk of the average percent change (APC) occurred in the H HVR category (–0.258 percent with sage-grouse and –0.163 percent without sage-grouse) compared with 0.097 percent for the M category and –0.063 percent for the VH HVR category. The Southwest, Southeast, and Eastern FPUs were projected to have the largest APC. The higher than average risk in these areas is primarily related to the amount of critical habitat and key sage-grouse habitat located in these FPUs. On an area basis, the bulk of the Total Change Equivalent (TCE) was in the H HVR category within the Southeast, Eastern, and Southwest FPUs and totaled roughly 35,000 of the approximately 43,000 acres. TCE for other FPUs was relatively minor for other HVR categories.

The results of the burn probability analyses are consistent with recent wildfire activity within Oregon. However, data on HVR loss from these fires is not typically available—with the exception of habitat area for the northern spotted owl. Hence, comparisons to historic trends with outputs like those presented here (APC and TCE) are not possible. As demonstrated above, exclusion of key habitat for the sage-grouse shifted some of the FPU rankings and significantly reduced the projected risk in Southeast and Eastern Oregon. Further sensitivity analyses related to HVR and response functions assignment will be included in subsequent analyses.

Overall, the risk projections calculated here are useful for establishing base line information about wildfire threats to human and ecological values. These projections can be used for ranking relative risk among FPUs and geographic areas and for monitoring risk over time. The various risk and hazard metrics included in this study (BP, Hazard, APC, and TCE) provide a robust set of spatially explicit indicators that can be applied at a wide range of scales to address management and policy questions pertaining to wildfire threats.

Resource Value Issues

Consistent data availability at the national scale is a key component of risk assessments and a topic of growing interest to Federal land management agencies, emergency relief and rescue agencies, the Department of Homeland Security and the Department of Defense. National or centrally located enterprise data sets are becoming more readily available; however, effort is needed to enhance national data sets to reflect recent changes and to maintain data accuracy. Various data sets used in this study have been developed using data standards to establish consistency and accuracy; this is documented in associated metadata. Yet with other national data sets, nation-wide coverage is achieved through a collection of data compiled at the local or state level. Often these data are assembled using differing or no data standards, creating attribution and scale inconsistencies. For national risk assessment efforts, potential data inconsistencies within data sets collated from local or regional sources need to be recognized and carefully evaluated for potential impacts to the assessment.

Nationally mapped data layers often omit or overlook local level resource detail. Such data are frequently developed at a map scale of 1:250,000 to 1:2,000,000, which equates to an on-the-ground accuracy of approximately 4 to 32 miles, respectively (USGS 2009a). Yet often national data sets are considered the best available and using them is necessary to call attention to needed improvements for future data set publications. Frequently, the data set's intended use is not made clear in metadata, or metadata is not included with downloaded data sets. If data are intended to be used for mapping and analysis, data stewards must re-engage with these data to correct known errors and to improve accuracy.

Local data constructed at a fine map scale proves to be more accurate for local planning and management purposes. However, many challenges exist in acquiring and using local data for national analysis purposes and management applications. Past and current efforts to obtain data about resources considered highly valued (for example, threatened and endangered species habitat, energy resources, and Federal historic structures) have produced irregular or often incomplete data sets mapped at the local, rather than the national scale. Because data standards, types, and completeness vary or may conflict from one locale to the next, use and aggregation of local data for a national mapping exercise is not yet feasible. These data issues are well known among Federal fire management agencies and efforts are underway to establish standards between FS and DOI agencies to develop, collect, and aggregate local data to the national extent (discussed in "Data Direction and Roles").

Although a great deal of effort was made to collect the best available data for this report, several sets were incomplete and lacked appropriate detail to accurately distinguish the resources of highest value from those of lower value. The Sage-Grouse Key Habitat layer is one data set that presented challenges when used in this exercise. As indicated in table 12, due to the coarseness of the data set, large portions of the southeastern Oregon FPUs in particular are indicated at risk because they contain large amounts of sage-grouse habitat. According to BLM, this data set was the first attempt at a national sage-grouse habitat layer and, therefore, is not at a sufficiently fine scale to approximate the highest priority sage-grouse habitat. BLM is working to produce a data set that includes more detailed mapping of critical sage-grouse habitat. This improved data set will most likely be more accurate for use in the second and subsequent approximations of wildfire risk.

Issues of data scale and attribution also presented challenges in assigning resource value to the appropriate value category and response function. For example, the inconsistent value and campground type attribution of the Federal Recreation Sites and Campgrounds HVR layer among various agencies' data sets made it impossible to reduce the data set to include only the resources of very high value. While the BLM Campgrounds layer and much of the NPS Campgrounds layer contained sufficient detail to distinguish between developed and unimproved campsites, FS and FWS data did not make the distinction. In order to prevent overvaluing data with incomplete attribution and essentially discounting data sets with comprehensive attribution, all campground records were retained for the final HVR data layer. Complete attribution may have resulted in some areas being assigned to a higher value category than the current Moderate designation (particularly those with significant visitation or historic significance), while others might not have been included as HVR.

Contrastingly, the Class I Airsheds layer is a data set that presented challenges not related to incomplete attribution. Class I Airsheds generally represent National Parks and National Wilderness Areas (P.L. 108–201)—landscapes that often present good opportunities for wildfire use. Assigning a value greater than Moderate might overvalue a relatively large geographic area and imply that these areas are inappropriate candidates for fire use, or worse yet, suggest they are appropriate areas for active suppression. Additionally, the Class I designation serves to protect air quality (including visibility) of designated lands, but smoke dispersion affects visibility beyond the boundaries of the Class I lands. Using a backward dispersion model like Air Quality Impacts Planning Tool (AQUIPT) could potentially improve future assessments (www.fs.fed.us/pnw/about/programs/mdr/airfire-sacc.shtml). The AQUIPT allows managers to combine historical weather data and fuels characteristics with other burn parameters to map wildfire locations that would produce severe impact to each Class I Airshed (Larkin, personal communication).

Assigning appropriate response functions was most challenging for the Critical Habitat layer. Within the data layer, species were identified as fire-tolerant, fire-neutral, or fire-susceptible. Because additional data and input from the scientific community was needed in order to understand the full spectrum of impact to species' habitat, it was not possible to accurately assign response functions to both fire-tolerant and fire-neutral species. We decided to include only fire-susceptible species for the first approximation exercise until further recommendations from the scientific community can be acquired.

The data sets acquired for this first approximation of risk represent the best available HVR data defined by the FPA Executive Oversight Group and the authors of this study. As discussed above, most of these data are still incomplete with respect to extent and attribution, and we do not fully understand the effects of fire on these resources. Despite our best efforts to present complete and accurate HVR data layers, a bias exists toward data that are readily available due to agency priorities for data completion. A firm understanding of the limitations and inherent biases is important when using these data. While the resources presented here do represent some of the HVR impacting management of wildfire, they do not provide a comprehensive representation of all possible HVR. Undoubtedly, the second approximation of wildfire risk will include data set revisions and a modified HVR list—excluding some layers presented here and adding data that was unavailable at the time of this study.

Data Direction and Roles

One of the purposes of this study was to identify the best available, nationally consistent data and to call attention to those data sets that need improvement and updating. Data challenges similar to those described here exist in other areas of wildland fire management planning and response. As previously discussed, the WFDSS values-at-risk assessment (RAVAR) requires geospatial data related to National Critical Infrastructure (NCI) and natural and cultural resources. Many of the NCI data are available from sources used in this exercise, such as Homeland Security Infrastructure Program (HSIP), ESRI Data and Maps, and National Transportation Atlas Database. However, natural and cultural resources data are rarely maintained by an authoritative national source. Data of this nature are inherently different from data managed and created in the private sector due to the lack of commercial opportunities and incentives. Not only are Federal agencies limited to the finances already allocated for data development, but catastrophic events have not catalyzed natural resource data amelioration in the same way natural disasters and terrorist attacks have motivated NCI data development.

Natural resource data are most often collected and compiled at the local scale, within the jurisdictional Federal agency. For example, threatened and endangered species habitat is often mapped at a local scale and the extent is limited to the land management agency's administrative boundaries (for example, National Forest, National Park, or Wildlife Refuge), resulting in data sets that do not accurately represent the full habitat extent. In order for these data to be used in national mapping exercises, data must be compiled from all local units and integrated into larger or national data layers. These endeavors are time intensive and often result in data sets with gaps where geospatial data are unavailable or where data are limited to one land management agency. These gaps make it impossible to determine whether the species or resource is not present in the area of interest or whether the geospatial data are simply unavailable.

Much attention and financial resources are being directed toward improving national data sets used in wildland fire management, planning, and response. Efforts are underway to address undoubtedly the greatest challenge in this process—acquiring natural resource data managed by Federal agencies. The WFDSS Data Coordinator and cooperating Federal wildland fire management agencies are identifying individuals to lead data collection efforts from within geographic areas (generally organized by Geographic Area Coordination Center (GACC) boundaries) and between land management agencies. As priority resource data are identified from within geographic areas, those area leads will coordinate with other agency leads to identify priority resource overlap. Although this process was initiated in the 2009 fire season, clear direction and prioritization of resources from agency leadership is needed in order to re-task individuals to address these data issues and achieve long-term success (Appendix C).

To effectively support a national monitoring exercise or decision support system, data must be consistent in scale and extent. Although the wildland fire community is aware of the data issues previously discussed, an inherent lag exists between problem identification and data solutions development. The practice of employing "best available" data must be the interim solution while Federal land management agencies work together to establish data standards that create consistent resource data across management boundaries.

Understanding Fire Effects on Highly Valued Resources

Input related to data interpretation is another critical component of successful risk analysis of HVR. The authors consulted with experts and senior leadership in the wildland fire community for assistance in valuing resources and interpreting fire effects on resources, in order to adequately assign response functions in this report. We intend to involve more input from the scientific and research communities in subsequent exercises to better inform management decisions related to fire effects on resources and sensitive species. This input is critical to accurately interpret model results.

It is also anticipated that as natural resource data prioritization is determined within geographic areas, data stewards and fire management personnel will engage with local scientists and resource specialists to determine how to interpret these data within the context of wildland fire management. Familiarity with data sources and knowledge of resource locations within one's geographic area is an added benefit of compiling local data to create coverage at a larger geographic extent.

Using the data and response functions developed in this study creates significant opportunities to explore tradeoffs associated with alternative policies and budgeting mechanisms. However, there remain two primary challenges: (1) the quality and availability of resource value data (previously discussed), and (2) the state of economic valuation in quantifying change to non-market resources. It appears that the existing state of non-market economics is not sufficiently advanced to provide price-based mechanisms to guide the prioritization of goal programming exercises to explore efficient resource distribution and policy (Venn and Calkin 2009). A variety of multi-criteria decision analysis models may be applied to provide useful approximations that help guide management activity prioritization where multiple resource values interact with wildfire threat. The application and extension of the HVR data to goal programming efforts may be very informative. However, due to these challenges it is critical that all efforts evaluate the implications of these known limitations to any results.

Conclusion

This paper presented methods to incorporate wildfire spread, fire intensity, and change in value for a range of human and ecological values into a risk framework. The spatial, temporal, and social dimensions of the wildfire risk problem are challenging the Federal land management agencies to meet societal needs while maintaining the health of the lands they manage. Recent fire management data and modeling developments, such as LANDFIRE, Fire Program Analysis (FPA), and Wildland Fire Decision Support System (WFDSS), among others, allow a level of analysis and assessment that were, until very recently, impossible. These developments pose opportunities to analyze, communicate, and implement a more risk-informed fire management policy that can reduce Federal fire management costs and improve land condition. Extensions of these efforts, such as the one described in this report, demonstrate the potential of a national risk assessment framework. This study is scalable from local project planning to national assessments and can accommodate a broad range of fire management activities, such as fuel treatment scheduling, fire planning, suppression decisions support, and fire resource budgeting.

This first approximation established an appropriate risk framework to meet the three goals identified in the introduction—the framework: (1) addressed the WFLC monitoring questions on wildfire hazard by identifying Fire Planning Units (FPUs) with high burn probabilities and/or high fire intensities; (2) established a base line to inform the prioritization of fuels treatments and identified FPUs where mitigation measures might most effectively reduce wildfire risk (i.e., areas with the potential for high loss of highly developed and natural resources); and (3) responded to calls from oversight agencies for risk-based performance measures of fire management efforts by identifying HVR data sets to track in order to evaluate cost effectiveness of suppression measures.

Work remains to improve the quality, extent, and consistency of spatial data for highly valued resources (HVR) and the economic valuation of the effects of fire on these HVR. Of particular concern are spatial data that represent consistent resource value such that all characterized areas belong in the assigned HVR category. This is a particular problem if the distribution of misrepresented HVR differs in a way that could affect policy. For example, suppose you are trying to allocate treatment dollars between two FPUs. In one FPU, all campgrounds are highly developed and very high valued; in the other, all the campgrounds are dispersed and undeveloped and of low value—the composite average value is moderate. Resources could be misallocated to protect the low value campgrounds.

The application of annual value change to quantify risk to HVR creates additional challenges because some of the identified HVR are proxies for the real underlying value at risk. For example, consider the Critical Habitat layer. Its role in preventing extinction is what is most important. If the entire habitat is destroyed in the short-term, it will not matter if it recovers quickly because the species that depend on it may become extinct in the meantime. If half the habitat is destroyed now and then recovers, but the other half is destroyed later, the species may survive. These are two very different outcomes for the same aggregate value change. Given these challenges and recognized limitations, the authors recommend caution in utilizing these results to distribute budgets and prioritize large areas for fuel treatment and mitigation efforts. This is because of the potential biases created by the current state of spatial data and challenges in assigning relative value to the modeled resources.

However, we believe this first approximation demonstrates that it is now possible to represent and quantify risk at the broad scale of the sub-regions of the United States using the best available data. We also believe this first approximation has identified future efforts that could make this framework more applicable to fire management resource distribution efforts. Existing models' analytical capabilities could be enhanced by incorporating the effects of fire on HVR. The authors are encouraged by the efforts that Federal fire management officials and agencies have made to date and we believe the potential payoffs from this focus far outweigh the costs.

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Appendix A: Biological Data Not Included in the Model

Ecological Spatial Data Sets Discarded

The following list of ecological spatial data sets were collected, evaluated, and discarded from further consideration in this report for a variety of reasons. This summary is organized and presented in four main categories of data problems:

(1) Spatial resolution is too coarse;
(2) Map extent is incomplete (not national coverage);
(3) Data set is inappropriate to assign response functions; and
(4) Data set might make a viable input with further refinement.

1. **Spatial resolution is too coarse**
   a. **Conservation International Hotspots Revisited**
   The Conservation International Hotspots Revisited data set consists of regions known to hold especially high numbers of species found nowhere else, yet their total remaining habitat covers a little more than 2 percent of Earth's land surface (figure A1). To qualify, an area must: (1) contain at least 1,500 endemic, native vascular plant species, and (2) have already lost at least 70 percent of its primary, native vegetation. As evidence of their urgent need for global conservation, hotspots also house exceptionally high numbers of threatened vertebrates, including 50 percent of threatened mammals, 73 percent of threatened birds, and 79 percent of threatened amphibians as endemics (Conservation International 2004; Mittermeier and others 2004). Although some areas within the regions would be valuable inputs to the model, the coarse nature of the representation makes it inappropriate.

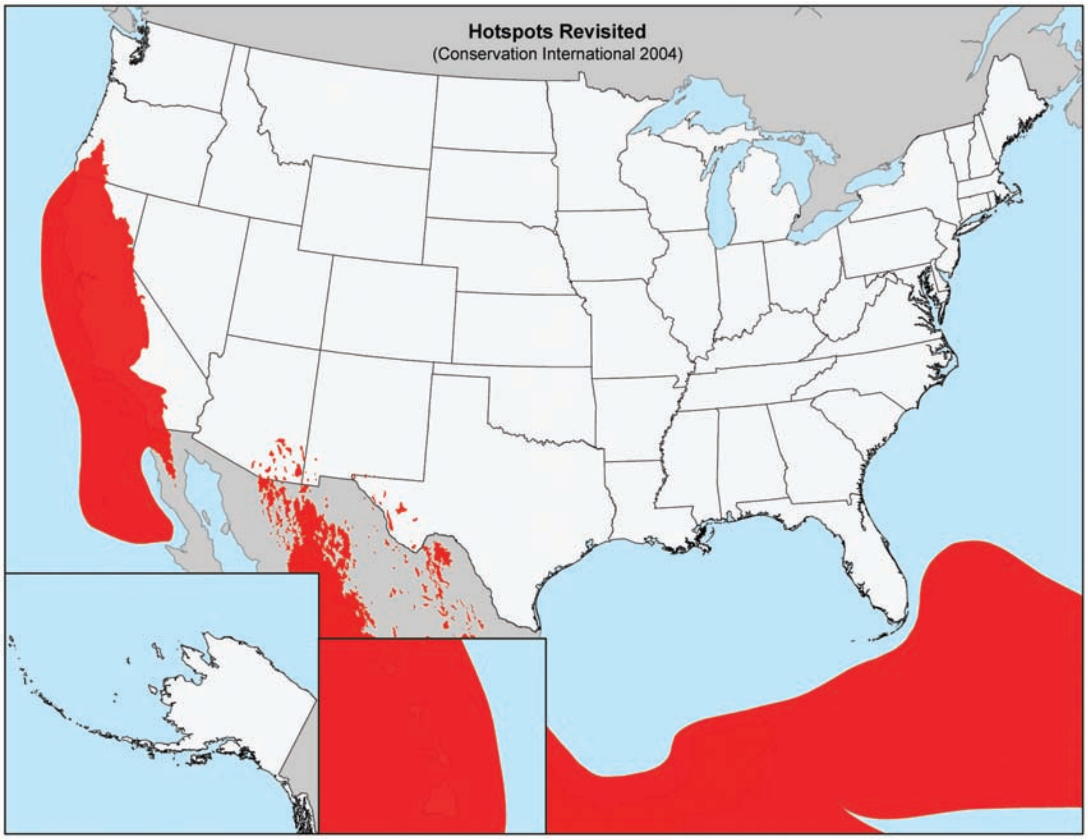

Figure A1—Conservation International Hotspots Revisited data set. Red shaded areas represent habitat of unique species.

b. Global 200 Most Biologically Valuable Ecoregions

The Global 200 Most Biologically Valuable Ecoregions are defined as ecoregions whose conservation would achieve the goal of saving a broad diversity of the Earth's ecosystems, including those with exceptional levels of biodiversity, such as high species richness or endemism, or those with unusual ecological or evolutionary phenomena (figure A2). This data set aims to represent all of the world's biodiversity by identifying outstanding ecoregions in all of the world's biomes and biogeographic realms (World Wildlife Fund 2006a; Olson and Dinerstein 1998).

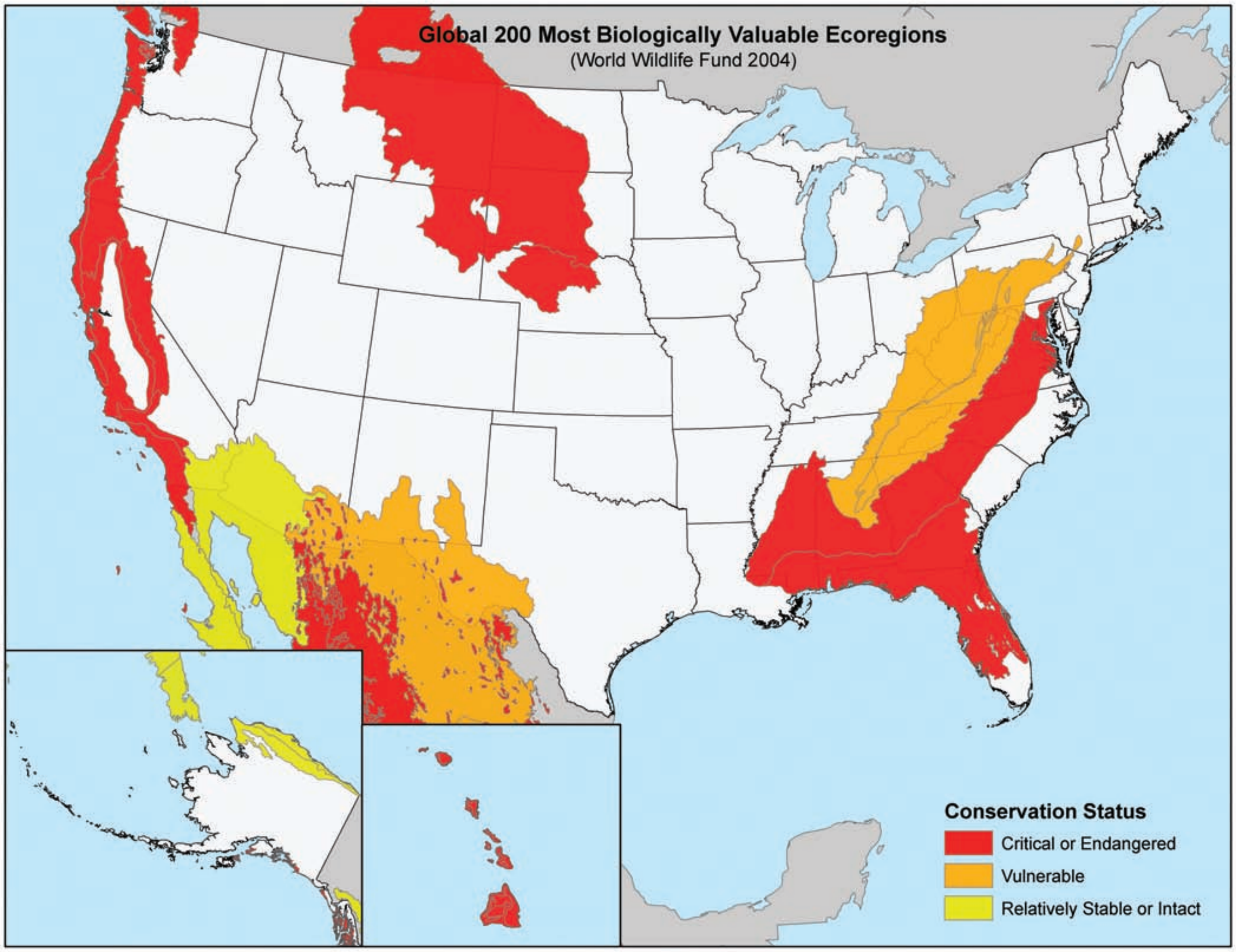

Figure A2—Global 200 Most Biologically Valuable Ecoregions.

c. Global Wetlands

The Global Wetlands dataset represents wetlands in danger (Dungan 1993) as defined by the United Nations Environmental Program World Conservation Monitoring Center (figure A3).

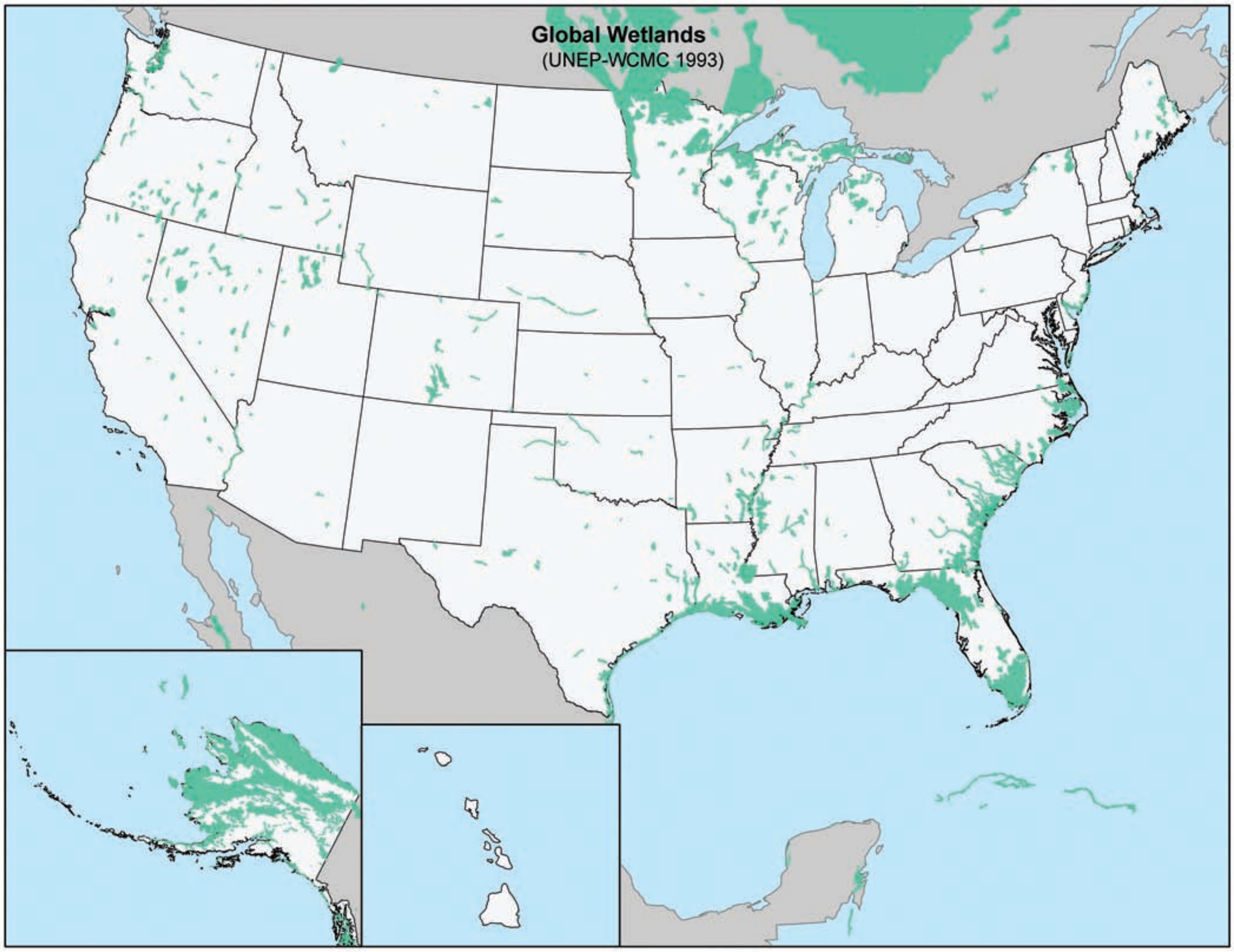

Figure A3—Global Wetlands data set.

d. Species Richness by Taxa

The Species Richness by Taxa data set represents the number of mammal, bird, reptile, and amphibian species known to occur by ecoregion (figures A4, A5, A6, and A7). The dataset is available by WWF Terrestrial Ecoregion (World Wildlife Fund 2006b).

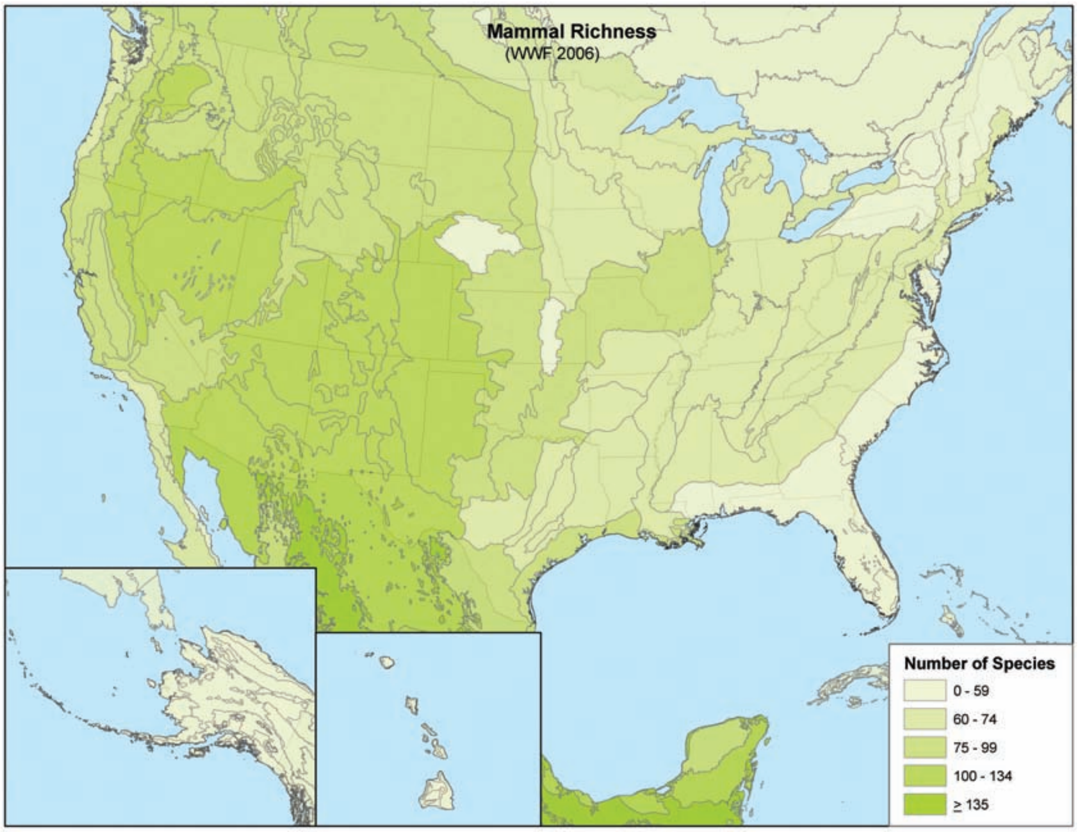

Figure A4—Mammal species richness by WWF Terrestrial Ecoregion.

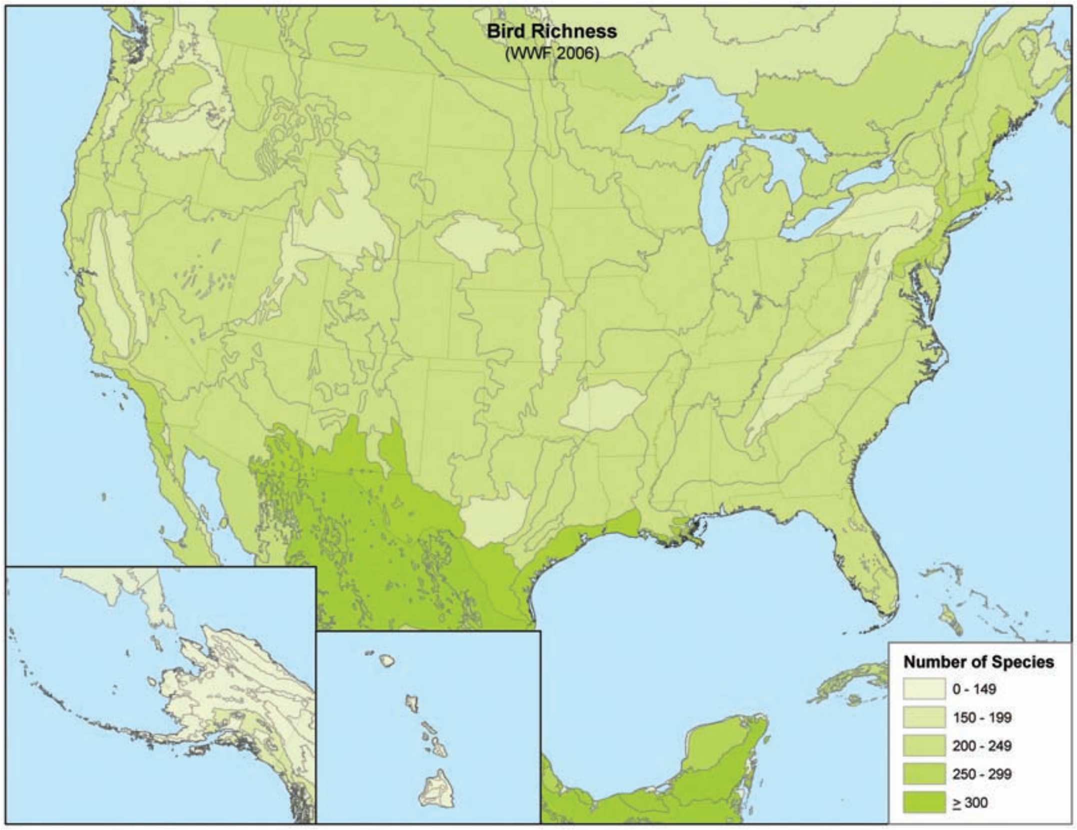

Figure A5—Bird species richness by WWF Terrestrial Ecoregion.

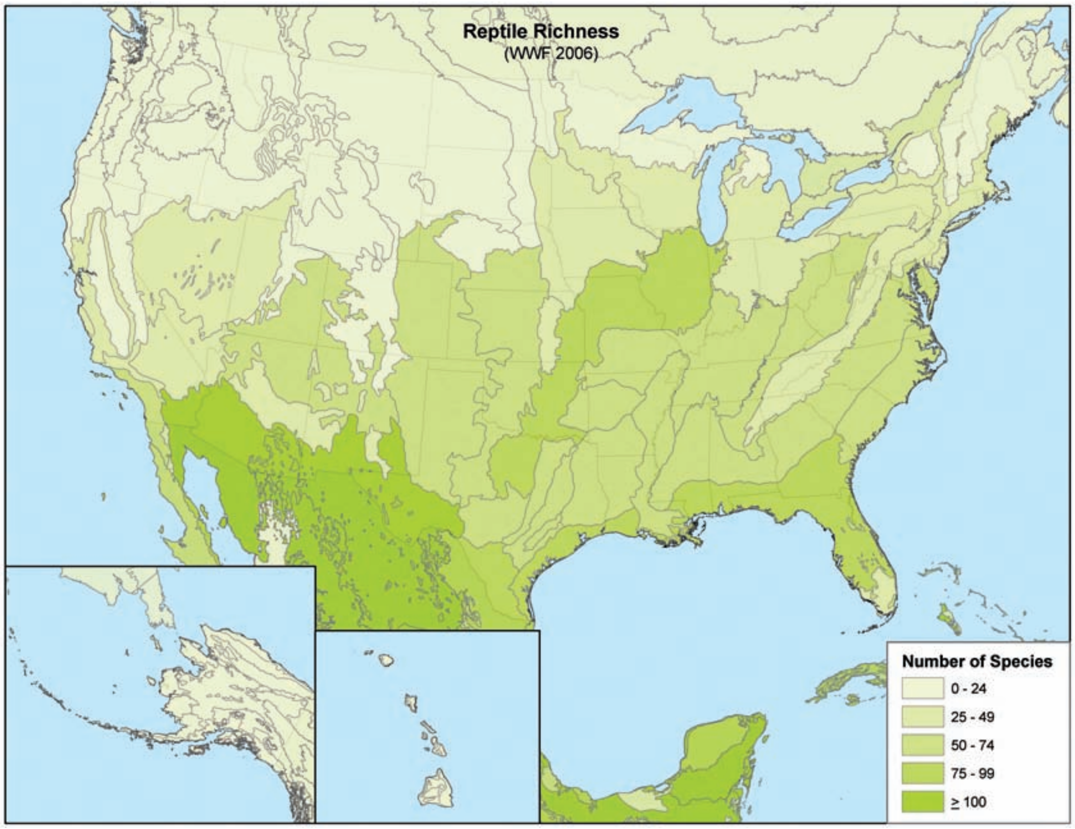

Figure A6—Reptile species richness by WWF Terrestrial Ecoregion.

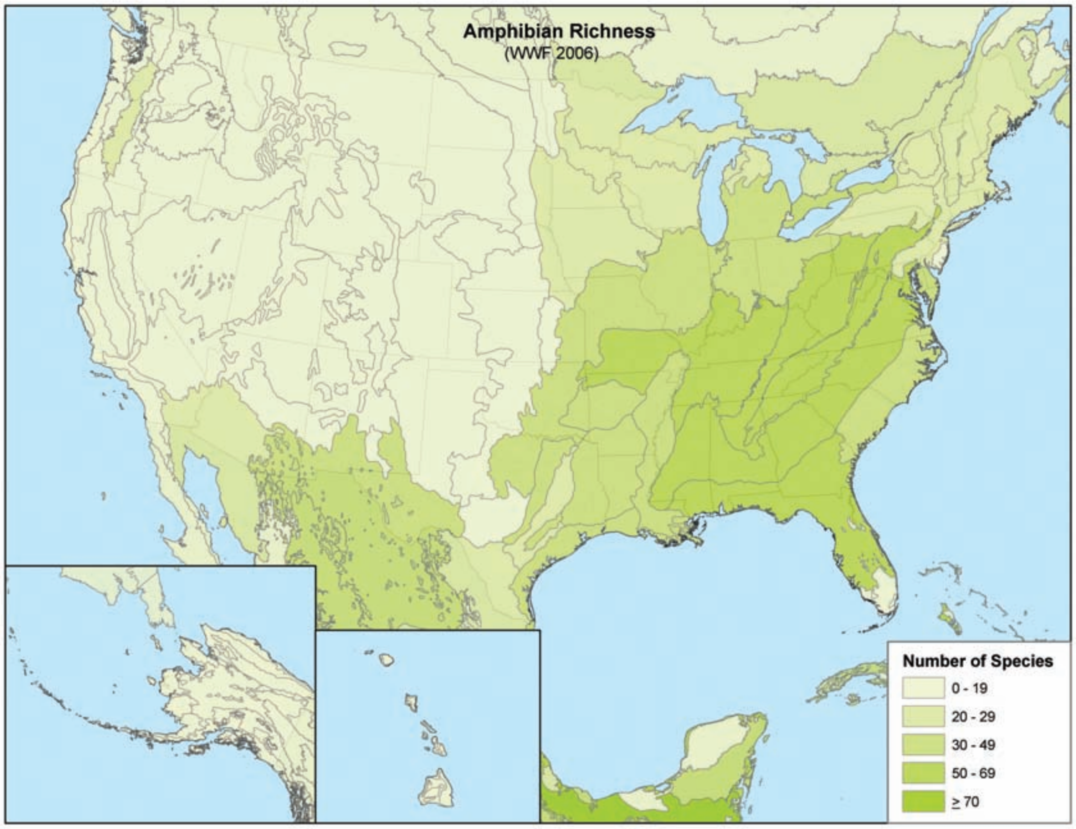

Figure A7—Amphibian species richness by WWF Terrestrial Ecoregion.

e. Species Endemism by Taxa

The Species Endemism by Taxa data set represents the number of endemic mammal, bird, reptile, and amphibian species (figures A8, A9, A10, and A11). The data set is available by WWF Terrestrial Ecoregion. Endemic species are of particular concern because conservation options are so geographically limited (World Wildlife Fund 2006b).

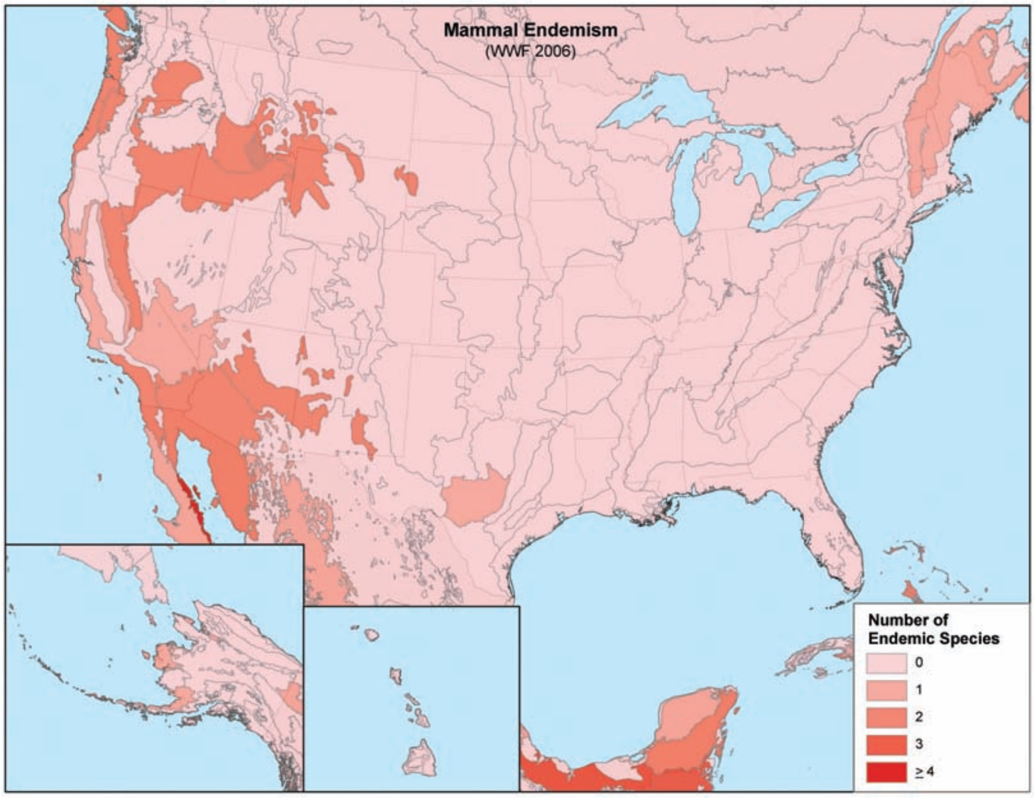

Figure A8—Mammal endemism by WWF Terrestrial Ecoregion.

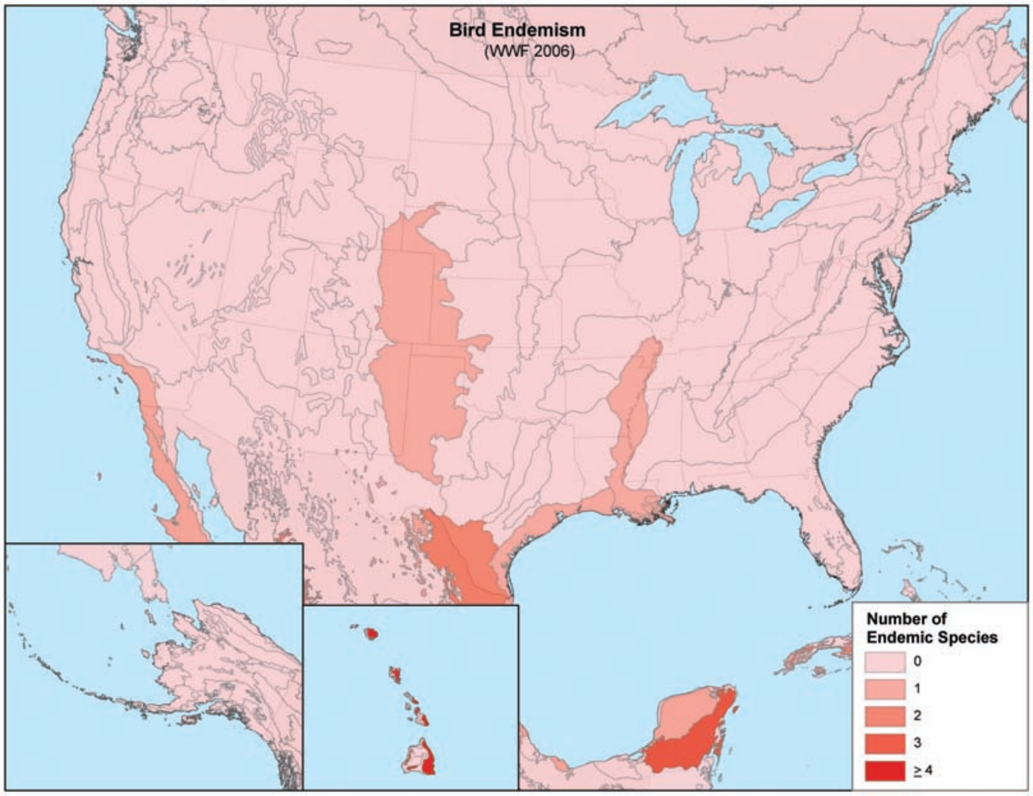

Figure A9—Bird endemism by WWF Terrestrial Ecoregion.

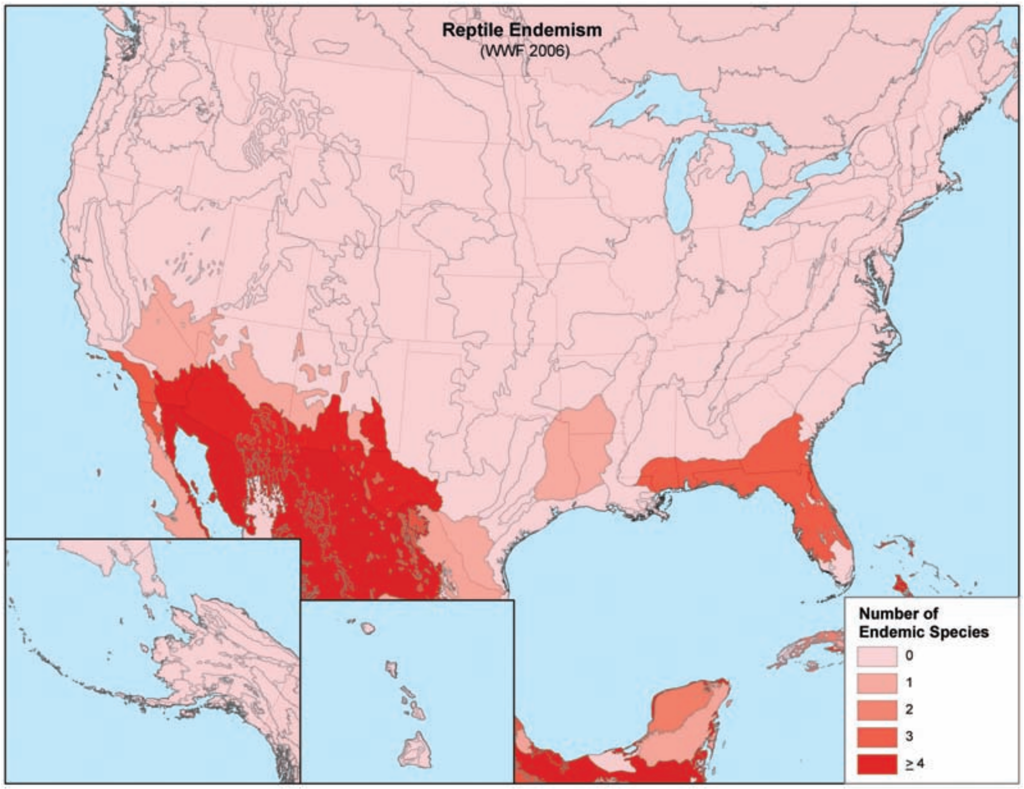

Figure A10—Reptile endemism by WWF Terrestrial Ecoregion.

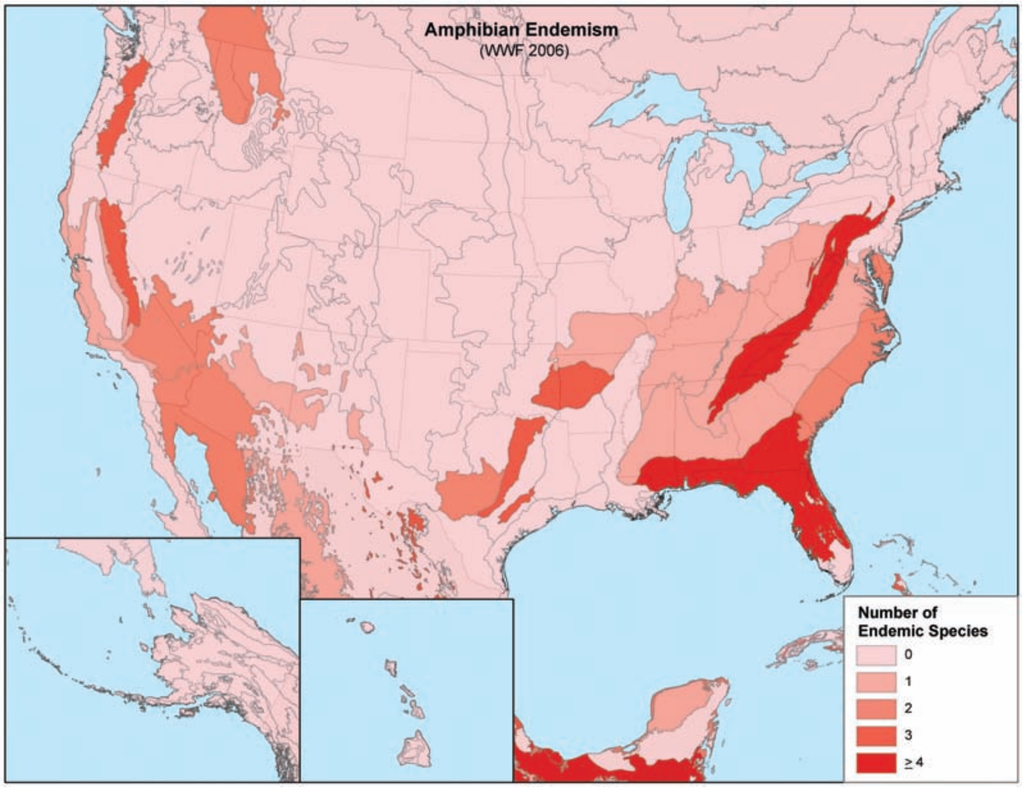

Figure A11—Amphibian endemism by WWF Terrestrial Ecoregion.

f. Species Rarity by Taxa

The Species Rarity by Taxa data set represents the number of mammal, bird, reptile, and amphibian species on the IUCN Red List of Threatened Species by WWF Terrestrial Ecoregion (figures A12, A13, A14, and A15). The "threatened" designation includes species listed as Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) (World Wildlife Fund 2006b).

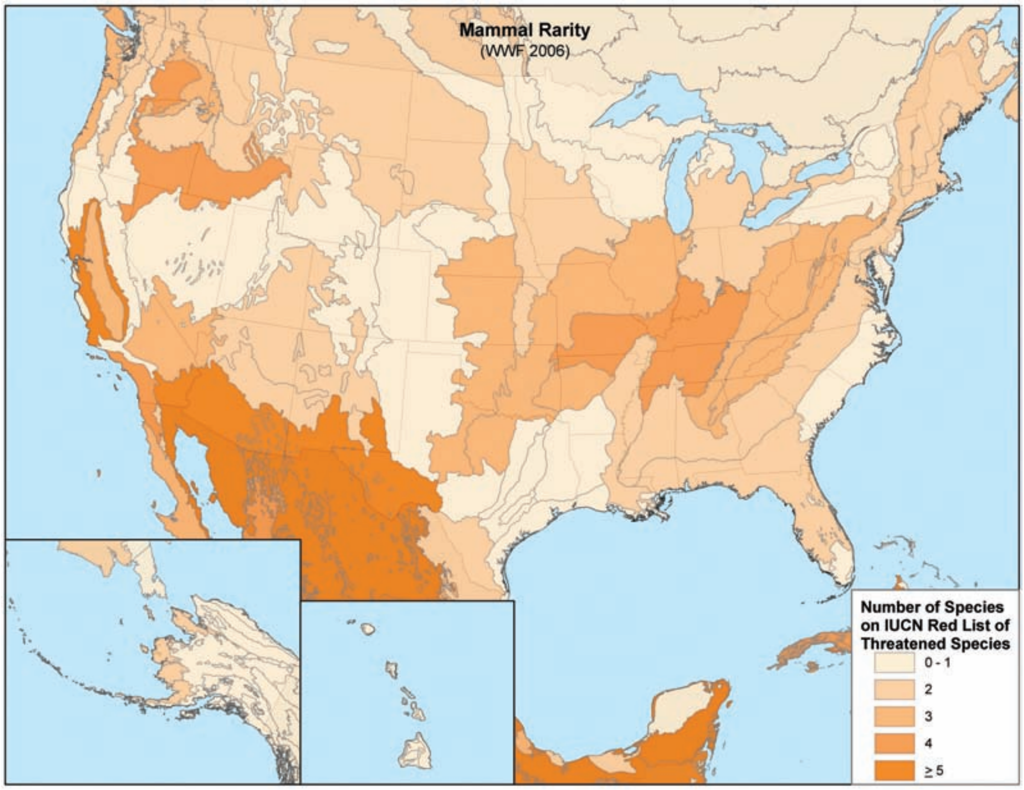

Figure A12—Number of mammal species on the IUCN Red List of Threatened Species by WWF Terrestrial Ecoregion.

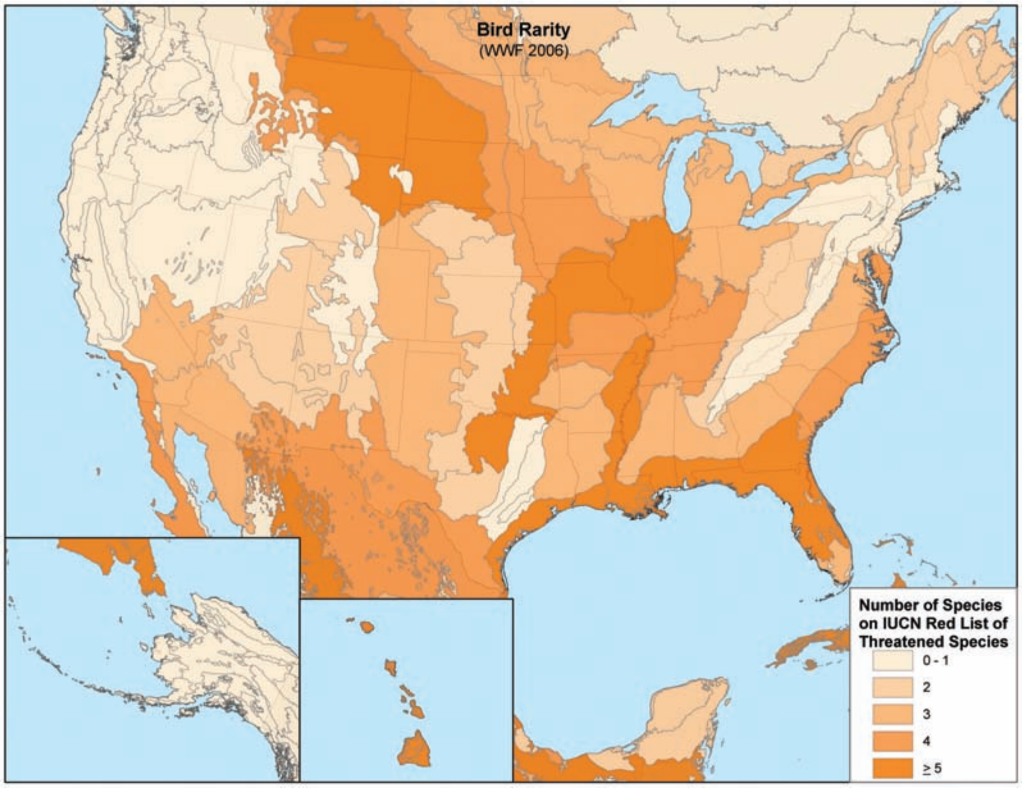

Figure A13—Number of bird species on the IUCN Red List of Threatened Species by WWF Terrestrial Ecoregion.

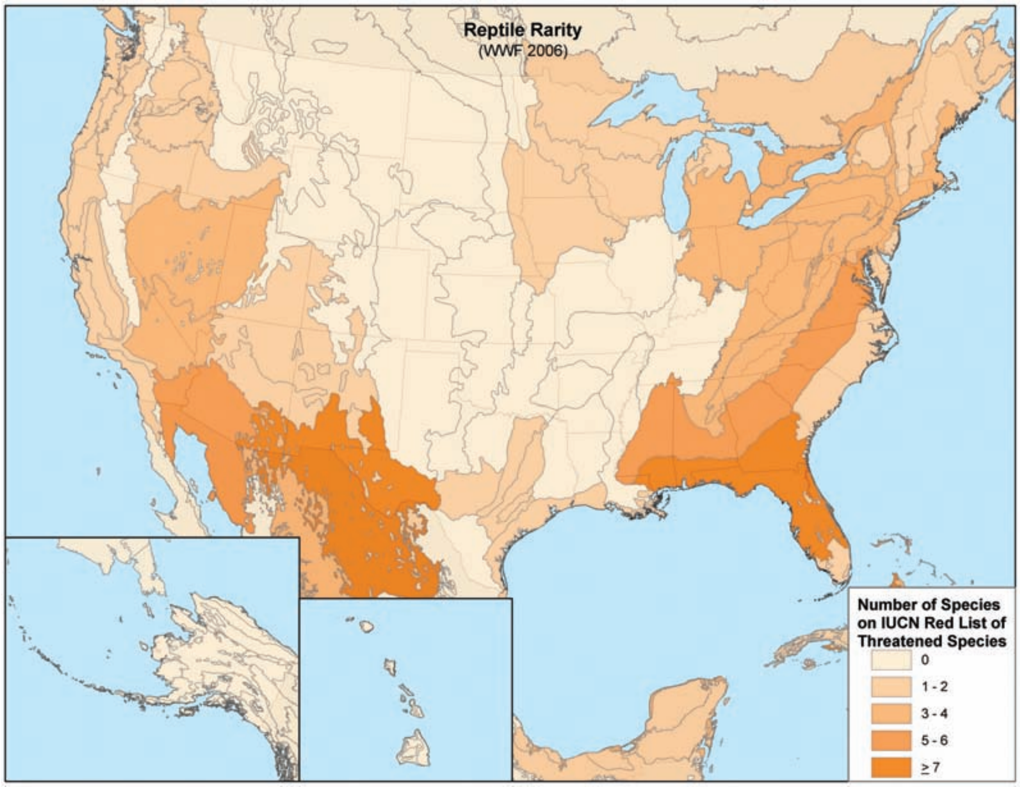

Figure A14—Number of reptile species on the IUCN Red List of Threatened Species by WWF Terrestrial Ecoregion.

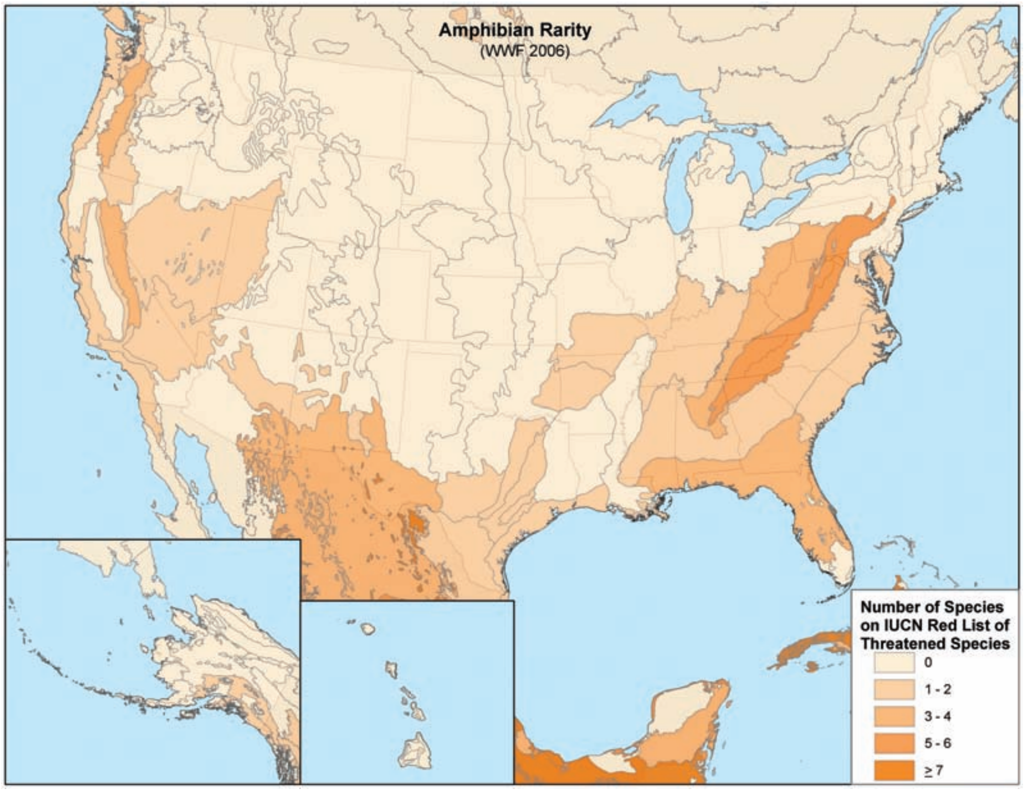

Figure A15—Number of amphibian species on the IUCN Red List of Threatened Species by WWF Terrestrial Ecoregion.

g. Centers of Plant Diversity

World Wildlife Fund and International Union for Conservation of Nature identified centers of plant diversity (figure A16) using the following criteria. The sites had to be either particularly species-rich or contain a large number of endemic species. Mainland centers had to contain at least 1,000 vascular plant species (estimated), with 100 or more endemics, and the island centers had to contain at least 50 endemics or at least 10 percent of the flora had to be endemic. To be considered, sites also had to contain: an important gene-pool of plants having value, or potential value, to humans; a diverse range of habitat types; a significant proportion of species adapted to special soil conditions; and must be under threat of large-scale devastation (Davis and others 1995).

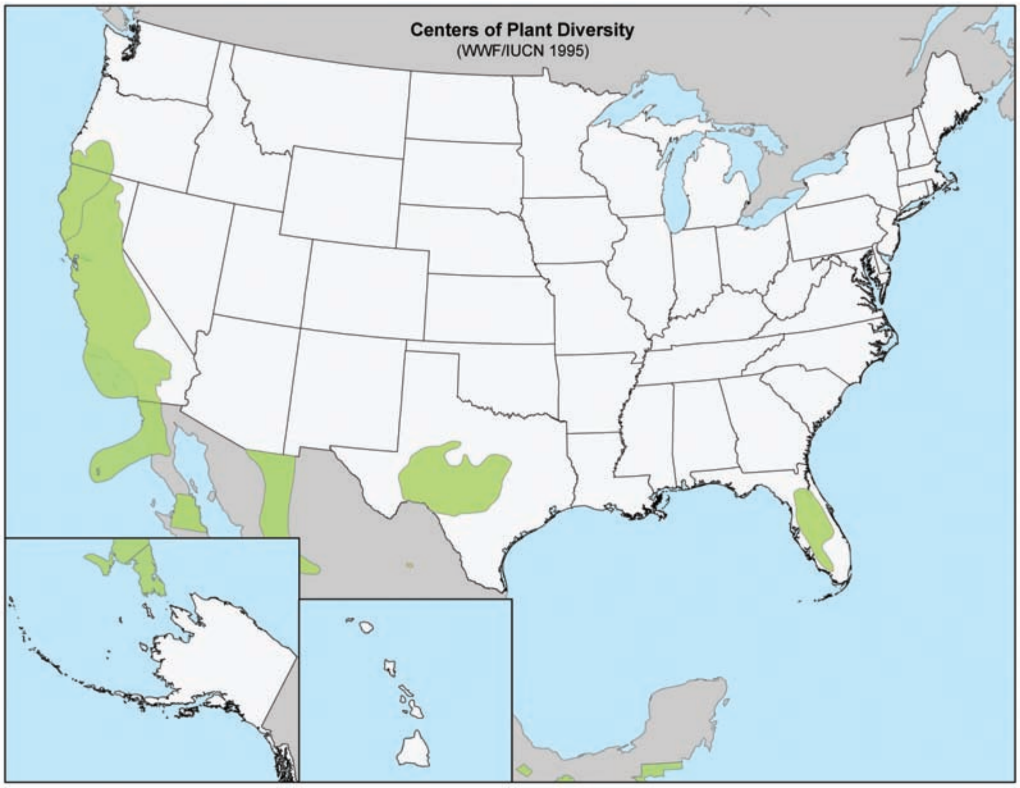

Figure A16—Plant diversity centers.

h. Forest Intactness

Relative forest intactness is spatially represented in this data set for 39 forested ecoregions of the coterminous United States (figure A17). Forest intactness was mapped within “landunits” that were defined by highways and urban areas that contained more than 50,000 people. For each landunit, road density was calculated as well as a suite of class and landscape level fragmentation metrics, including class area, percentage of landscape, total core area index, and mean nearest neighbor, from which an overall relative forest intactness score was derived. The data set from the Conservation Biology Institute identifies remaining, relatively intact forest and good regional restoration candidates (Heilman and others 2002).

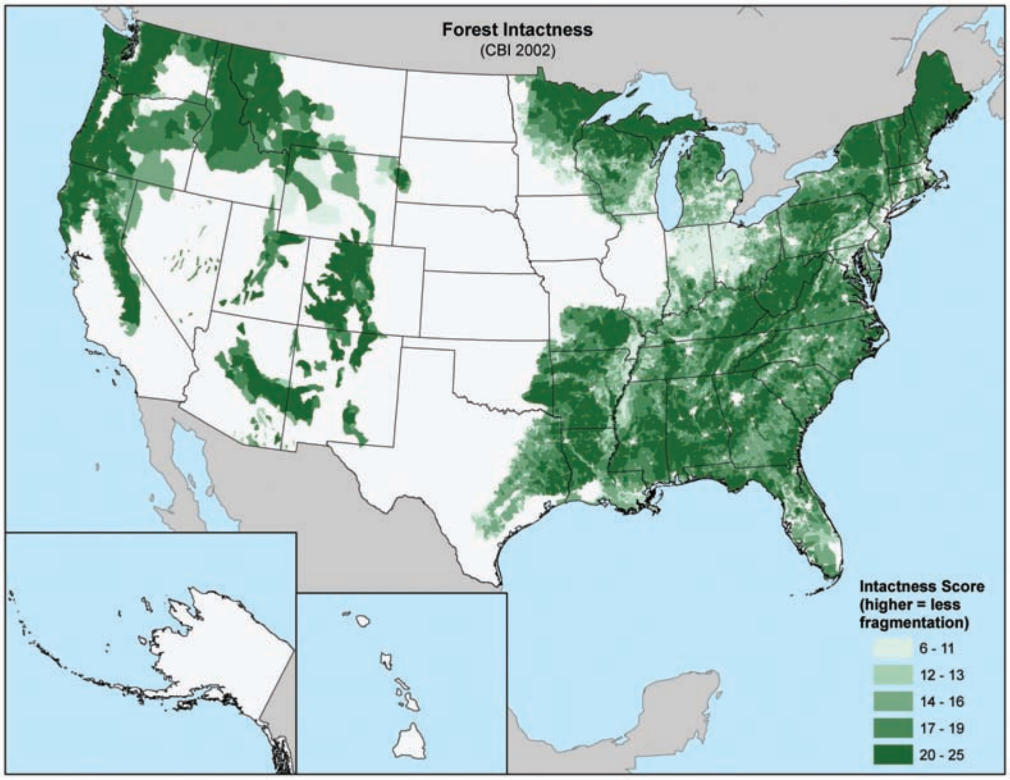

Figure A17—Forest intactness.

i. Critical Watersheds for Conserving Aquatic Biodiversity

NatureServe identified the 15 percent of the U.S. watershed areas that will conserve the greatest proportion of at-risk freshwater fish and mussel species (www.natureserve.org/publications/preciousHeritageCharts.jsp) (figure A18; Stein and others 2000).

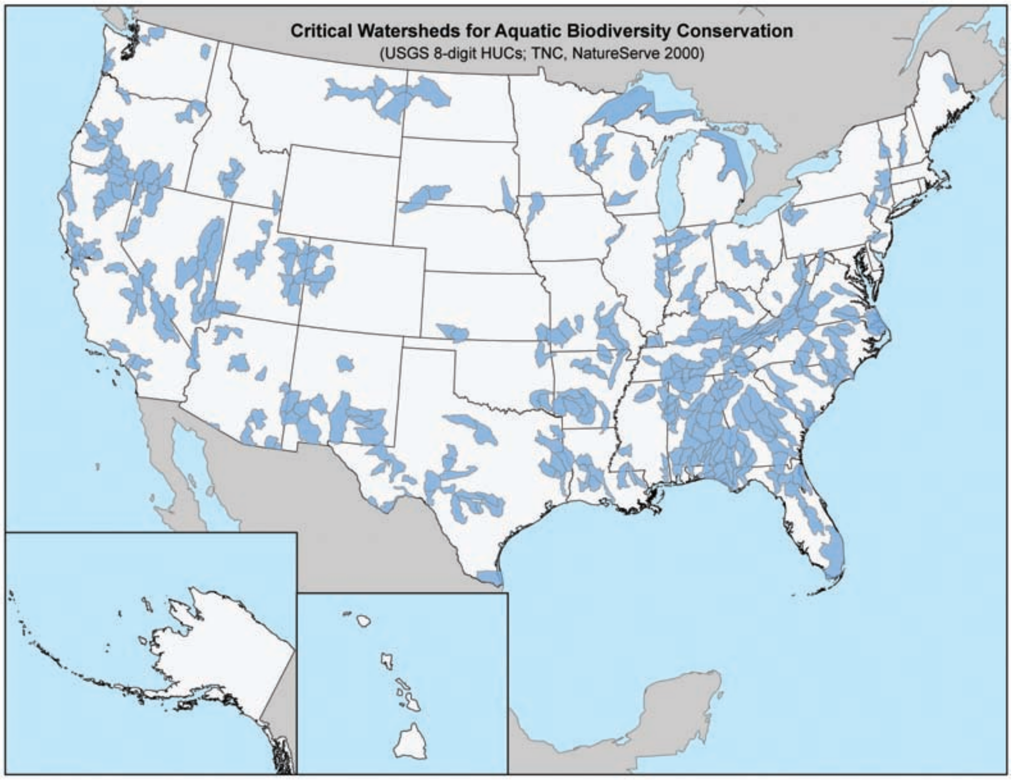

Figure A18—Critical watersheds for aquatic biodiversity conservation.

j. Crayfish Rarity

NatureServe identified USGS 8-digit Hydrologic Unit Codes (HUC) with known occurrences of G1-G3 (globally critically imperiled, imperiled, or vulnerable) crayfish species (figure A19). Half of U.S. crayfish species are at risk (Stein and others 2000).

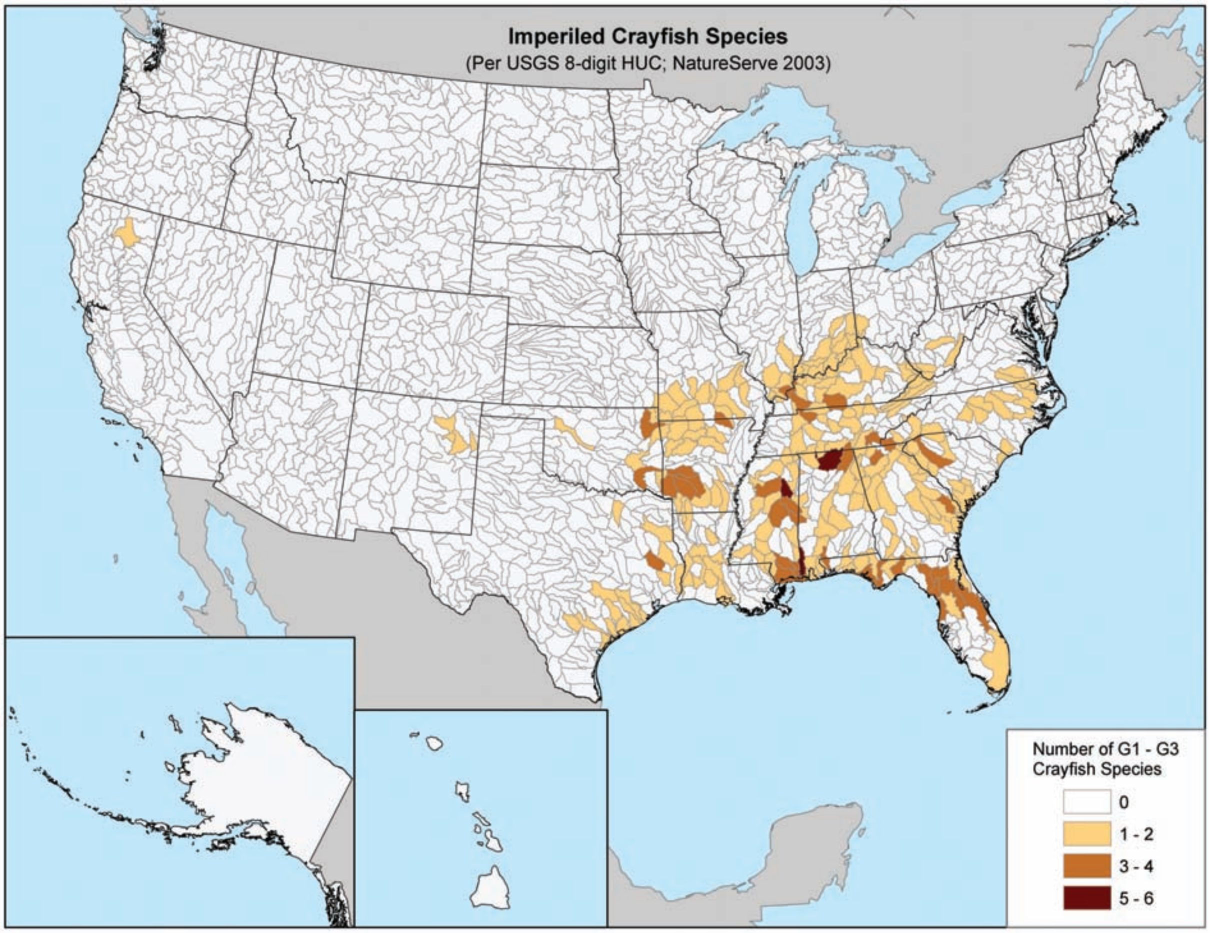

Figure A19—Number of imperiled crayfish species by USGS 8-digit HUC.

k. Mussel Rarity

NatureServe identified USGS 8-digit HUCs with known occurrences of G1-G3 (globally critically imperiled, imperiled, or vulnerable) freshwater mussel species (figure A20). Two-thirds of U.S. fresh water mussel species are at risk (Stein and others 2000).

l. Imperiled Species by Equal Area Hexagon

NatureServe identified EPA EMAP hexagons (160,000 acres) with known occurrences of G1-G2 (globally critically imperiled or imperiled) species (Stein and others 2000). Not only is the resolution of this data set too coarse, but the content is outdated (figure A21).

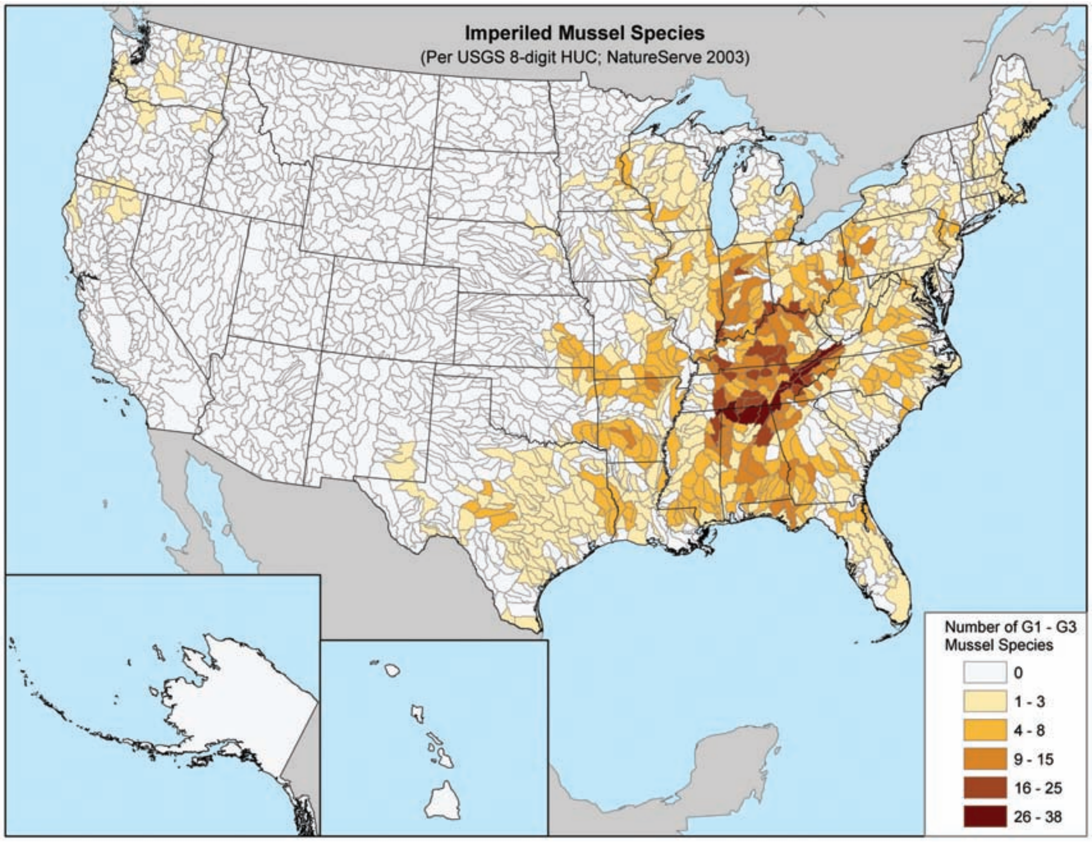

Figure A20—Number of imperiled mussel species by USGS 8-digit HUC.

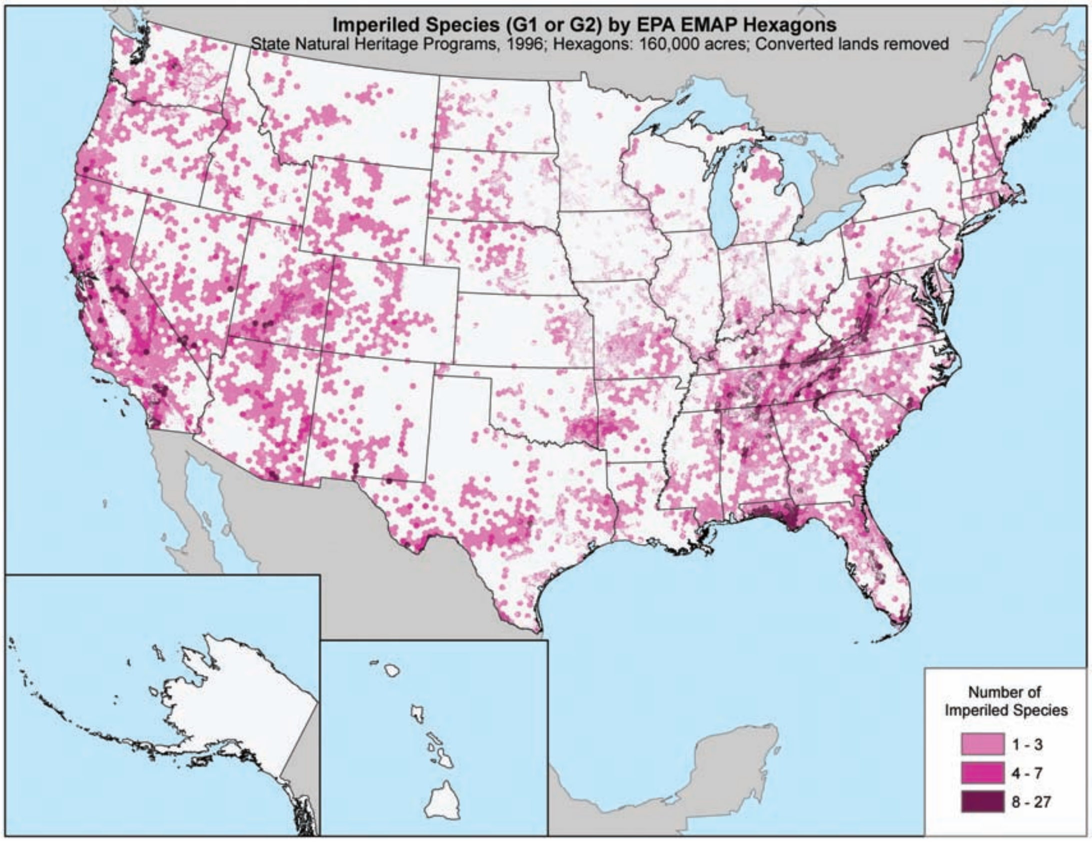

Figure A21—Number of imperiled species by EPA EMAP hexagon.

2. Map extent is incomplete

a. **Priority Conservation Areas**
The Nature Conservancy identified conservation interest areas that represent landscapes of mixed land use where compatible activities should be integrated properly to allow ecosystems to sustain an adequate level of functional stability and to provide connecting habitat corridors for the movement of species and maintenance of biological diversity. These areas are a mix of existing public land and private conservation areas, recommended acquisition areas, and areas of conservation interest where less than fee simple techniques should be used in addition to purchasing. Data are available for the Western, Northwestern, Northeastern, and Southern United States; while CA, HI, AK, and the Midwest are missing (The Nature Conservancy 2007; The Nature Conservancy, 2009 n.d.).

b. **National Wetlands Inventory**
The National Wetlands Inventory identifies type, size, and location of wetlands and deepwater habitats in the United States. Full digital availability exists for only 26 states with sporadic extent (USFWS 2009).

c. **Species Richness layer creation from GAP Vertebrate data**
Species richness data are available by EMAP hexagon or 30- by 30-m grid for 26 states. Twenty-three states have distribution data for creation of richness grids/hexagons, and data are unavailable for two states (USGS n.d.).

d. **Underrepresented Plant Communities from GAP Landcover data**
GAP Landcover regionally updated data sets are available for the Southwest (NV, UT, CO, NM, and AZ), Northwest (OR and WA), and Southeast (KY, TN, MS, AL, FL, GA, SC, NC, and VA). Original regional data sets are available for the Northeast (VT, NH, CT, MA, RI, MD, DE, and NJ). The remaining 25 states must be downloaded individually from original GAP data. Classes differ between all 31 layers, and "underrepresented" plant classes must be defined. All data grids must be reclassed and edges must be matched/joined. No data exists for AK (USGS n.d.).

3. Inappropriate to assign response functions

The following conservation data sets, by their nature, are inappropriate for the fire model as these lands are valued for their lack of human management. Natural disturbance regimes (including fire) are also highly valued in these landscapes making them poor candidates for the fire risk modeling.

a. **Frontier Forests**
Frontier forests, mapped in 1997 by Global Forest Watch and the World Resources Institute, are defined as being primarily forested; of sufficient size to support viable populations of the full range of indigenous species associated with that particular forest ecosystem given periodic natural disturbance episodes; and exhibiting a structure and composition shaped largely by natural events, as well as by limited human disturbance from traditional activities (figure A22). Frontier forests are relatively unmanaged, are home to most if not all of the species associated with that ecosystem type, are dominated by indigenous tree species associated with that ecosystem type, and are characterized by mosaics of forest patches representing a range of seral stages in areas where such landscape heterogeneity would be expected to occur under natural conditions (Bryant and others 1997). The data set is available from Global Forest Watch (www.globalforestwatch.org).

b. **Last of the Wild**
The Last of the Wild data set was derived from the Human Footprint Dataset (figure A23). The ten largest wild polygons of more than 5 km^2 within each biome by realm are selected and identified (Columbia University 2002).

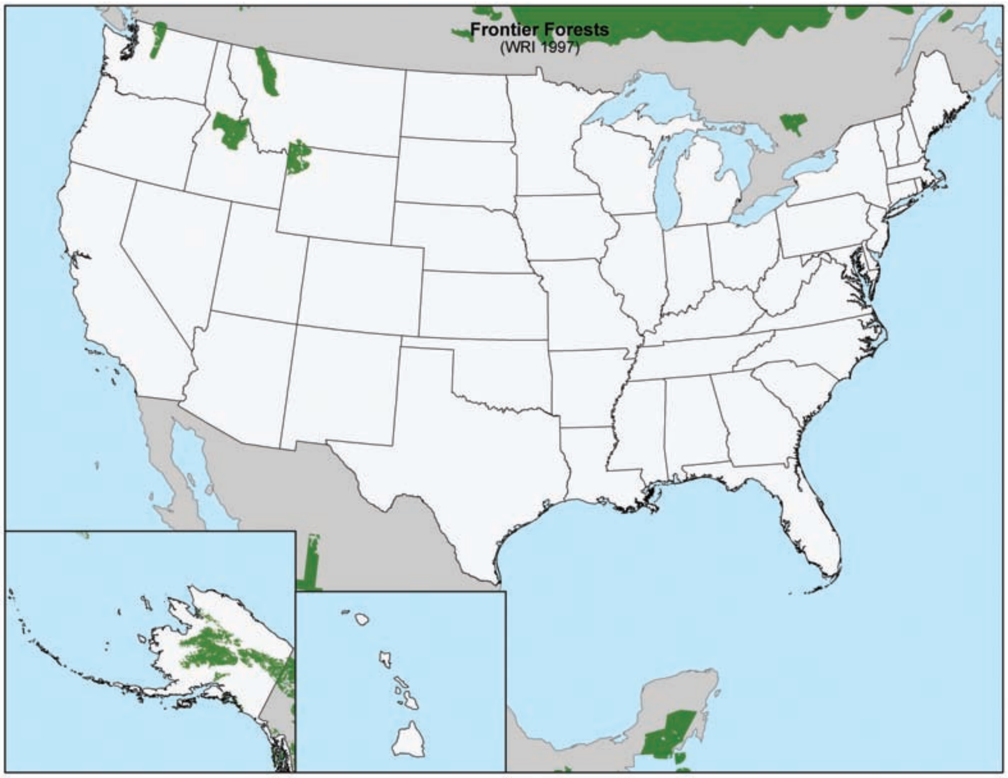

Figure A22—Frontier Forests as delineated by Global Forest Watch and the World Resources Institute.

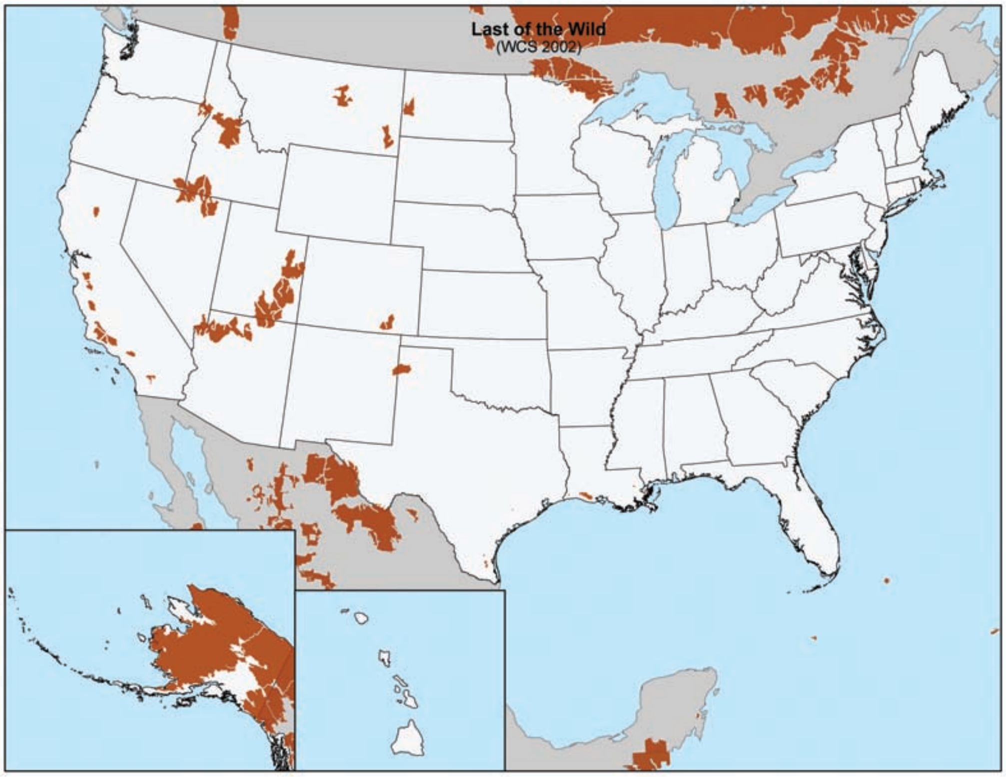

Figure A23—Wildlife Conservation Society's Last of the Wild data set.

c. Top 1 Percent Wild Areas

This data set was derived from the Human Footprint Dataset (figure A24). The top 1 percent of the wild areas within each biome by realm are selected and identified (Columbia University 2002).

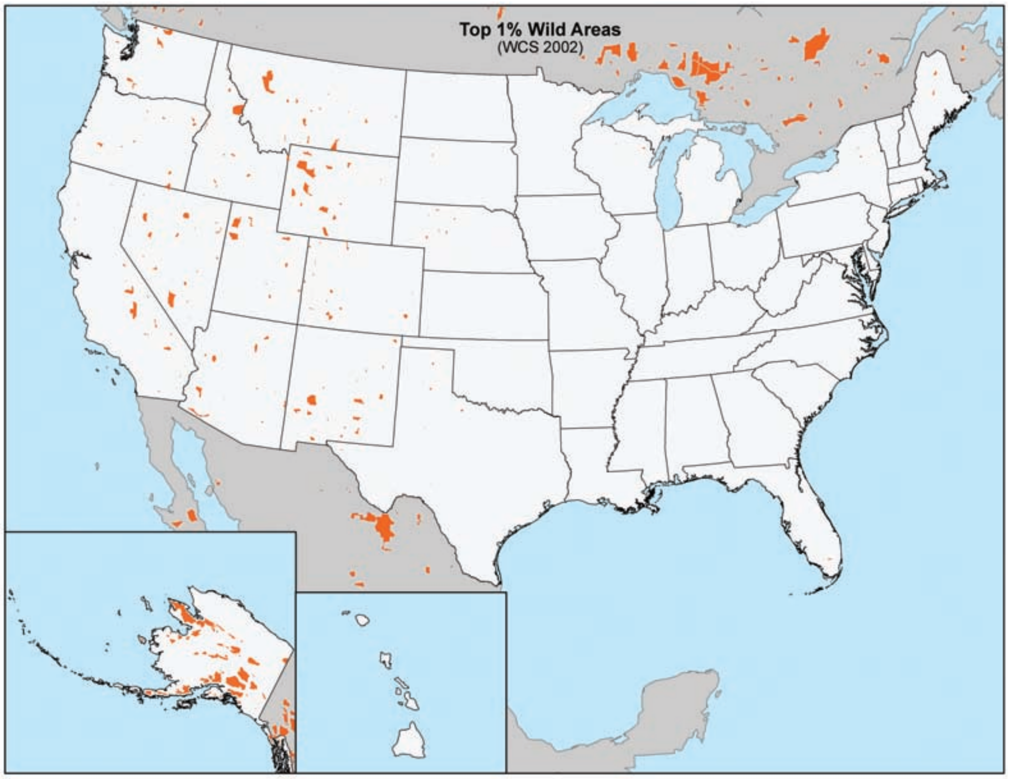

Figure A24—The top 1 percent of the wild areas as delineated by the Wildlife Conservation Society.

4. Viable input with further refinement

a. State Level Natural Heritage Data

Each state has its own Natural Heritage Program that routinely collects field level natural heritage data and manages the findings in spatial databases. NatureServe is the umbrella organization that establishes data collection and maintenance standards and provides national summary information for a variety of planning purposes. Coarse level roll-ups are inappropriate for inclusion in the wildfire risk model; however, the more detailed point data collected at the state level may prove far more promising. For example, the following figures show Federally listed species locations collected by the Oregon Natural Heritage Program (figure A25) compared to similar data organized by EMAP hexagons (figure A26). The enhanced spatial specificity of the former data set provides much greater value for the wildfire risk model; however, several additional considerations need to be examined before proper implementation of the risk model can be achieved.

Natural heritage data sets contain thousands of records for hundreds of species. In order to assign meaningful response functions, each species of interest would need to be examined individually. There is no one response function that applies to all rare species—responses to fire intensity would need to be addressed on a species-by-species basis. It may be possible to “bundle” species into response function groups (e.g., these six species share the same response to fire), but doing so would require an additional post-processing step after each species of interest was assessed. Regardless of whether species were treated individually or in groups, a short-list of species would need to be developed.

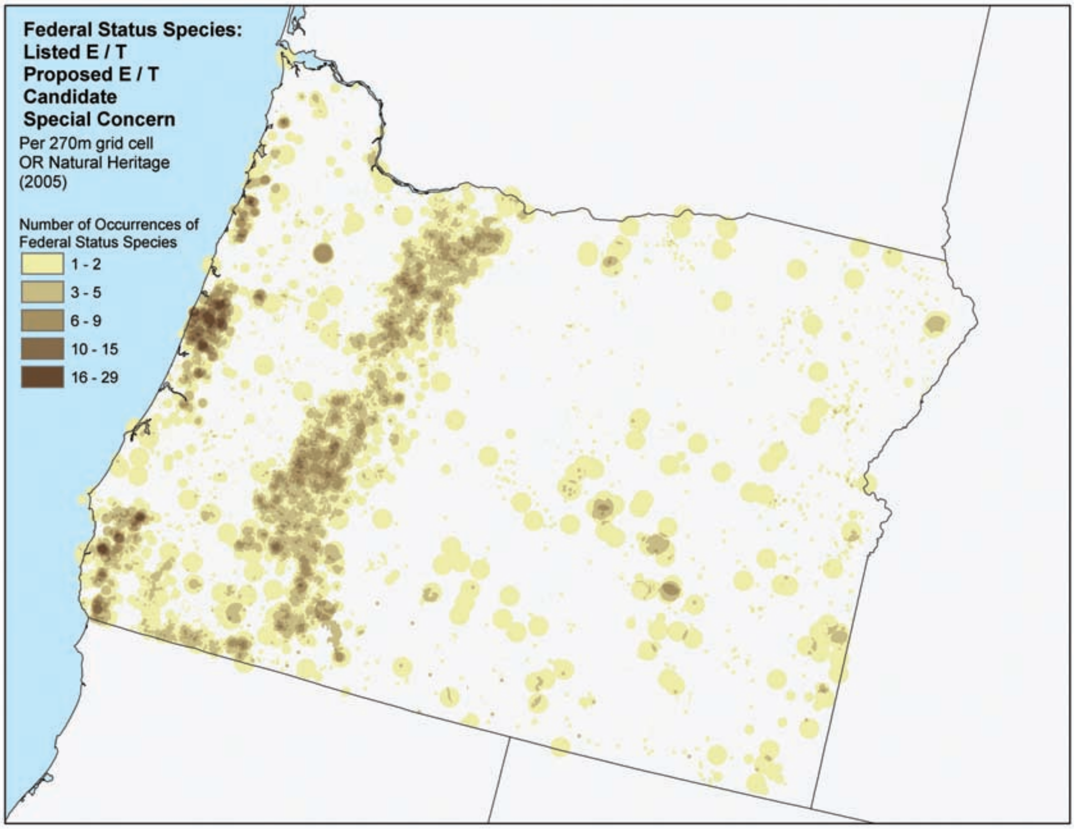

Figure A25—Number of Federal status species records in the Oregon Natural Heritage data set per 270-m grid cell for Oregon.

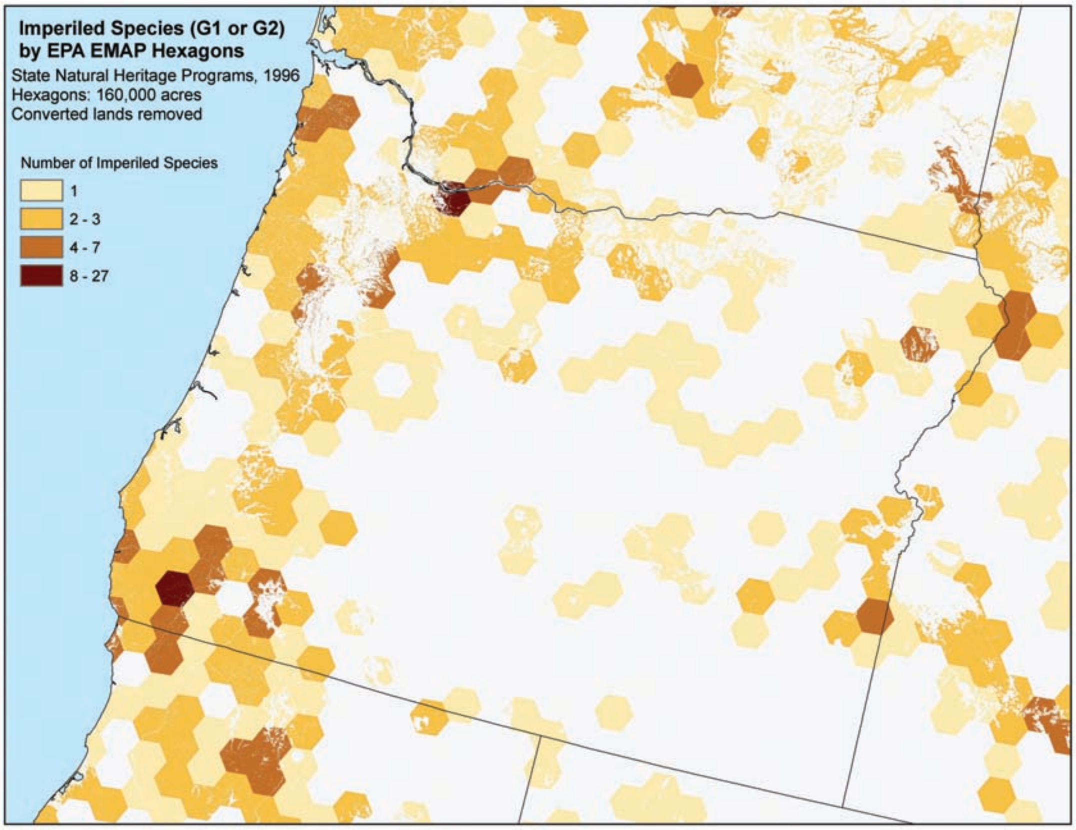

Figure A26—Number of imperiled species by EPA EMAP hexagon for Oregon.

Another factor to consider is the data format used by each state heritage program. Even though there are data collection standards being implemented across the country, there are several different ways individual heritage programs publish these data. Some provide actual point locations, others summarize point locations over larger geographic areas (e.g., regular grid array of some size), and still others represent their data using different sized circles around point locations to denote level of precision. These different approaches would need to be brought together into a single file format, which would be somewhat tedious if data were collected on a state-by-state basis and then processed. A far superior alternative would be to work directly with NatureServe to provide the service required for this component in the risk model. NatureServe was founded to provide the overarching support for state heritage programs and to provide these types of services.

b. Protected Lands

Using the CBI-PAD version 4.5 (Conservation Biology Institute 2008), GAP Status 1 and 2 lands were considered for inclusion in the wildfire risk model (figure A27; DellaSalla and others 2001). However, after closer examination of the attributes currently available, it is difficult to assign response functions to these polygons. Complicating this exercise further are the definitions of these two GAP categories:

- GAP Status 1: lands having permanent protection from conversion of natural land cover and mandated management plans to maintain a natural state, and maintenance of natural disturbance events.
- GAP Status 2: lands having permanent protection from conversion of natural land cover and mandated management plans to maintain a primarily natural state, but allowing for management practices that degrade the quality of existing natural communities, including suppression of natural disturbances.

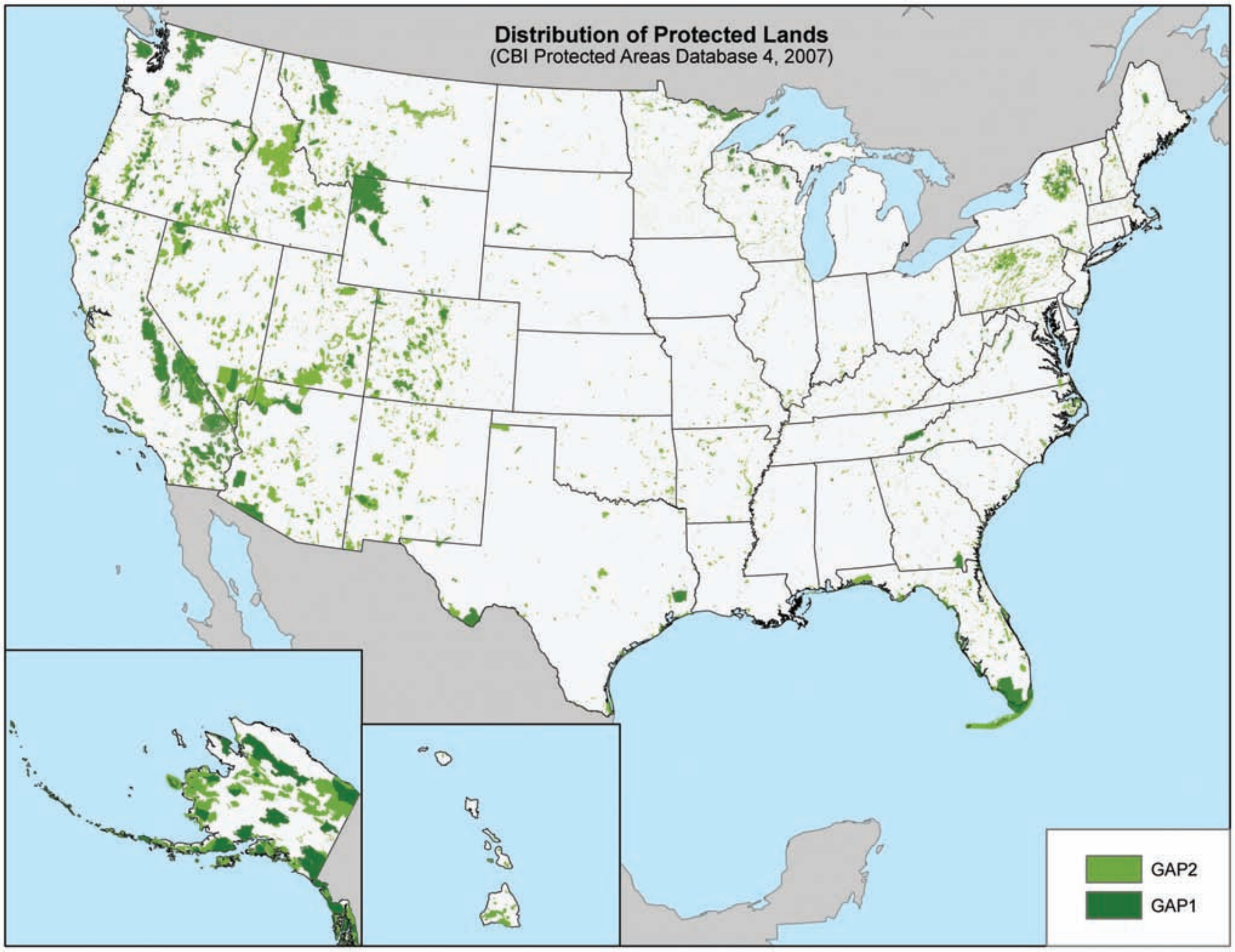

Figure A27—Protected lands (with GAP Status 1 or 2) from the CBI-PAD.

Regardless of the protection status, the fact that these lands are protected does not easily translate into specific response functions in a wildfire risk model. Risk is a function of what is on the ground, not its particular management designation. This data set may provide some information about rare or vulnerable ecological values (e.g., botanic areas and research natural areas), but these designated places are small and difficult to assess without additional information. Not all botanic areas, for example, would be characterized by the same response functions. It would depend upon what plant communities are present.

The new United States Protected Areas Database (PAD-US) will likely expand its attribute table to describe more than just management intent expressed through GAP codes. Discussions are underway to provide additional information about various ecological values contained in each mapped polygon. In the not too distant future, the new PAD-US database may provide important inputs to future wildfire risk modeling.

c. Rare and Vulnerable Ecological Systems

Using the existing data on ecological systems mapping for the country (a joint Landfire-NatureServe effort) we considered including these data in the wildfire risk model (USGS 2008; www.natureserve.org/explorer/servlet/NatureServe).

Ecological systems are medium resolution vegetation community types comprised of several association/alliance level communities. The associations (greater than 400 types) that comprise each system are fully described, but their locations are not mapped; therefore, the spatial extent of each is unknown. Those ecological systems that are most rare in the country (covering less than 0.05 percent of the U.S. landcover) were mapped (figure A28). These systems are either naturally rare or rare due to anthropogenic changes.

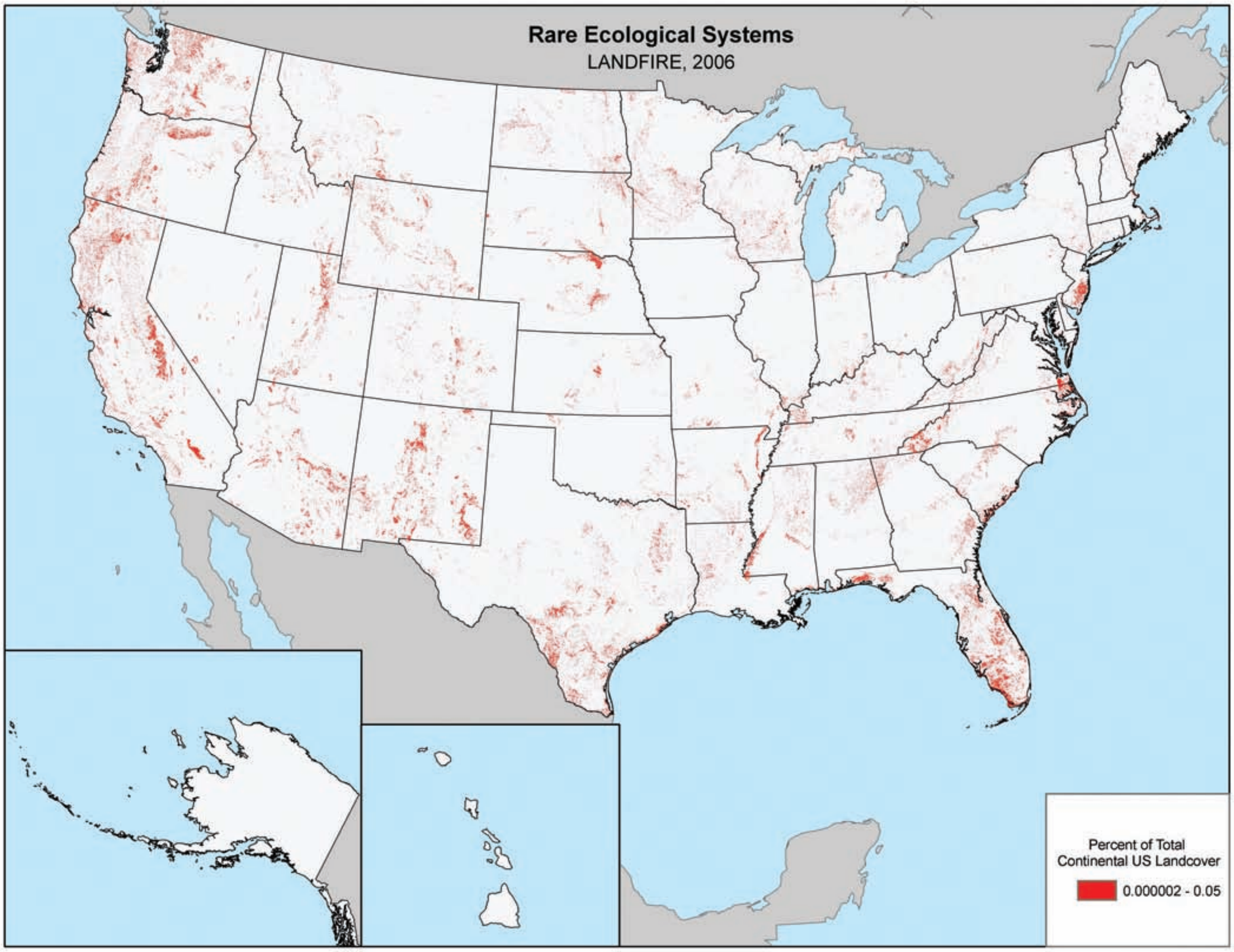

Figure A28—Rare ecological systems.

We could also query those ecological systems that contained high numbers of rare plant communities, but the exact location and extent of a given system could not be delineated. For example, system A has 10 member associations, eight of which are G1-G2. System A would be considered to have a high percentage of imperiled associations (80 percent). However, the spatial extent of the eight imperiled associations is unknown: they may cover only 10 percent of the system's mapped extent or 90 percent (figure A29).

By combining these two primary inputs, it may be possible to map areas that cover little area and contain high levels of imperiled plant communities. A follow-up step would evaluate the systems of highest concern in terms of response functions.

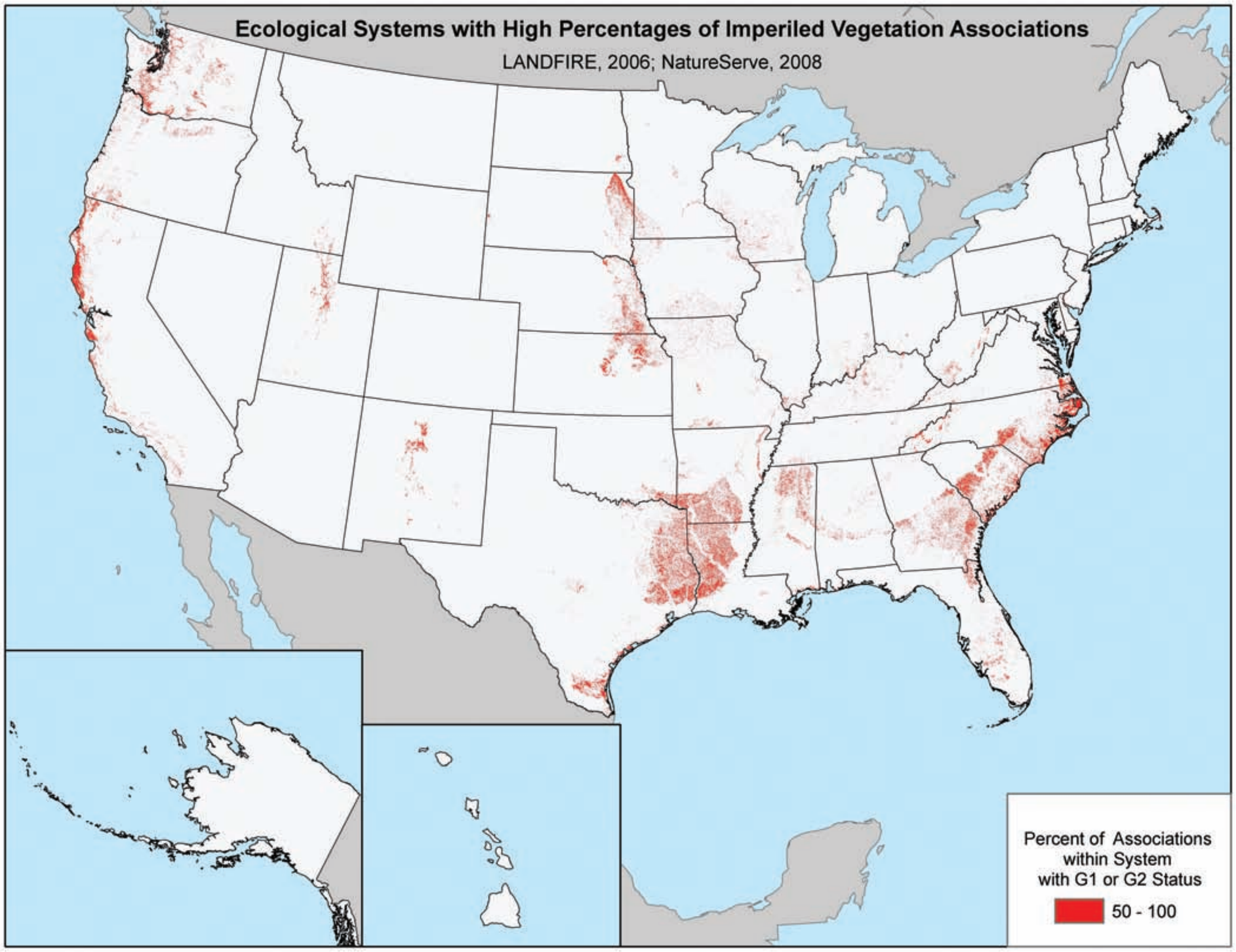

Figure A29—Ecological systems with high percentages of imperiled vegetation associations.

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Appendix B: Modules of the Risk Assessment Model

Import FPA 2 Raster

This module reads in the text files produced by FSim, which contain probabilities of wildland fire by flame lengths under specified fuel and weather conditions analyzed at the FPU level (see figure 1 in main text for a map of the Oregon FPUs, or visit http://www.fpa.nifc.gov/Implementation/TechInfo/Docs/SizeA_FPU_Basemap_20081231.pdf for the national FPU map). The text files contain (X,Y) coordinates and six flame lengths—F1 through F6. Point locations in the files are on a 270-m grid. These points are converted to an intermediate database (dbf) file; in this conversion process, the six flame length fields are collapsed into four flame length classes (FLCs)—L, M, H, and VH:

L = F1 (less than 4 ft)
M = F2 + F3 (greater than 4 to 8 ft)
H = F4 + F5 (greater than 8 to 12 ft)
VH = F6 (greater than 12 ft)

The database file is converted to an intermediate (X,Y) event table. A raster file for FLC for the FPU is then created (FPU_FLC).

FLC_HVR

The output files from the *Import FPA 2 Raster* module contain FLC values for all pixels in the FPU; the *FLC_HVR* module masks these input FPU_FLC files so that only those pixels corresponding to the highly valued resources (HVR) are output. The HVR raster files have been processed so they correspond properly with the 270-m grid of the FPU_FLC file. The input FPA files contain pixel values outside the FPU boundary, so an additional mask is applied in this module to output only pixels inside the FPU boundary.

BL_Calc

For each HVR, an initial value (IV) of L, M, H, or VH was assigned (see Categorizing Highly Valued Resources in main text). This final module calculates the percent change in IV for the HVR pixels based on a fire event of a particular intensity (FLC). This percent change is calculated by multiplying a coefficient for each FLC with the FLC_HVR pixel value (i.e., the reclassed FPA flame length values). These coefficients are obtained from a user-defined response function (Benefit/Loss (BL) number that the module uses to reference a table with the coefficient values see (table 3 in main text). Output from this step of the module is a raster file of percent change pixels for the HVR for each of the FLCs. These output pixels are then summed by HVR, producing a raster file of total percent change for the HVR across all FLCs. The third output is a sum of these total percent change values for all HVR assigned to a particular initial HVR category value (see figure 4 in main text). This module was also engineered to run as an ArcToolBox Model with a user-friendly interface.

Appendix C: Efforts to Improve HVR Data Sets

Identification of Key Data Sets to Inform Fire and Fuel Management Decisions

As previously discussed, efforts by Federal wildland fire agencies are underway to identify agency leads, prioritize resource data layers, and in some cases, appropriate financial resources to address the need for nationally consistent natural resource data layers. The development of the Wildland Fire Decision Support System (WFDSS) Geographic Information System (GIS) Team is one step toward this end. The GIS Team consists of interagency personnel involved in fire-related GIS and/or decision support management. Identified geographic area GIS personnel and WFDSS Geographic Area Editors will work to collect data and coordinate with interagency individuals to incorporate data to a larger geographic extent. As this effort begins to unfold, the team will be identifying priority data layers to serve as a representative model for how this process will take place. The wildland fire community would be well-served by appointment of a GIS or Data Management Specialist at each Geographic Area Coordination Center (GACC) to facilitate this critical data effort and ensure project success.

The first steps following identification of priority data layers will be to develop data standards and request data input from the appropriate agencies along particular themes. For example, within the theme of threatened and endangered species habitat, certain species will be identified whose terrestrial range encompasses the administrative authority of multiple land management agencies. It will be recommended to each agency to collect the data of all smaller management units within their management jurisdiction or geographic area. From this collection, areas of no-data will be identified and polygons will be attributed in the corresponding records. Once this level of accuracy is assured within a particular geographic area and/or agency, these data can be combined with resulting layers from neighboring agencies.

Additionally, Forest Service Fire and Aviation Management GIS have developed a contract with ESRI to design an enterprise geodatabase that will house interagency, nationally consistent GIS data with national coverage (where possible). These data will be accessible for many projects requiring national geospatial data sets that are otherwise unavailable. The specific intent of this geodatabase is to avoid future duplication of data efforts within Federal agencies and to allow for easy access and enhanced development of these data. Although the platform for this project has been established, the development will be ongoing and data (especially of more challenging data sets) may not be available for years.

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of the National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals. Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications may be found worldwide.

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