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Forest Health Monitoring in the Interior West

A baseline summary of forest issues, 1996–1999

Research Summary

Although *forest health* may be difficult to define and measure, a strong demand exists for assessment of forest conditions at various state, regional, and national scales. Forest Health Monitoring (FHM) is a national program designed to measure the status, changes, and trends of forest conditions annually. This report presents a broad view of forest health issues affecting the Interior West region of Montana, Idaho, Wyoming, Utah, Nevada, Colorado, New Mexico, and Arizona. We found that the forests of the Interior West have changed considerably in the past century. What is more difficult to assess is whether humans have promoted change that is irreversible, or whether the change we see in the forested landscape is within healthy bounds. Discussions of forest health and forest cover change, the developed and wildland interface, insect and disease disturbances, watershed health, biodiversity, and air quality comprise the body of this report.

This initial report sets the stage for more in-depth reports on forest health in the Interior West by introducing the FHM program, defining "the forest" regionally, discussing prominent issues, and displaying summary FHM data taken from 1996–1999. A website address is provided on the inside back cover of this report to solicit reader suggestions for improving future FHM reports.

Keywords: regions, biodiversity, disturbance, ecology, long-term, large-scale, watersheds, air quality, insects, disease, wildland interface, aspen, ecosystems

The Authors

Paul Rogers is an Ecologist in the Interior West Resource Inventory, Monitoring, and Evaluation Program at the Rocky Mountain Research Station, Forestry Sciences Laboratory, Ogden, UT. His primary responsibility is to conduct field work and report on Forest Health Monitoring efforts in the Interior West. He holds a B.S. degree in geography from Utah State University and an M.S. degree in geography from the University of Wisconsin-Madison. Since beginning his career with the Forest Service in 1987, he has specialized in conducting large-scale field and remote vegetative surveys.

David Atkins is the Forest Health Monitoring Coordinator for the Northern and Intermountain Regions of the USDA Forest Service. He is a forest ecologist in Forest Health Protection, State and Private Forestry, located in Missoula, Montana. His interest is in sustainable forest management for a broad spectrum of values. He has a B.S. degree in Forest Science from Humboldt State University and an M.S. in Forest Ecology from the University of Montana.

Michelle Frank is the Forest Health Monitoring Coordinator for the Rocky Mountain Region of the Forest Service. She is an entomologist working in the Forest Health Management staff unit of Renewable Resources, located in Denver, Colorado. She has a B.A. degree in biology from Marietta College, a B.S. degree in forestry from the University of Michigan, and an M.S. degree in entomology from the University of Maine.

Douglas Parker is the Assistant Director of Forestry and Forest Health, USDA Forest Service, Forest Health Protection, State and Private Forestry, located in Albuquerque, New Mexico. His current duties include providing technical assistance to federal, state, and private managers on forest health and pesticide-use management and coordination. His work interest is the development of herbicide techniques for use in Integrated Vegetation Management programs for the control of invasive plants and noxious weeds.

Forest Health Monitoring in the Interior West: A baseline summary of forest issues, 1996–1999

Paul Rogers
David Atkins
Michelle Frank
Douglas Parker

Photos by Paul Rogers unless otherwise noted

USDA Forest Service, Rocky Mountain Research Station,
in cooperation with USDA Forest Service, State and Private Forestry,
Regions 1– 4

Contents

Forest Health Highlights

Forest Health Monitoring (FHM) has been active in this region since 1992. This is the first regional assessment under the FHM program for the Interior West. It would be difficult to present a complete health assessment with first-time measurements. Instead we focus on issues affecting change on the forested landscape. This baseline report should be used as a benchmark for comparing future regional assessments. The following highlights represent the prominent messages presented in this document.

- FHM plot data appear to support the hypothesis of regional aspen decline. Fire suppression, livestock grazing, and ungulate browsing favor encroachment by more shade-tolerant conifers where aspen once dominated.

- A pressing regional forest health issue is the rapid expansion of human development near forests. Urban and rural development in or near forested areas brings forth a unique set of concerns, such as loss of forest area and wildlife habitat, wildlife-human encounters, fire protection, fire starts, and forest thinning for life and property protection.

- Insect and disease outbreaks cycle through Interior West forests. Subalpine fir decline and western spruce budworm are on the rise. Infestations may threaten or regulate forests depending on human values and proximity to commercial or residential forests.

- Upland changes in vegetation types and density have drastically altered some watersheds, notably in more arid parts of the region. Forest health directly affects watershed conditions, including water quality, by regulating the amount, timing, and sedimentation of runoff.

- Regional forests are naturally diverse, from northern Idaho to the Sonoran chaparral. However, people continue to alter biodiversity by introducing exotic plants and animals and by damaging wildlife habitat through forest fragmentation.

- Overall, the air quality in the Interior West is very good. FHM uses vascular plants and lichens as bioindicators of air pollution effects on forests. Some urban areas and point sources have had marked effects on downwind lichen communities surveyed by FHM.

Introduction

The Interior West includes Montana, Idaho, Wyoming, Utah, Nevada, Colorado, New Mexico, and Arizona. Forests cover about 25 percent of this region (Powell and others 1993) and provide important recreational opportunities, wildlife habitat, aesthetic benefits, timber products, and watershed values. In some areas, however, human demands of the past century have taxed the health and sustainability of forest ecosystems. Native and exotic pathogens, air pollution, management practices (including logging, grazing, and fire suppression), and climate change are some of the primary stressors that concern the public, private forest landowners, and land managers. These groups share the responsibility for maintaining long-term viability of the region's forests, but until recently they lacked consistent information that spanned ownership and political boundaries.

Monitoring *all* forest ecosystems is an important first step in fulfilling stewardship responsibilities. Through appraisal of resource conditions, scientists can evaluate change and assess significant trends that may deviate from expected ranges. Forest Health Monitoring (FHM) is a national program designed to determine the status, changes, and trends in forest conditions, (such as species, landscape, and ecosystem health) on an annual basis. The purpose of this initial FHM report is to address the prominent forest health (see sidebar) issues in the Interior West.

Overview of the Forest Health Monitoring (FHM) Program

FHM measures forest change and assesses the resilience of ecosystems to disturbances. The United States Forest Service is working closely with state natural resource agencies, as well as other federal agencies and universities, to implement FHM at four principal levels: Detection Monitoring, Evaluation Monitoring, Intensive Site Monitoring, and Research on Monitoring Techniques. Detection Monitoring is designed to detect changes and make preliminary assessments of significant findings based on systematic data collection. Baseline data (such as tree species tally, crown measures, and lichen sampling) presented in this report were collected at the Detection Monitoring level (see Data Sources). If important unexplained changes are detected, Evaluation Monitoring is activated to investigate the extent and severity of changes. Intensive Site Monitoring involves establishing a small national network of sites for research on ecological processes related to elements of change in specific ecosystem types. Finally, Research on Monitoring Techniques is charged with developing reliable forest health indicator measurements (such as plant sampling techniques).

FHM reports on forest-related issues on a large scale. The principal levels of reporting in FHM include state, regional, and national/international (see sidebar, Forest Sustainability Criteria). Local or special reports are produced as issues arise and where FHM and other data sets are appropriate for the area of consideration.

What do we mean by a "healthy forest"?

A healthy forest displays resilience to disturbance by maintaining a dynamic set of structures, compositions, and functions across the landscape. Secondly, healthy forests meet the current and future needs of people in terms of values, products, and services. These two components are interrelated and may oppose each other in the short-term. However, forests cannot meet social needs indefinitely without sustained ecological capacity to recover from human or natural disturbance.

Data Sources

Plot Network—A plot is a permanent sample location that is measured on a regular cycle. The sample area of a plot is approximately 2.5 acres (1 hectare). Field crews gather data on tree species and diameters, crown conditions, tree damage, lichen communities, ozone bioindicators, and soils (USDA Forest Service 1999). These measurements act as indicators of forest health. Field crews are rigorously trained in all forest measurements and regularly tested to ensure high standards of quality. As the program develops, new indicators such as understory vegetation and woody debris may be added to supplement the current suite of field measurements.

In 1992 the USDA Forest Service and the Colorado State Forest Service began cooperating to establish permanent FHM plots across that state's forested lands. In subsequent years, Idaho (1996) and Wyoming (1997) were included in the FHM plot network. Utah and Nevada were added to the program in 1999. For each state, a baseline measurement of all plots was performed followed by annual measurements of about one-fourth of the original plots. In this way a remeasurement of all the plots is accomplished in a total of 5 years (an additional cycle year was added to each state in 2000). Field plots are spread evenly across the state in any given year. This

Forest sustainability criteria

The United States is committed to reporting on the criteria and indicators of sustainable forests found in the Santiago Declaration—Montreal Process (Anonymous 1997). Five of the seven internationally agreed upon criteria relate directly to FHM: biological diversity, productive capacity, ecosystem health and vitality, soil and water resources, and global carbon cycles. The two criteria not addressed here are the socio-economic and legal aspects of sustainable forest management. Regional forest health issues closely parallel the criteria and indicators found in this agreement. Issues and data summaries found in regional reports contribute to national reporting efforts in accordance with the Santiago Declaration (Stolte 1997).

system provides annual measurement of forest conditions across these states and eventually the entire region. Remeasurement of specific forest indicators allow researchers to assess trends in forest conditions. This report contains only data from first-time, or single visit, measurements.

Survey Component—The survey component of FHM provides a record of broad-scale disturbance events, such as large-scale insect and disease outbreaks, that may not be detected by the FHM plot network. Survey information provides a context for interpreting plot data and for identifying likely factors that contribute to forest health changes.

Aerial detection is the primary survey activity. Systematic aerial surveys of forest conditions have been conducted in this region for the past 30 years by state and federal cooperators. Other survey activities include: 1) ground surveys for specific insect and/or disease activity such as dwarf mistletoe and mountain pine beetle; 2) analyses of other plot-based data from Forest Inventory and Analysis (FIA), National Forest inventories, and Forest Health Protection insect and disease plot inventories; and 3) service trip reports and technical reports for historical data or trends.

Scope of Report

This report addresses forest health in two ways: by discussing forest-related issues and by summarizing data in several appendices. FHM is a long-term monitoring program; therefore, the data presented in this report must be viewed in that light. This report presents a first-time, or baseline, summary. Subsequent reports will address trends as the current plots and other detection surveys are remeasured.

In this report, we first describe the forest resource to familiarize the reader with regional forest cover, ecoregion, and ownership patterns. The body of this report will focus on the following forest-related issues in the Interior West today:

1. **Forest Cover Change** addresses successional changes in species composition that appear to significantly deviate from patterns found a century ago. Does this change signal a distressed forest resulting from poor management, or is this simply a healthy forest developing along an alternative course?
2. Human-populated forests are a special concern and may affect our perception of healthy forests in a **Developed and Wildland Interface** setting. On these lands, many would agree that additional management of forests is warranted to protect lives and property.
3. **Insect and Disease Disturbances** fluctuate over time. We will examine some of the primary agents currently at work in this region.
4. **Watershed Health** is a critical issue throughout the region. How do our forest management actions affect water quality and quantity?
5. **Biodiversity** is a long-standing issue of concern with the public. We need to objectively and consistently address regional diversity, including impacts from exotic species.
6. Poor **Air Quality** can broadly affect the health and vigor of forests. FHM measures impacts of air quality on forest ecosystems using bioindicator plants.

A brief look at emerging issues follows specific issue discussions.

Data summaries from FHM plot data are found in these appendices:

A. Plot Distribution by State and Land Use
B. Distribution of Forest Land by Stand-level Categories
C. Total Tree and Regeneration Counts
D. Crown Condition Ratings
E. Distribution of Damage Types by Species
F. Data Available From FHM Plots

Please note that we are interested in your suggestions and feedback. Appendix G includes sources to contact for further information. An internet website address is provided on the inside back cover for further information and to register reader comments.

The Forest Resource

The Interior West is noted for its variety of forest cover, from moist cedar-hemlock in the north, to high elevation spruce-fir, to dry pinyon-juniper in the high deserts. It is important to acknowledge the diversity of regional forests before proceeding to issue discussions. A regional forest health assessment is really a compilation of many issues applied to a variety of forest conditions. This section will briefly describe the forest types, ecological divisions, and land ownerships that often frame and complicate issues. Previous state inventory reports provide more detailed information on ownership and forest cover (for example, O'Brien 1999; or Brown and Chojnacky 1996). Additional sources on the region's geography and related forest health references are found in appendix H.

Forest Types

Forest type is generally synonymous with forest cover, or the dominant tree species in the overstory at a given site. Figure 1 depicts the general distribution of forest types across this region based on satellite imagery. Forest types taken from field surveys are a convenient way to group land cover, although sites commonly contain more than one species. For example, Douglas-fir forest types of central Idaho may contain ponderosa (*Pinus ponderosa)*, limber (*P. flexilis*), and lodgepole pine (*P. contorta*), plus aspen (*Populus tremuloides*) and Rocky Mountain maple (*Acer glabrum*). Forest types are influenced by factors such as climate, elevation, aspect, soil type, and disturbance history.

Ecoregions of the Interior West

The forest health issues addressed in this report cross forest type, ownership, and political boundaries. Past efforts to assess forest conditions were often hindered by incompatible data within agencies and across political boundaries. A practical approach to large-scale forest health issues is to use nonpolitical land divisions, such as ecoregions, to objectively assess contiguous forests. Bailey's (1995) *Description of the Ecoregions of the United States* presents a hierarchical framework for delineating ecological regions based on their unique combinations of physiography, soil type, potential vegetation, and climate. An ecoregion approach allows analysts to group field plots that have similar combinations of these physical traits.

The ecoregions of the United States are classified, in descending order, by domains, divisions, provinces, and sections. More than 99 percent of the Interior West lies within the Dry Domain. There are 14 distinct provinces (ecoregions) found in the Interior West (figure 2). Detailed descriptions of each of these provinces are found in Bailey (1995). All of these provinces contain forest conditions that will be sampled by FHM. Points sampled through 1999 are shown in figure 2.

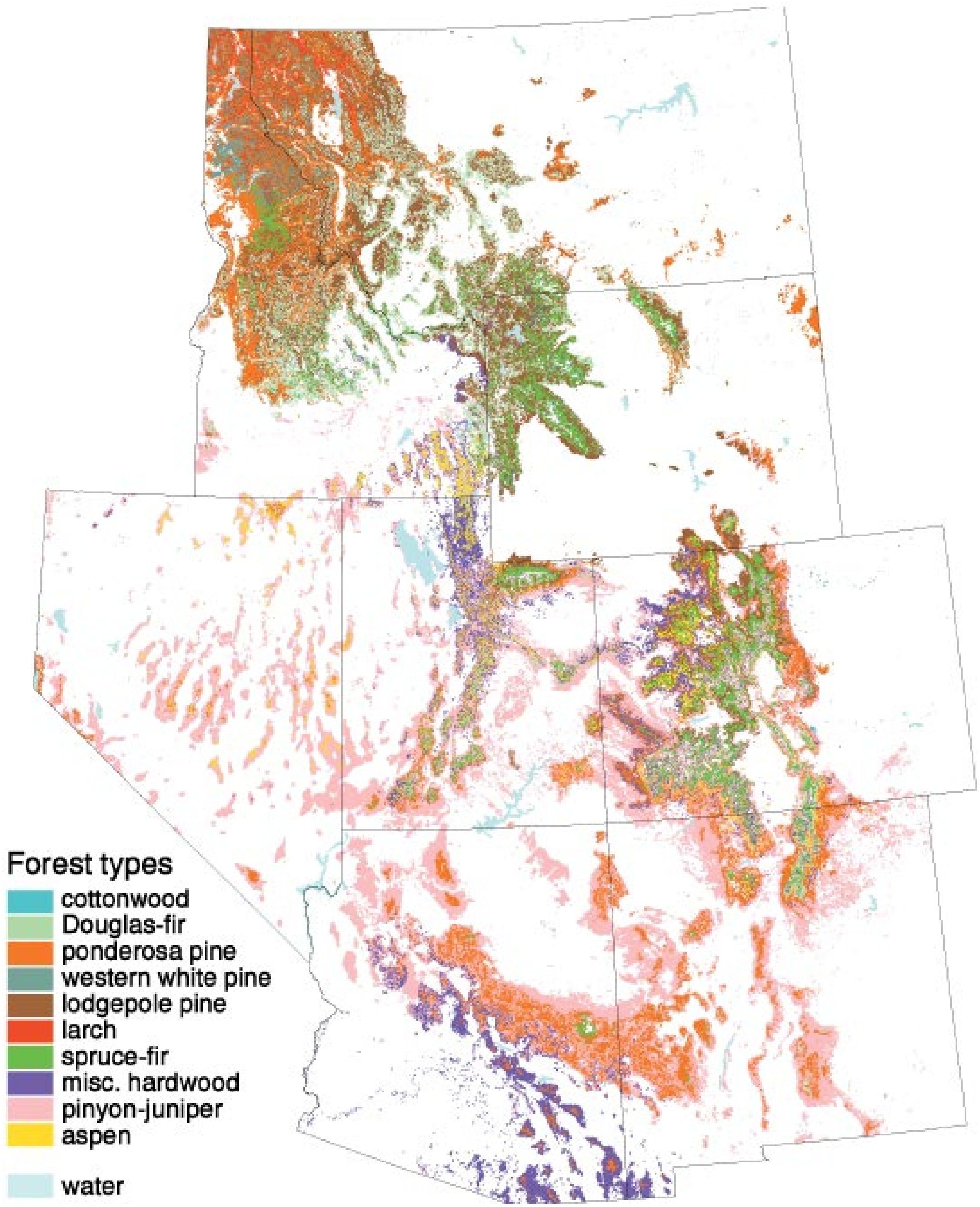


Figure 1*—Map of regional forest types derived from satellite imagery at 1 km resolution in the early 1990s. Source: AVHRR satellite, USDA Forest Service, Southern Forest Experiment Station, Forest Inventory and Analysis.*

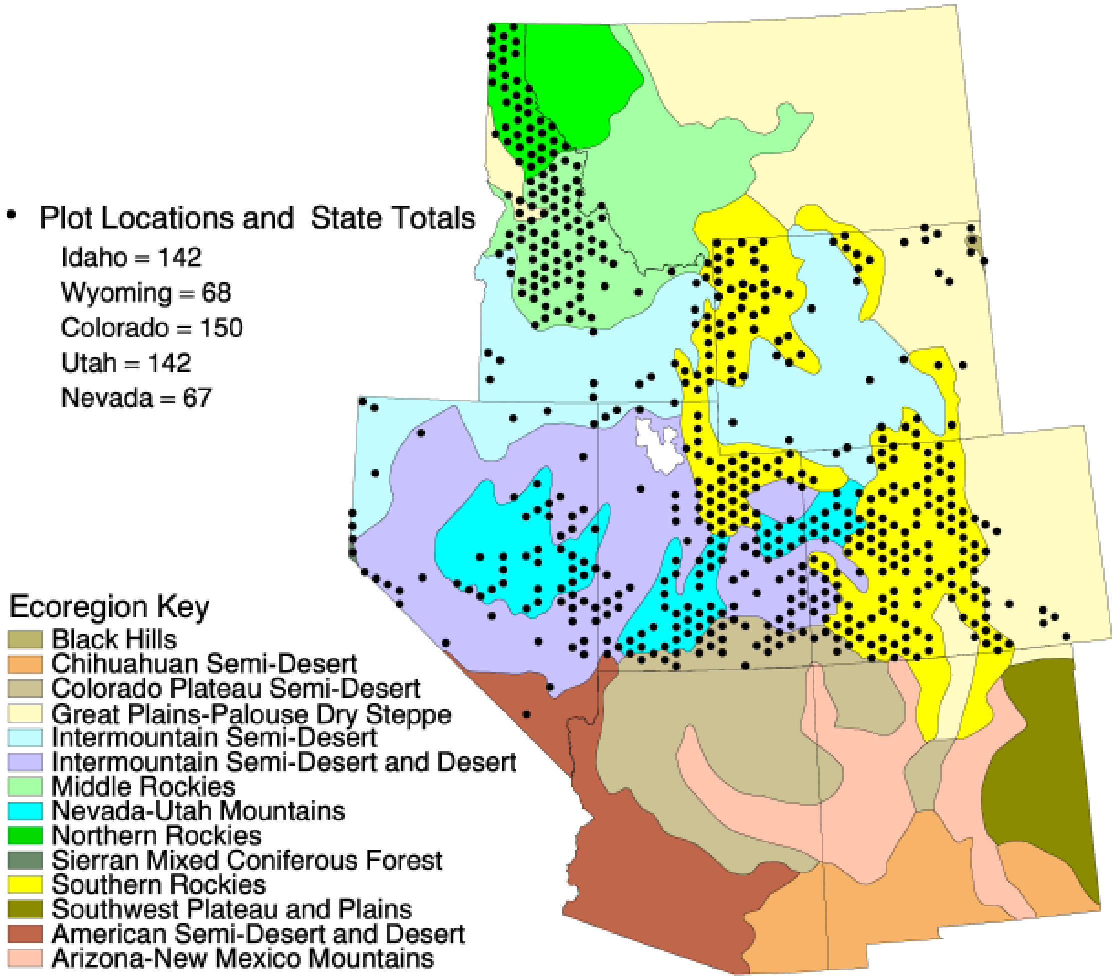


Figure 2*—Ecoregion provinces and FHM plot locations in the Interior West.*

Land Ownership

FHM samples all owner categories of forested lands. Management of forested lands across the region is complicated by a variety of ownership philosophies and directives. Nevada, Utah, and Idaho have greater than 50 percent of their land base in federal ownership, while the remaining five states each have more than 25 percent federal land (figure 3). In contrast, New Hampshire represents the most federally owned state (13 percent) east of the Rocky Mountains (Riebsame and Robb 1997). Regionally, most forest acres fall on National Forest or Bureau of Land Management lands, though significant portions are owned by private individuals or corporations. The remaining portions of the forested land base consist of State, National Park, Tribal Trust, and miscellaneous federal and county properties.

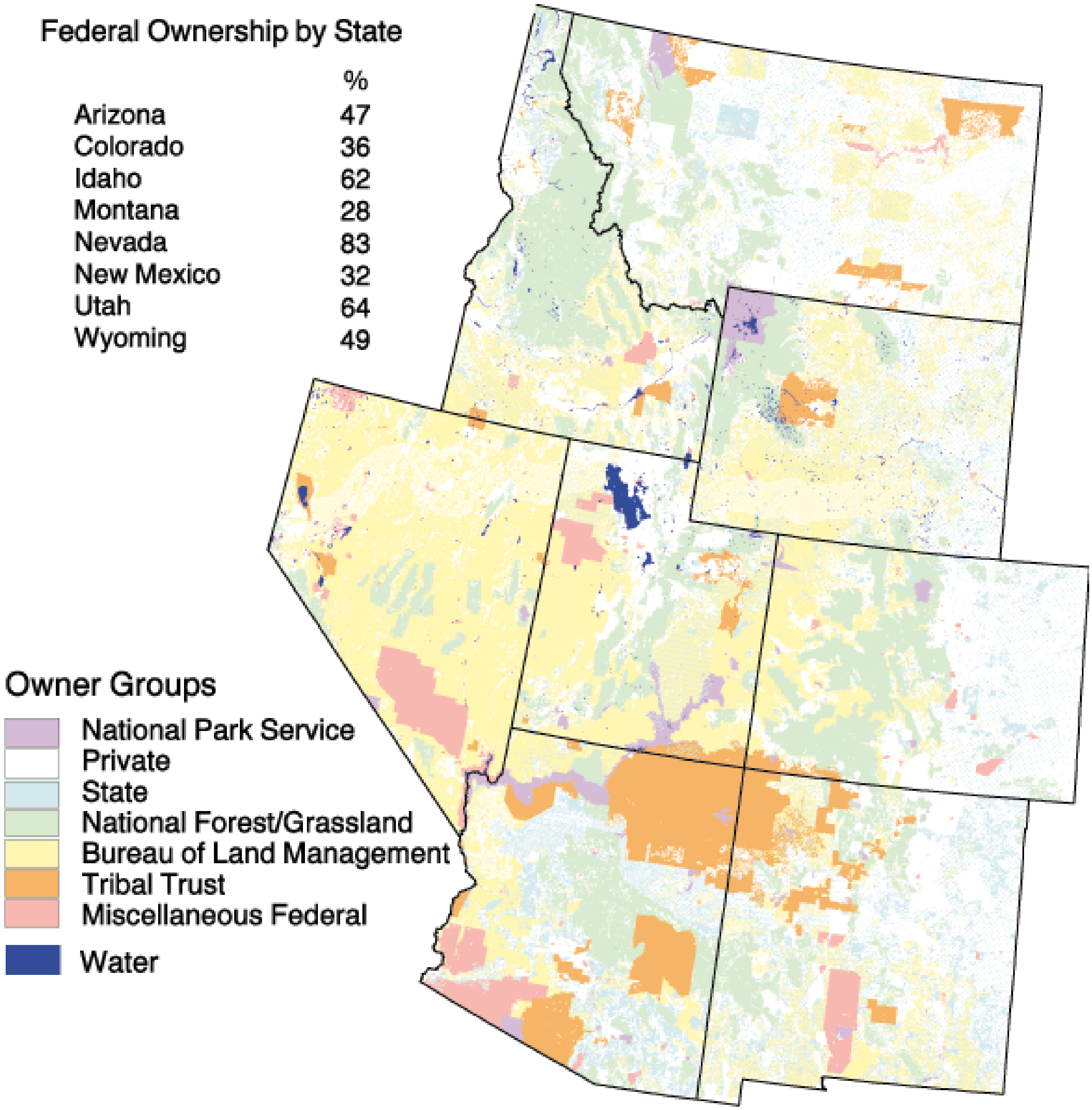
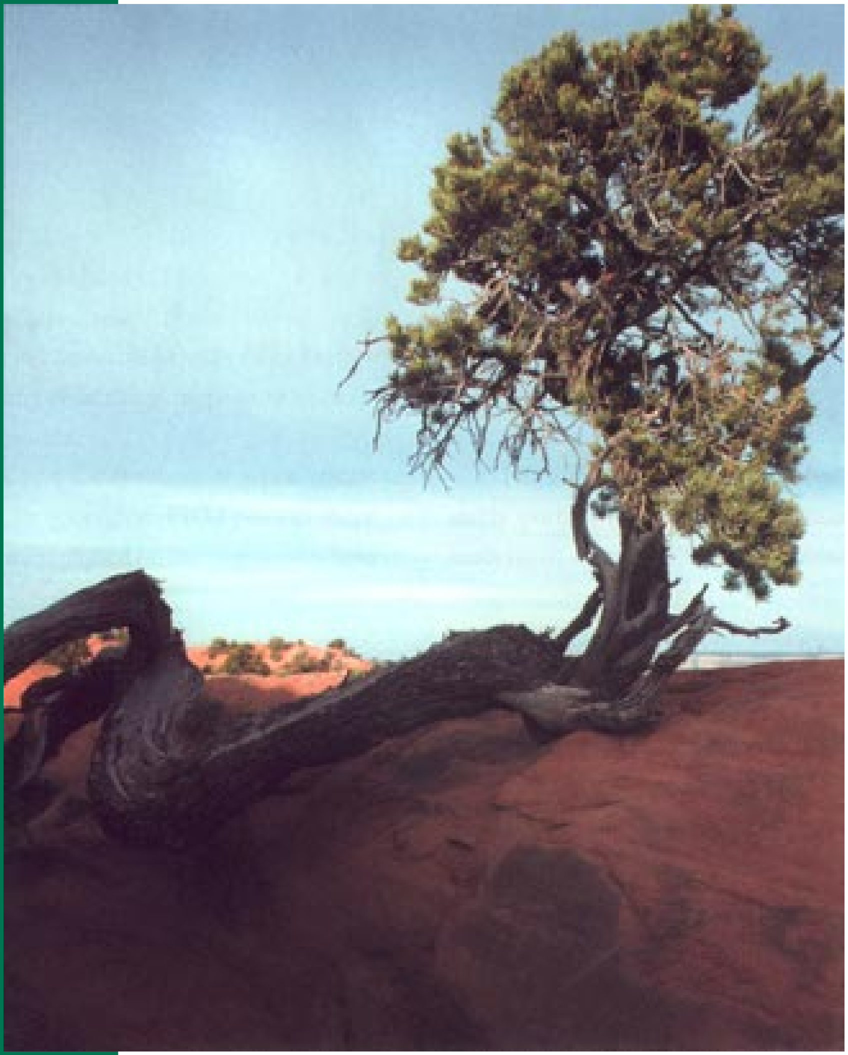


Figure 3—*Interior West land ownership patterns and percent federal ownership. Source: USDI, Bureau of Land Management, and Riebsame and Robb (1997).*

Forest Health Issues in the Interior West



Forest Cover Change

Examples of forest cover change cited by land managers in the Interior West include transition of western white pine (*Pinus monticola*) to Douglas-fir (*Pseudotsuga menziesii*) and true fir (*Abies sp.*) species in the northern Rockies, invasion of arid land tree and shrub species into adjacent grasslands in the southwest,

and a general trend that favors shade-tolerant species over seral species throughout the region. These type conversions are attributed fundamentally to post-settlement impacts on forest systems resulting from wildfire suppression, termination of aboriginal burning practices, tree cutting, and livestock grazing. Related disturbance cycles (for example, insect and disease outbreaks or wind-related events) and climatic variation work in tandem with human disruptions to affect forest cover change.

Forest Health Monitoring can measure change in species composition, forest structure, and frequency of disturbance by using species make-up, size, age, and relative dominance of all trees on a particular site. FHM also describes the condition of individual trees through assessing growth, mortality, regeneration, damage, and estimates of crown conditions. All of these variables affect forest cover and may be used to assess long-term change.

This section explores aspen forests as an example of regional cover change. There are some commonalities found between aspen and other tree species in this region; for example, the proliferation of shade-tolerant species where fire regimes have been altered. However, beyond their affinity for disturbance, aspen, ponderosa pine, and western white pine react very differently depending on post-disturbance interactions of climate, insects, disease, reproductive strategies, and other factors.

Aspen cover throughout the West appears to be decreasing (Brown 1995; Bartos and Campbell 1998; Rogers and others 1998; Rogers 2001). Shifts in forest cover occur over decades, or even centuries, so they may not be obvious to many forest visitors. Nonetheless, cover changes have far-reaching effects on a forest's susceptibility to fire, insects, or disease. Aspen, the predominant deciduous tree of the Interior West, also supports a unique range of understory plants and lichens that would likely decline with a loss in aspen overstory. Finally, aspen are highly valued as a regional aesthetic resource, providing an autumn shock of yellow among the sea of evergreen.

Aspen is one of a few tree species that readily regenerates after fire. Because aspen primarily regenerate by suckering from underground root stock (see Romme and others 1997 for exceptions), they maintain a certain advantage over other species whose reproductive parts (cones and seeds) are often consumed by fire or take longer to establish when they are not burned. It appears that a sharp reduction in regular burn events in the past century has led to a significant drop in aspen regeneration. Moreover, when disturbance is delayed in some stands, older aspen will eventually be replaced by competing conifers at about 80–150 years (Mueggler 1985). FHM data show that the average age of aspen forest types is 68 years, while the average age of non-aspen forest type stands (with aspen present) is 89 years. So, while few stands are regenerating due to the lack of fire, older stands of aspen are being replaced by shade-tolerant conifers. This basic formula, in combination with other factors such as grazing and browsing of seedlings, appears to be causing a decline in aspen type area.

In Idaho, Wyoming, and Colorado most aspen stands are in the Southern Rockies ecoregion. FHM plots in these states with aspen present were plotted on the map shown here (figure 4). Data from Utah and Nevada have not yet been compiled for this analysis. These plots may be logically split into aspen forest type (plots dominated by aspen) and plots dominated by other species where aspen is still present. Fifty percent of the forested plots with aspen present are now dominated by more shade-tolerant species. Previously, aspen was the dominant species found in an unknown (presumably larger) portion of these plots where it is currently only present in small numbers (Bartos and Campbell 1998; O'Brien 1999). Lack of large-scale disturbance has favored conifer species on these sites. The Southern Rockies appear to be more conducive to aspen establishment than surrounding provinces (figure 4). If indeed a threat to the health of aspen forests exists regionally, it is plausible that a decline would manifest itself first near the margins of the species' natural range (for example, Front Range of Colorado, figure 4), where climate and soil may already be limiting factors.

Plots taken in aspen forest types appear to represent the stable portion of the aspen community regionally. Further analysis of stand structure, regeneration, damage, mortality,

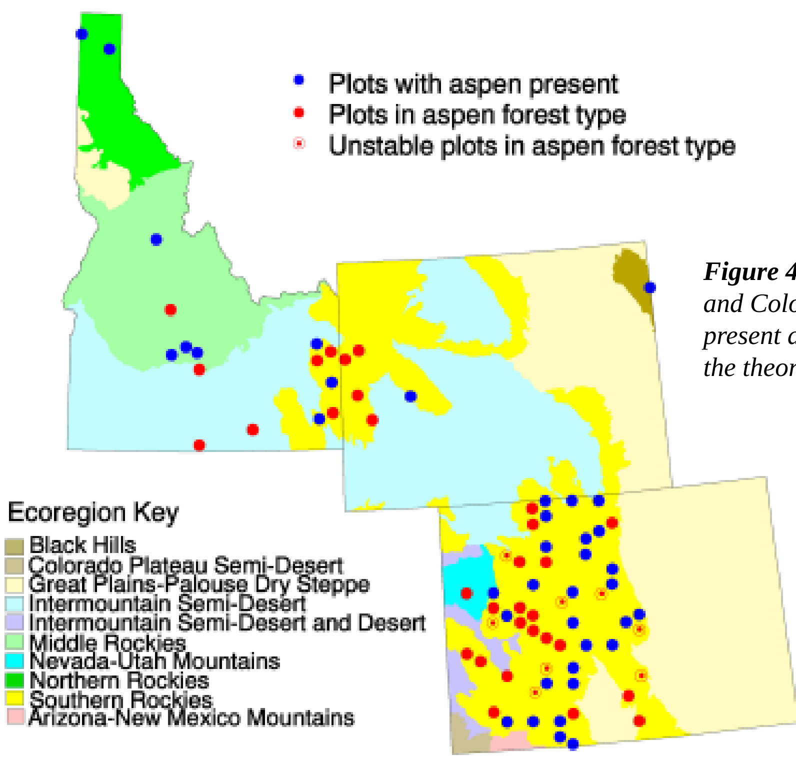


Figure 4*—Aspen plot distribution in Idaho, Wyoming, and Colorado. The combination of plots with aspen present and unstable aspen forest type plots support the theory of regional aspen decline.*

and age reveals that an additional 21 percent of aspen forest type plots were found to be unstable (in transition toward other forest types) in the absence of disturbance (Rogers 2001). Plots were considered unstable by statistical ranking of 10 tree-related variables: 1) stand age; 2) other species present; 3) aspen saplings present; 4) other species' saplings present; 5) aspen in lower canopy; 6) stand age 90 years or greater; 7) aspen mortality greater than 10 percent; 8) severe damage (conks, decays, cankers, and open wounds) greater than 20 percent; 9) presence of a second forest condition (forest type) of conifers; and 10) percent of conifer trees and saplings.

Another view of aspen community health is physical tree damage. Though deciduous trees typically display more tree damage than evergreens, aspens had a higher percentage of damage than any other major species (appendix E). Aspen also led all species in the most serious forms of damage, "cankers" and "decay." Seventy-three percent of all aspen damages observed were in these two most serious categories.

Data presented here support the hypothesis of a regional aspen decline over the last century but do not suggest the extent of that decline. Future remeasurements of plots, along with field plots in adjacent states not yet sampled by FHM, will give us a better idea of the rate and direction of this apparent trend. A reversal of this trend would logically involve widespread human or natural disturbances coupled with reductions in grazing and browsing where aspen are regenerating.

Developed and Wildland Interface

The developed and wildland interface includes expanding urban areas, rural developments and vacation homes, and public parks, campgrounds, and other recreational facilities in or near forests. A marked increase in development around forested lands has been particularly noticeable within the last 10 to 20 years. Data from the U.S. Bureau of Census (1990) indicates a net increase in population in the region. Six of the top 10 fastest growing states in the nation are found in the Interior West: Nevada, Idaho, Arizona, Colorado, Utah, and New Mexico (Riebsame and Robb 1997).

Over the past 150 years, land has been used for farming, grazing of livestock, mining, and the production of timber. Recently, with the large influx of people, land prices have increased, making it more profitable to sell parcels for building sites than to use them in traditional ways. Rural development may also lead to losses in recreation and aesthetic opportunities associated with less-developed lands.

In general, human values surrounding the management of interface lands are slowly changing from "living off the land" to "living in the land." Newcomers to the region are probably accelerating this change in attitude. In the context of forest health, increased development of forests will initiate more intensive management when disturbance agents either rapidly or gradually change surrounding forest conditions. For instance, a bark beetle infestation may leave a forest of large dead trees adjacent to valuable homes. These trees may damage property as they eventually topple, or they may present a more acute wildfire hazard in particulary dry years. Potential forest developers and owners buy home sites for their current aesthetic properties but often are unaware of changing conditions and potential hazards of interface areas. There are many preventive measures that can be taken to buffer homes from wildfire threats, including not building in fire-prone areas in the first place (Fuller 1991).

Wildlife may be severely impacted in interface zones. With forest land development there can be disruptions in the traditional migration routes, feeding sites, winter ranges, or birthing and denning areas of various wildlife species. Conflicts arise when wildlife invades trash cans, contaminates swimming pools, or feasts on the front lawn or garden. Some species prosper in developed areas (for example, skunks [*Mephitis mephitis*], raccoons [*Procyon lotor*], deer [*Odocoileus sp.*], and coyotes [*Canus latrans*]), while others struggle for survival (for example, pine martens [*Martes americana*], grizzly bears [*Ursus arctos horribilis*], and lynx [*Felis lynx*]). All of these species may contribute to human and wildlife conflicts associated with forest and adjacent land development.

With data from FHM plots, in conjunction with aerial surveys, we can begin to assess the regional extent of this issue and inform the public on recommendations for hazard

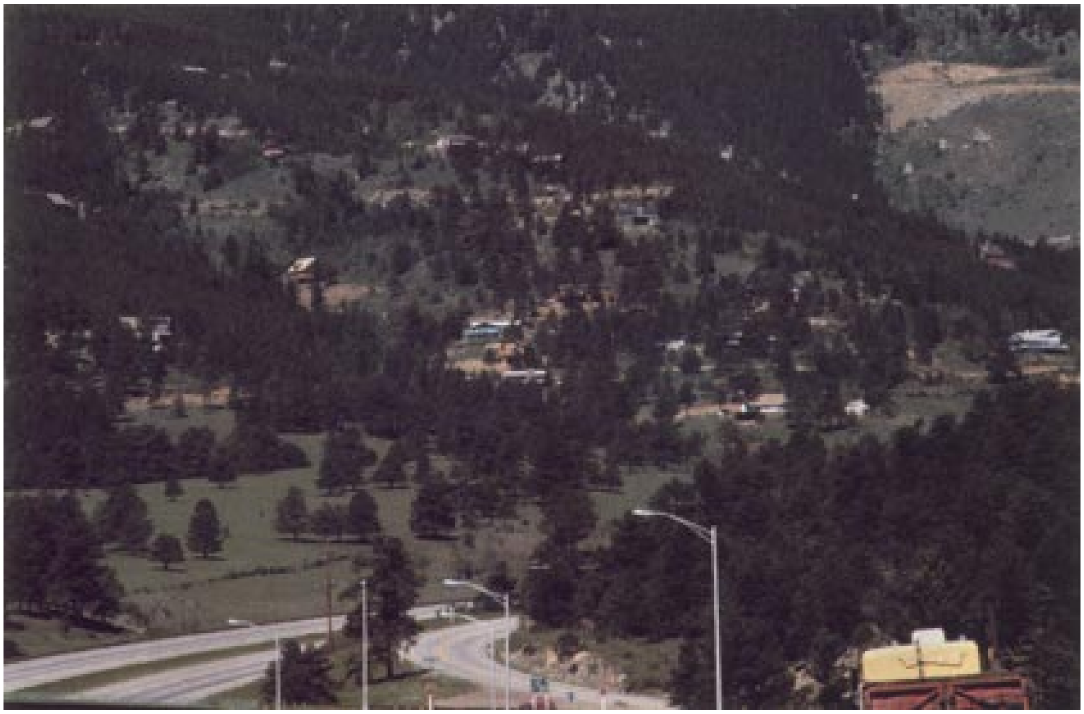


Photo by Michael Schomaker

prevention in highly susceptible areas. Maps of tree cover, damage, fire susceptibility, human development, and population growth are the first step in assessing the extent of the problem. In most cases private landowners will make the ultimate decisions on what actions are taken. However, adjacent public wildlands will likely be subjected to more intensive management where private properties will be affected by runaway fires or insect infestations.

Insect and Disease Disturbances

While tree-ring analysis has aided our understanding of presettlement fire regimes considerably, much less is known about long-term human impacts, if any, on insect and disease disturbances (Swetnam and Betancourt 1998). We do know that climate plays an important role in these events. Interior West forests experience frequent short-term advances and declines of insect and disease outbreaks. Many of these perturbations maintain healthy forest functions and species diversity over time. However, outbreaks are often seen as harmful to commercial and residential forests. Insect and disease events near developed land may provoke secondary disturbances, such as wildfire and hazard tree damage to private property. For these reasons, FHM tracks insect and disease occurrences on an annual basis over large areas.

Insect and disease outbreaks are monitored by aerial detection surveys and through the plot network. Additional ground surveys augment aerial survey information. Aerial survey data from 1998 shows infestations of insects and diseases affecting major timber species across the region (figure 5). Currently, subalpine fir decline (an insect and disease complex) and western spruce budworm (*Choristoneura occidentalis*) are affecting the largest acreages in the region. There is further concern over recent rises in mountain pine beetle (*Dendroctonus ponderosae*) outbreaks in the central and southern portions of this area.

Field crews collect tree damage data on the FHM plot network (USDA Forest Service 1999). Damages are assessed based on visible symptoms only (without chopping into the tree), beginning with the base of the tree and working up and out to the foliage. Damages found in the roots or lower bole of a tree generally are more serious than those found at the

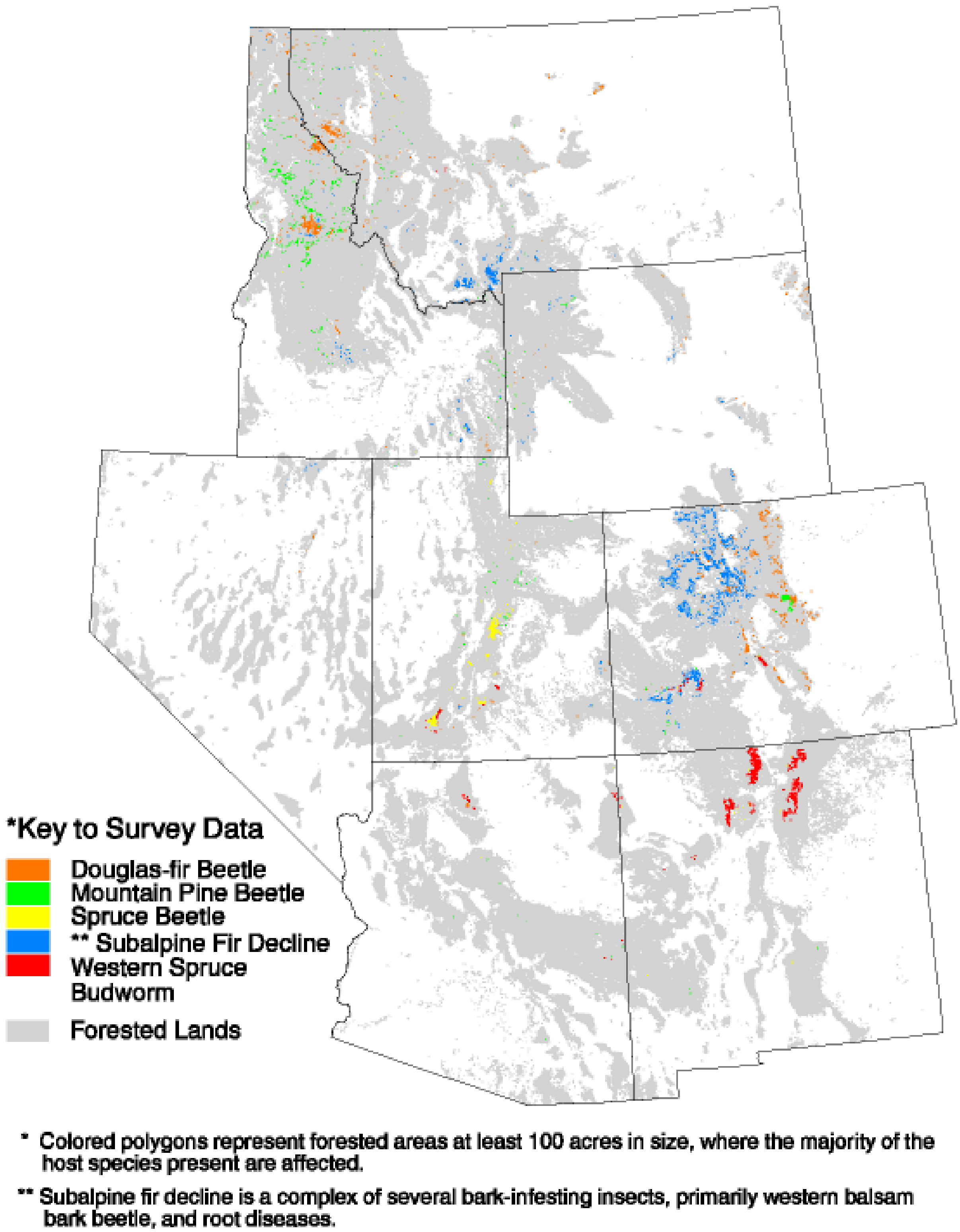


Figure 5*—Insect and disease disturbances detected from annual aerial surveys, 1998. Subalpine fir decline and western spruce budworm each affected over 300,000 acres in the region during this year.*

Photos courtesy of Rocky Mountain Research Station,
Bark Beetle Disturbance Project (RWU-4501)

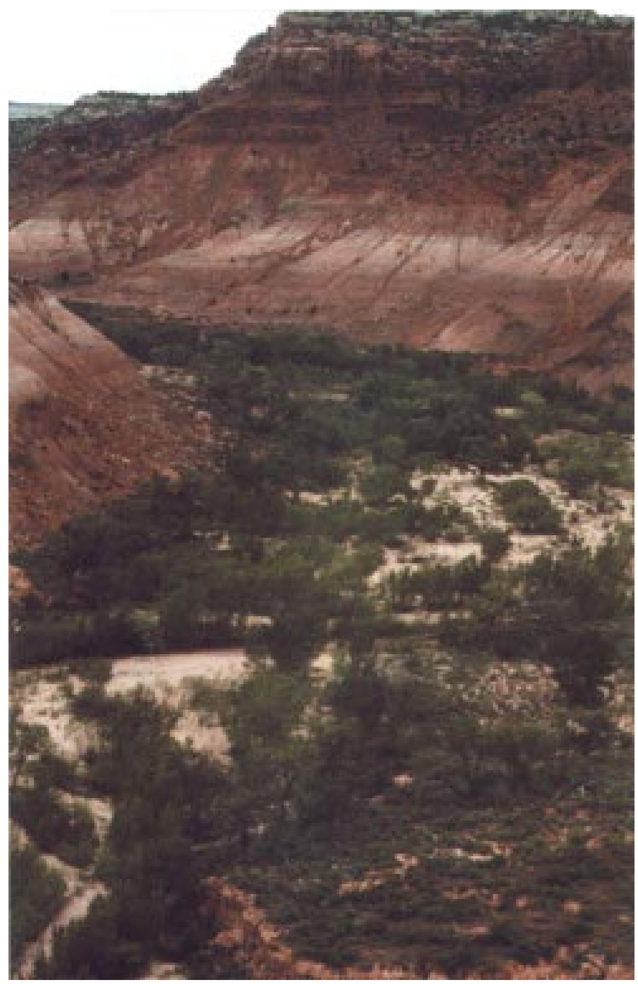
branch tips. In addition to damage locations, damage types are ranked for significance to growth and mortality of trees. For example, cankers or decays on the main stem are more serious than discolored foliage. Not all damages recorded with this system are related to insects and disease. Percent of each species with no damage, along with damage types by species, are shown in appendix E. Site or species-specific information found on plots can be combined with large-area aerial survey maps to provide a clearer view of where and how insects and disease affect regional forests.

Watershed Health

Rivers, streams, and riparian areas have drastically changed since the mid-19th century. Fire exclusion, beaver (*Castor canadensis*) trapping, overgrazing by livestock, wildlife browsing, dam building, and other human water developments have combined with climatic fluctuations to produce these changes. In some regional watersheds, increased forest density and changes in species composition have resulted in decreased runoff to major tributaries.

Upland vegetation conditions regulate groundwater recharge and the proportion of rainfall and snowmelt that reaches streams directly through runoff. Since the majority of the April to September streamflow comes from snowmelt rather than summer rains, the upland forest structure is a critical factor for watershed health. Forests that have converted from an open-canopy to closed-canopy condition collect more snow in branches and foliage. A larger portion of this snow evaporates into the atmosphere without reaching the soil. In the recent past, average annual precipitation levels have remained unchanged, although less water has been available for groundwater recharge, streamflow, and herbaceous plant growth. Reduced groundwater recharge is translated into reduced streamflows and increased water temperature. Some streams dry up completely during the summer where they did not previously.

Except for climate, the exclusion of natural wildfires probably has had the most impact in shaping forest and rangeland ecosystems of low and mid elevations (Covington and Moore 1994). Reduction in fire frequency has resulted in increased densities of trees and shrub species in many forest communities. Grazing and browsing by livestock and wildlife contribute to the increase of woody plants by reducing competition from grasses and other herbaceous plants. Increased tree and shrub densities result in higher interception and evapotranspiration rates, thereby reducing the amount of water available for streamflow. On the other hand, soil compaction caused by grazing domestic and wild animals slows infiltration of surface water. Construction of roads increases runoff through interception and concentration of surface flows. Together, these factors have generated rapid runoff and powerful floods, as well as severe soil loss and even slope failure in some areas (McClelland and others 1997). Flooding occurs because water runs off the surface rather than being absorbed into the soil and being slowly released to watercourses. Floods have been powerful enough



to remove the entire flood plain, incising channels through old alluvial deposits and destroying much of the riparian vegetation. In wet meadows, channel cutting has reduced water tables and drained hydric soils.

Dams, reservoirs, and irrigation projects on rivers have drastically modified channel dynamics, including erosion and deposition processes (Collier and others 1996). The regeneration of cottonwoods (*Populus sp.*) and willows (*Salix sp.*) depends on natural floods that rarely occur in some river systems. Additionally, many southwestern drainage basins were managed to eliminate cottonwoods in an effort to increase water flows (Dunne and Leopold 1978). Human alterations of stream dynamics and species composition have contributed to the proliferation of exotic trees like saltcedar (*Tamarix sp.*), Russian-olive (*Elaeagnus angustifolia*), and Siberian elm (*Ulmus procera*). Their presence has resulted in increasingly drier riparian systems. Salt in the leaf litter of dense saltcedar stands has prevented native plants from regenerating. New plant communities have resulted with different vertical and horizontal layers, understory species composition, and age class distribution. Additionally, the richness and abundance of bird and other wildlife species has been reduced. Changes in river systems have led to endangered status or complete loss of some native aquatic species.

Soil that is eroded from disturbances in riparian or upland areas is being deposited into streams. This adversely affects water quality and aquatic habitats in most streams where it does occur. Also, high-intensity wildfires in dense forests often lead to short-term intensification of soil erosion and sediment delivery to streams. Soil disturbance is particularly acute after heavy rain or snowmelt events in the months following a burn (Davenport and others 1998).

Our understanding of watershed and forest health interactions is limited because they occur over vast areas that transcend multiple ecological zones. However, we do know that streams experience long- and short-term disturbance regimes just as forests do. In the past there were undoubtedly shifts in stand densities, fluctuations in forest disturbance regimes, and climatic shifts that caused widely varying hydrologic cycles and fluvial disturbances. It is difficult to separate long-term vegetation and disturbance patterns from current forest health assessments. This rule applies equally to watershed health. Although we know that people have drastically altered some watersheds, we must also realize that periodic flooding, slope failure, and erosion will take place on forested landscapes that have been marginally affected by human actions. Forest measurements collected through the FHM program and related studies will help us to better understand some of these interactions.

Biodiversity

Biodiversity refers to the variety of living organisms occurring in a particular area. Society values sustainable healthy habitats for native wildlife, vertebrates, vascular plants, and non-vascular plants. These values stem from future applications in medicine, clean water, and air quality, as well as for the less tangible spiritual, philosophical, and instrinsic motivations for maintaining a wide variety of life forms. For these reasons, biological diversity is considered an important indicator of forest health.

Biological diversity is a broad and complex subject that may be measured with a variety of methods and at multiple scales. Biodiversity is most often examined at the genetic, species, or community-ecosystem levels (Langner and Flather 1994; Gaines and others 1999). It may focus on species populations directly or deal with habitat conditions by looking at the diversity of vegetation structure. The FHM program has a broad geographic focus with the desire to monitor long-term changes. Therefore the analysis of biodiversity in this program is primarily at the community-ecosystem level. Biodiversity measurements currently taken on FHM plots are tree and lichen species richness and forest structure. We monitor forest structure by examining the size, density, position, age, and damage of live and dead trees (for example, aspen cover change analysis). In addition to tree-level measurements, we map changing forest conditions of field plots by tracking disturbances over time. Procedures for monitoring understory vegetation diversity, down woody debris, and fuel loading are being tested for future implementation.

People influence biodiversity in many ways. The introduction of non-native species, often accidental, has caused major problems. These exotic diseases, insects, or plants can easily infiltrate native communities. White pine blister rust

(*Cronartium ribicola)* has reduced the western white pine and whitebark pine (*Pinus albicaulis*) communities in the Northern Rockies, tamarisk (*Tamarix sp.*) has overrun many riparian zones on the Colorado Plateau, and many invasive understory "weeds" (for example, dandelion [*Taraxacum sp.*], cheatgrass [*Bromus tectorum*], and Dyers woad [*Isatis tinctoria*]) are moving into forested zones. Efforts are underway to eradicate gypsy moth (*Lymantria dispar*) infestations detected in the region.

Previous management practices in this region over the past century, notably fire suppression and logging, have reduced the percentages of young and old stands, while increasing the percentage of mid-age forests (Langner and Flather 1994). Great reductions in some forest types, such as western white pine and aspen, may result in reduced regional diversity through the loss of associated plant and animal communities. Native diversity is best maintained with a variety of forest type and stand structure conditions across a landscape or region (Halpern and Spies 1995).

FHM will assess human impacts on biodiversity by using plot data in combination with pertinent studies conducted elsewhere, for example remote sensing projects already underway (Merrill and others 1995). As part of the current FHM plot protocol, field crews note recent natural and human disturbances. Documentation of plot disturbances can be classified and compared to the number and type of plant species found on plots as an indicator of human effects on species diversity and richness (Stapanian and others 1998). FHM will also use soil and erosion data, in part, to document how recent disturbance has affected basic soil properties. Significant alteration of the soil can affect the types and richness of communities that can be supported. Overall, the long-term assessment of regional diversity will involve a concerted effort to integrate several types of monitoring activities currently being implemented by agencies and universities around the region.

Air Quality

Forest Health Monitoring is concerned with the effects of air quality on forest vegetation. In areas of consistently poor air quality, certain plants such as the shrub ninebark (*Physcocarpus malvaceus*) or ponderosa pine trees are damaged or show dieback (Mavity and others 1995; James and Staley 1980). Other plants, notably certain lichen species, display even less pollution tolerance and may disappear from affected forest environments.

Lichens gage air quality, add significantly to forest diversity, enhance nutrient cycling, and are a critical food source for wildlife (McCune 2000). Lichens are sensitive to changes in air quality because of their dependence on atmospheric nutrients for survival. FHM crews collect lichens and rate their abundance on every field plot. Lichenologists identify all species and perform data analysis. Lichen sampling in Colorado, in conjunction with a supplemental gradient sample in that state, have produced some interesting preliminary results (figures 6 and 7). These maps depict the range of lichen species richness and associated air quality scores derived from FHM plots in Colorado. Reductions in lichen diversity appear to have taken place along the Front Range and near Steamboat Springs (McCune and others 1998). A detailed lichen survey of the Yampa Valley is planned for an upcoming Evaluation Monitoring study.

High ozone levels have negatively affected plant and tree health in the eastern United States and southern California for decades (Smith 1985). Trees weakened by ozone damage may be predisposed to damage by other disturbances, such as fire, insects, disease, and wind storms. Field crews examine bioindicator plants to detect and monitor trends in air quality (for example, phytotoxicity rates) for ozone near plot locations. Thus far no ozone damage has been recorded on FHM plots in the three Interior West states inventoried prior to the 1999 field season (Smith 1999). Preliminary evaluation of Utah and Nevada ozone monitoring in 1999 also reveals no damage to indicator species. The next step in evaluating ozone effects on forests in this region will be to concentrate bioindicator sites near areas of known poor air quality.

An ongoing method of observing the effects of air quality on forest health is to evaluate tree foliage conditions on the FHM plots. Visual crown ratings and damage surveys have been successfully applied to forest health evaluations in mixed hardwood stands in Europe and Eastern North America since the mid 1980s (Tomlinson and Tomlinson 1990). Field crews in the Interior West estimate density, dieback, and transparency of the crowns of all trees on sample plots (appendix D). Since plot installation began in 1992, no clear sign of crown decline or damage has been detected in our region. Future assessment of pollution on forest health will compare FHM data sets with data collected by a variety of state and federal agencies that monitor air quality.

Figure 6*—Lichen species richness map of Colorado ecoregions taken from FHM plot samples. Generally, the more species present (larger map symbols), the healthier the forest ecosystem, although available moisture plays an important role in lichen diversity. Pinyon-juniper sites usually have fewer epiphytic lichens than montane forests.*

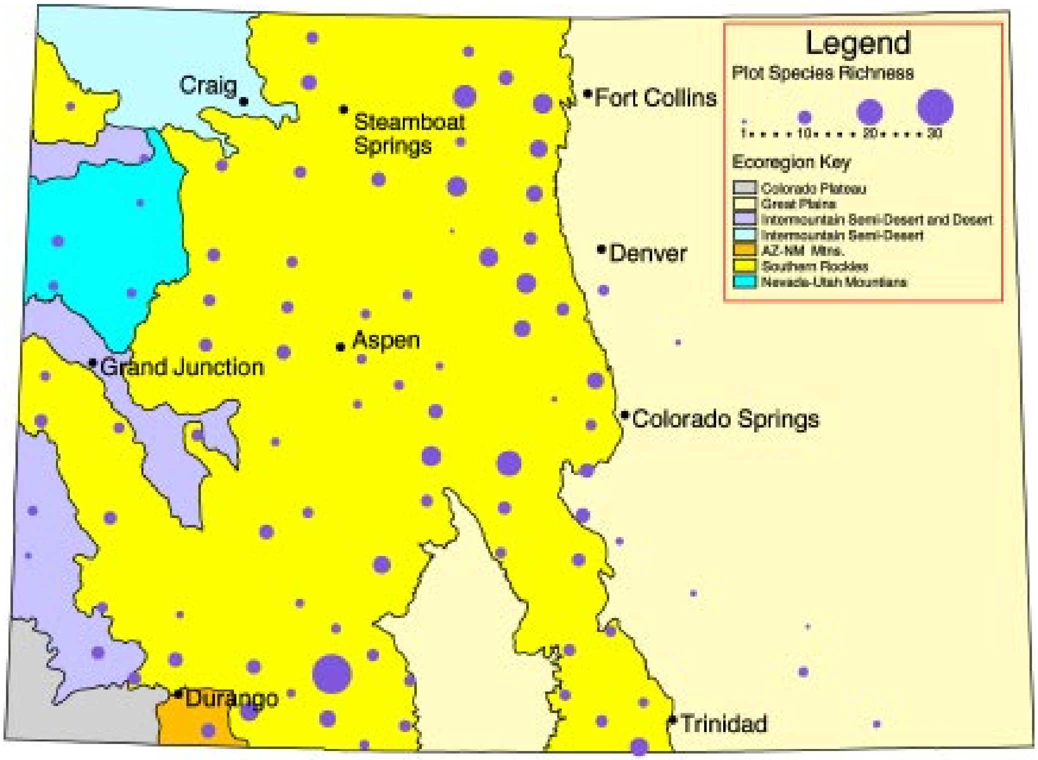
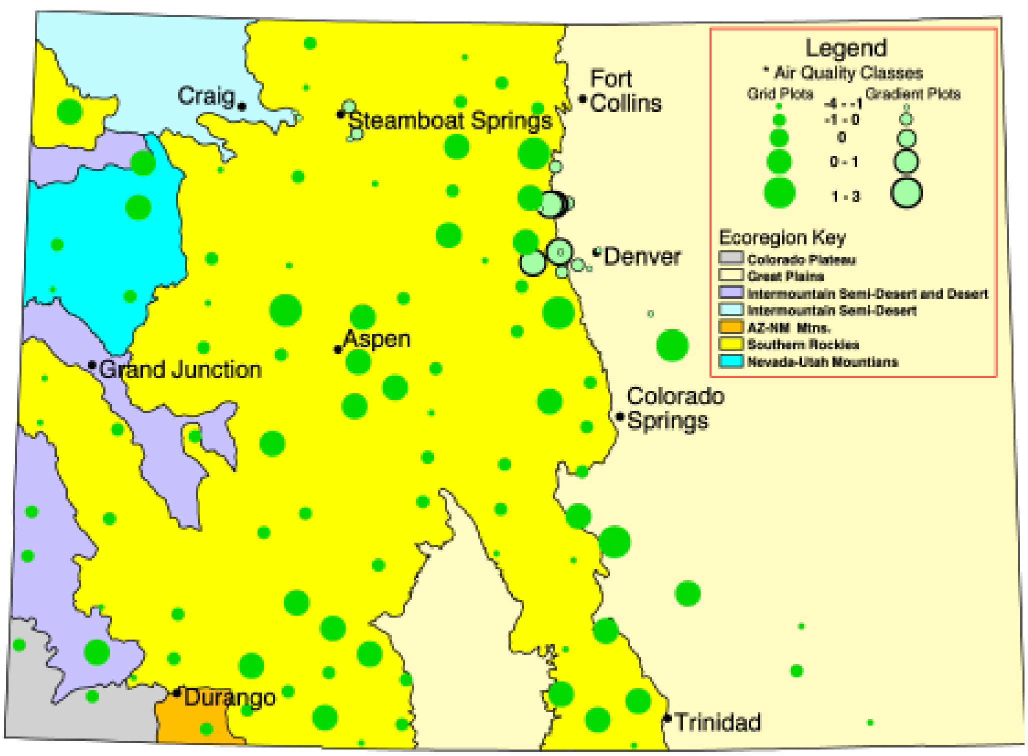


Figure 7*—The clustered (light green) circles represent gradient analysis sites where lichens were sampled in Colorado. The gradient is designed to assess relative tolerance of lichen species to varying levels of air pollution; hence, sites are located at intervals from known pollution sites to known good air quality sites. Lichen plots on the FHM grid (dark green) depict air quality based on the index developed for lichen species from the gradient. Larger circles represent higher air quality.*



*Data presented here represent the number of standard deviations from the raw air quality score. These values are derived from an adjustment made to the raw air quality scores based on elevation.

Emerging Issues

The discussion of forest health issues in the preceding sections was not meant to be all encompassing. New issues will emerge, others will decline in prominence, and some will remain with us for decades. Moreover, local issues are too numerous to address regionally, and the FHM design makes it impossible to address issues at finer scales without plot intensification. This does not belittle the importance of forest-related issues on a smaller scale. Interested readers may wish to obtain Forest Health Monitoring reports compiled at the state level (see appendix H), or consult with federal land management districts, state offices, or university extension units to gain a perspective on issues of local concern.

Emerging issues are those that FHM has not looked at thus far, but that we hope to address in future reports. Among these is **forest fragmentation**. While closely related to the biodiversity issue, continued fragmentation from road building, logging, and development may cause severe disruptions in forest functions (Reed and others 1998; Hargis and others 1999). Many **forest-dependent wildlife** issues are associated with forest fragmentation. Changes in some use patterns, such as closing forest roads, are expected to result in measurable improvements to forest fragmentation, forest-dependent wildlife, and overall forest health.

Two other criteria (potential forest health issues) explicitly required by the Santiago Declaration (Anonymous 1997) are **global carbon cycles** and **soil resources**. Both of these issues involve measurement of basic ecological variables to gain an understanding of the long-term sustainability of forest ecosystems. Measuring global carbon cycles involves monitoring the balance of carbon going into and coming out of forest systems. Carbon is stored in biomass above ground and below ground in organic material (live and dead decaying organisms). Future FHM surveys plan to measure understory vegetation and down woody debris. This information, combined with current tree measurements, will assist analysts in calculating regional and national carbon budgets. "Soil health" will give us information on the quality of the soil resource that supports the forest. Loss of topsoil or contamination by foreign chemicals could significantly degrade forest sustainability. An FHM soil indicator is in pilot mode and is planned for national implementation during the 2001 field season.

Conclusion

Consistent long-term monitoring over large regions is critical to both the overall understanding of how healthy forests function and to the detection of human-caused changes in forests over time. This baseline report of FHM data has presented an overview of forest-related issues affecting the Interior West today. This region covers many ecological provinces, so analysis will be difficult because of this breadth. FHM was conceived to detect changes at ecoregional, regional, and national levels. In effect, both the plot and survey components of FHM act as a "broad net approach" to monitoring forests. Some issues, such as monitoring endangered species, will be better dealt with at smaller geographic scales or with more intense surveys designed for specific concerns.

Issues of concern today may only be fully understood through the collection and analysis of long-term data sets, such as those being provided by FHM. We anticipate forest health issues changing in the future. The FHM program will continue to monitor new and evolving issues.

Forest health issues can be quite complex. This initial report has likely raised more questions than it has answered. Moreover, human values regarding what actions to take, or not to take, complicate forest-related issues. In this report we have attempted to remain objective in describing issues and have purposely not provided prescriptions. Individuals and organizations concerned with forest management must weigh the evidence and decide for themselves where action is warranted. It is through further monitoring, analysis, and public discussion that we hope to stimulate participation and understanding, and possibly even consensus, among forest users.

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Appendix A: Plot Distribution by State and Land Use

Plot Distribution in the Interior West by State and Land Use
(totals are in fractions of plots)

Land Use Category	Colorado	Idaho	Utah	Nevada	Wyoming	Region
Timberland	91.59	124.76	36.28	5.25	50.40	**308.28**
Woodland	46.02	8.25	86.99	58.51	7.87	**207.64**
* Inaccessible	9.25	3.00	11.03	26.00	4.25	**53.53**
Non-Forest	267.14	188.99	200.70	359.24	329.48	**1345.55**
Totals	414.00	325.00	335.00	449.00	392.00	**1915.00**

* Inaccessible plot locations were not visited because private landowners denied access or plot locations were difficult to safely sample (for example, steep terrain).

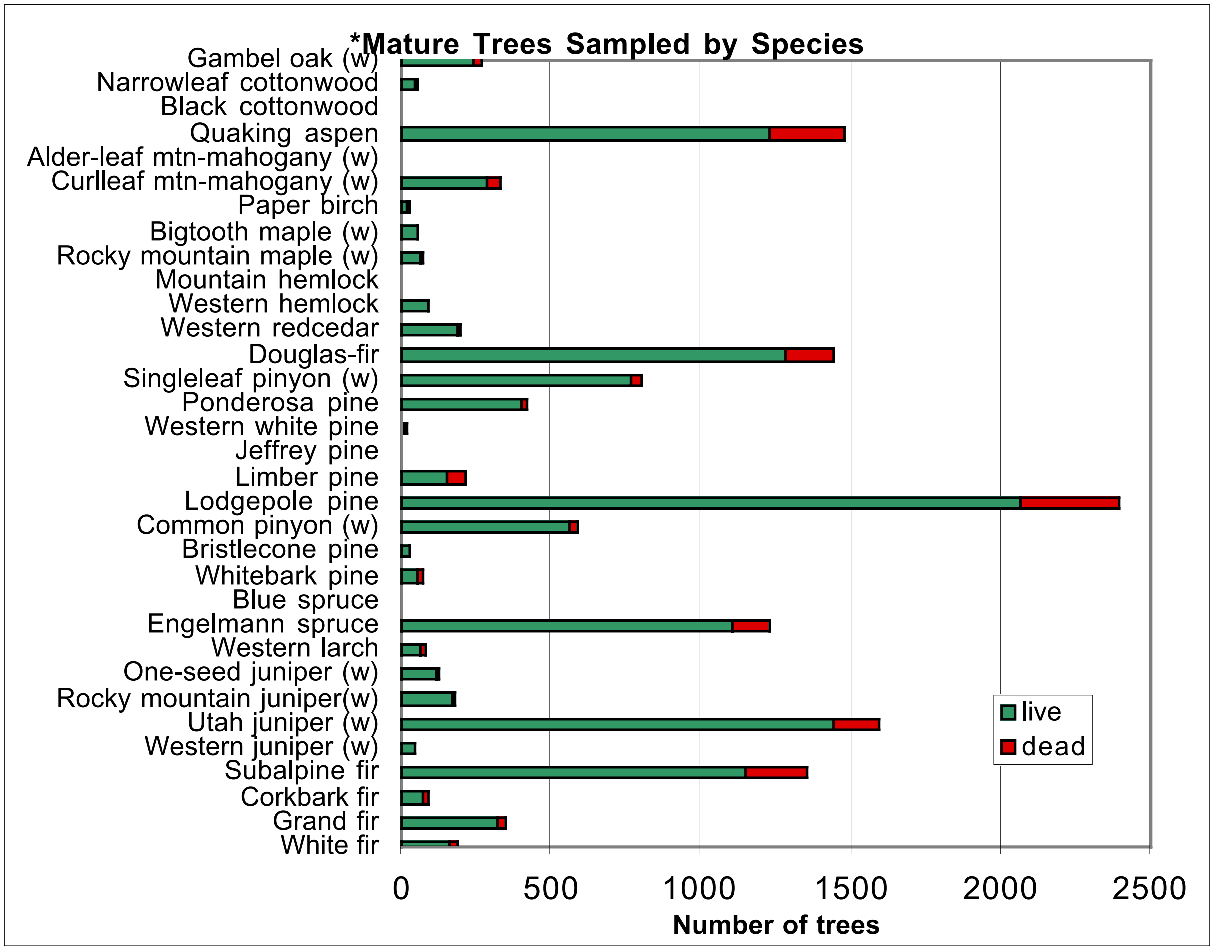
Appendix B: Distribution of Forest Land in Colorado, Idaho, Nevada, Utah, and Wyoming by Stand-Level Categories

Stand-level category	% of plots
Forest type group	
Douglas-fir	11.97
Ponderosa pine	6.91
Lodgepole pine	10.53
Spruce/fir	14.00
Grand fir/white fir	5.12
Blue spruce	0.15
5-Needle pines	1.16
Misc. sfwd. timberland	2.31
Aspen	6.83
Misc. hrwd. timberland	0.75
Pinyon-juniper	33.32
Misc. hrwd. woodland	6.63
Other timberland	0.32
Stand origin	
Natural	99.40
Planted	0.60
Stand size	
Sawtimber	59.59
Poletimber	30.42
Seedling/sapling	9.01
Non-stocked	0.98
Stand age* (years)	
0–50	13.02
51–100	52.92
101–150	25.87
151–200	4.90
201–250	1.53
250+	1.76

Stand-level category	% of plots
Number of seedlings/acre	
0–999	74.96
1000–1999	10.96
2000–2999	4.97
3000–3999	2.54
4000–4999	1.54
5000–5999	1.26
6000+	3.77
Number of snags/acre	
0	35.82
1–24	41.40
25–49	13.15
50–74	5.17
75–99	1.93
100+	2.53
Basal area (ft.^{2})/acre	
0–39	21.59
40–79	21.98
80–119	21.93
120–159	18.17
160+	16.33

* Woodland forest types (207.64 plots) are excluded from stand age.

Appendix C: Total Tree and Regeneration Counts



* Mature Trees are those greater than 5.0 inches at breast height or root collar. Species marked with a (w) were measured at root collar due to typically irregular form at breast height.

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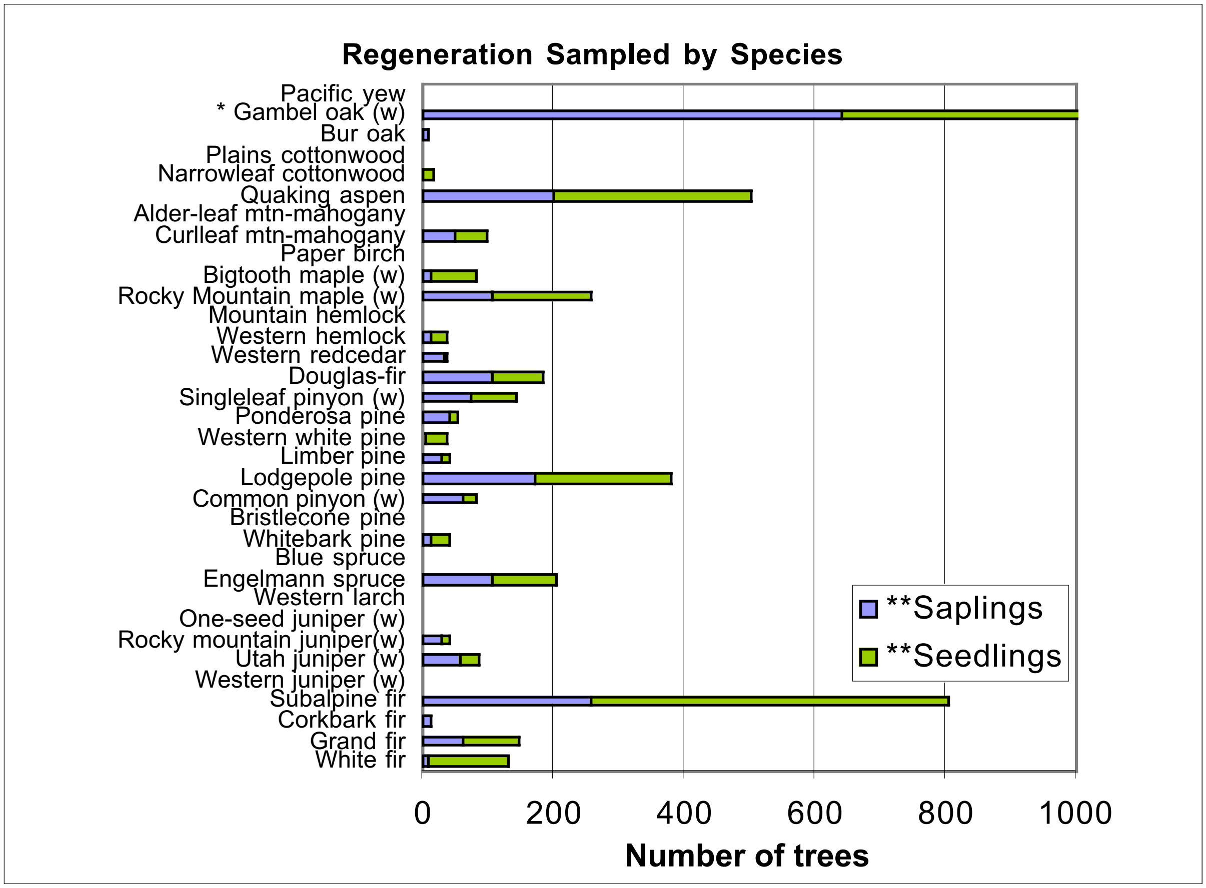
Appendix C: (continued)

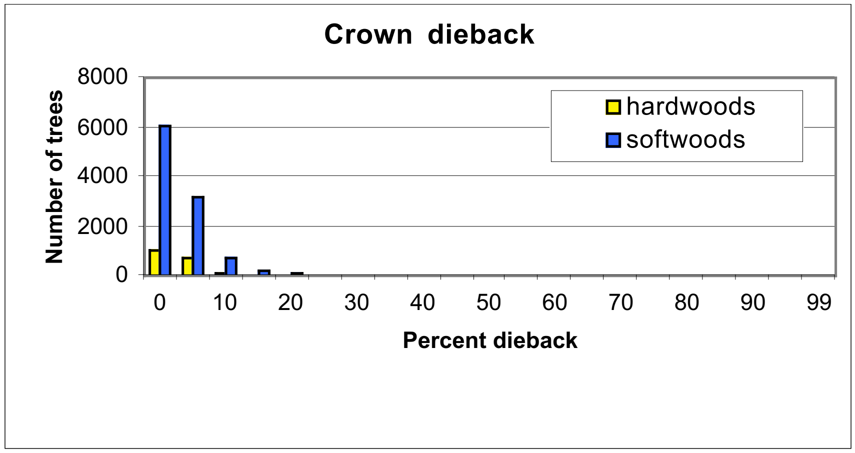


* Actual number of gambel oak seedlings is 1,779. To improve the overall graphic, the full number was not displayed here.

** Saplings are trees with diameters between 1.0 inches and 5.0 inches at breast height or root collar. Saplings marked with a (w) were measured at root collar due to typically irregular form at breast height. Seedlings are trees less than 1.0 inches at breast height or root collar and greater than 1 foot in total height.

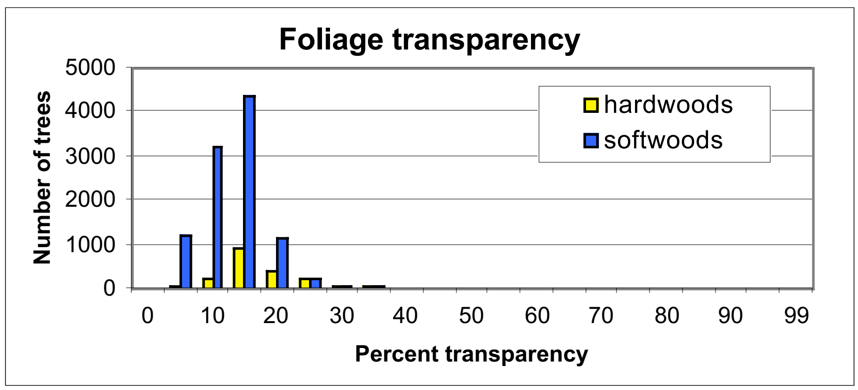
Appendix D: Interior West Crown Conditions

***Dieback** is the percent of the tree crown that has died from the branch tips inward toward the center of the crown. The graph here clearly shows that most trees in the region have little or no dieback. Only 1.2% of all trees in the region have a dieback of more than 25%. Dieback over 25% is more prominent in hardwoods (3.1%) than softwoods (0.9%).

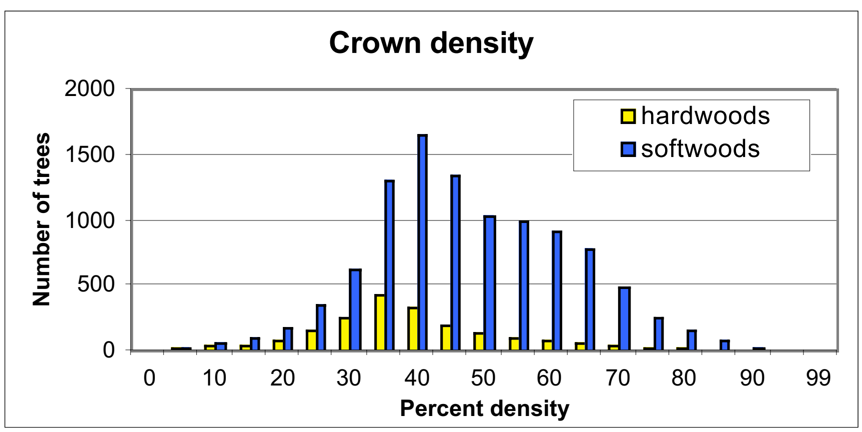


*** Total crown sample:**
Hardwoods = 1,946
Softwoods = 10,293
Total = 12,239

***Transparency** is the percent of light that passes through the foliated part of the crown, excluding tree branches and main stems. Most trees in the region have transparencies from 10–20%. Overall, there are 2.4% of trees with greater than 25% transparency. Hardwoods have a significantly greater percent (8.1) than softwoods (1.4) of transparency ratings over 25%.



***Density** refers to the percent of the crown area that blocks light from passing through. This rating does include the woody portions of the crown, so it is not the exact opposite of foliage transparency. Currently, 94% of all trees fall between 25–75% density. Trees with less than 25% density are likely showing signs of severe decline, while most trees with greater than 75% density will be generally vigorous. Higher percentages of hardwoods (8.4) than softwoods (3.5) have density ratings below 25%.



Appendix E: Regional Distribution of Damage Types by Species for Live Trees (5 inch dbh/drc and larger)

	trees with no damage (%)	# damages recorded**	cankers	conks and decays	open wounds	resinosis	cracks and seams	broken bole	brooms on bole	broken roots	loss of apic. dominance	broken branches	excess. branching	damaged shoots	discolored foliage	other
Softwoods																
Douglas-Fir	1116 (87)	199	15	34	14	7	1	2	0	0	69	26	30	0	1	0
Ponderosa Pine	322 (80)	110	7	14	26	0	3	0	0	1	20	10	19	0	10	0
Lodgepole Pine	1466 (71)	810	117	92	221	10	4	3	2	1	140	69	139	0	11	1
Subalpine Fir	982 (81)	281	59	60	41	7	4	4	2	1	65	29	5	0	4	0
Engelmann Spruce	921 (84)	212	23	18	34	23	2	0	0	3	61	39	9	0	0	0
Other Softwoods	927 (84)	218	11	61	40	3	4	4	0	2	57	20	3	1	11	1
Softwood Woodland	2007 (65)	1580	35	83	738	22	0	15	0	4	160	453	46	3	21	0
Subtotal, Softwoods	7741 (75)	3410	267	362	1114	72	18	28	4	12	572	646	251	4	58	2
Hardwoods																
Aspen	693 (56)	756	328	238	60	3	2	2	0	0	65	51	0	7	0	0
Cottonwood	28 (52)	31	0	14	3	0	0	0	0	0	6	8	0	0	0	0
Other Hardwoods	13 (62)	9	0	2	1	0	0	0	0	0	4	2	0	0	0	0
Hardwood Woodland	413 (64)	281	2	19	59	0	0	4	1	0	27	117	13	36	3	0
Subtotal, Hardwoods	1147 (59)	1077	330	273	123	3	2	6	1	0	102	178	13	43	3	0
Totals	8888 (73)	4487	597	635	1237	75	20	34	5	12	674	824	264	47	61	2

Total sample size = 12,239 trees

** # of damages recorded may include multiple damages, up to 3, for individual trees.

Appendix F: Data Available From FHM Plots

Variable name	Data type*	Variable name	Data type*
MENSURATION, CROWNS, DAMAGE			
Plot level			
County number	code	Current plot status	code
Elevation	num.	FHM region	code
Hexagon (location number)	num.	Measurement type	code
Overlap	code	Old plot status	code
Panel	code	Quality assurance status	code
Plot mensuration year	num.	Plot number	num.
Plot status	code	Plot type	code
Project	code	State	code
Condition level			
Condition class	num.	Condition class change	code
Density check	code	Disturbance year 1	num.
Disturbance year 2	num.	Disturbance year 3	num.
Forest type	code	Land use class	code
Past disturbance 1	code	Past disturbance 2	code
Past disturbance 3	code	Previous stand age	num.
Stand age	num.	Stand origin	code
Stand size	code		
Tree level (trees, saplings, site trees)			
Basal area factor (site tree)	num.	Cause of death	code
Competing basal area	num.	Crown density	num.
Crown diameter (mean)	num.	Crown dieback	num.
Crown light exposure	code	Crown position	code
Crown vigor (saplings)	code	Current tree history	code
DBH(diameter breast height)	num	DRC (diameter root collar)	num.
Damage 1–3	code	Description (tree notes)	alpha.
Foliage transparency	num.	Ground year	num.
Live crown ratio	num.	Location (damage) 1–3	code
Mortality year	num	Nonforest year	num.
Old DBH	num.	Old DRC (woodland)	num.
Old stem count (woodland)	num.	Old tree history	code
Severity (damage)	code	Species	code
Stem count (woodland)	num	Tree age at DBH	num.
Tree height	num.		
Understory cover and seedlings			
Crown light exposure	code	Crown position	code
Crown vigor	code	Percent ferns	num.
Percent herbs	num.	Percent moss	num.
Percent seedlings	num.	Percent shrubs	num.
Seedling count	num.	Species	code

*Data types: num. = numeric value code = numeric code alpha. = letters or words

(con.)

Appendix F: (continued)

Variable name	Data type*	Variable name	Data type*
SOILS (soil sampling, erosion)			
A texture	code	A thickness (N,S,E,W)	num.
Depth to subsoil	num.	Litter decomposition	alpha.
Litter depth 1–3	num.	O thickness (N,S,E,W)	num.
Percent bare (mineral) soil	num.	Percent litter cover	num.
Percent plant cover	num.	Slope length	num.
Underlying texture	code		
OZONE BIOINDICATORS			
Amount of injury	code	Bio site availability	code
Bio site disturbance	code	Bio site status	code
First species	code	Number of plants 1–3	num.
Plot moisture	code	Plots size	code
Second species	code	Severity of injury	code
Soil depth	code	Soil drainage	code
Third species	code		
LICHEN COMMUNITIES			
Species	alpha.	Abundance	code

Appendix G: Contacts for Further Information...

Kenneth Stolte
Acting National Program Manager
USDA Forest Service
Southern Research Station
3041 Cornwallis Road
Research Triangle Park, NC 28802
(919)549-4022

David A. Anderson, Director
Renewable Resources
Rocky Mountain Region
USDA Forest Service
P. O. Box 25127
Denver, CO 80225
(303)275-5026

Leonard Lucero, Director
Forestry and Forest Health
Southwestern Region
USDA Forest Service
517 Gold Avenue, SW
Albuquerque, NM 87102
(505)842-3240

William Boettcher, Director
Forest Health Protection
Intermountain and Northern Regions
USDA Forest Service
P.O Box 7669
Missoula, MT 59807
(406)329-3280

Dwane Van Hooser,
Interior West Program Manager
Rocky Mountain Research Station
USDA Forest Service
507 25th Street
Ogden, UT 84401
(801)625-5388

Forest Health Monitoring Web Sites:

National Program: www.na.fs.fed.us/spfo/fhm
Regional Forest Health Protection Sites: www.fs.fed.us/r2/fhm/
Regional Forest Inventory/Analysis: www.fs.fed.us/rm/ogden/index.html

Appendix H: Related Reading

Atkins, D.; Byler, J.; Livingston, L.; Rogers, P.; Bennett, D. 1999. Health of Idaho's forests: a summary of conditions, issues, and implications. Report No. 99-4. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Forest Health Protection. 44 p.

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DeByle, N.; Winokur, R., eds. 1985. Aspen: ecology and management in the WesternUnited States. Gen. Tech. Rep. RM-GTR-119. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 283 p.

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Rogers, P.; Schomaker, M.; McLain, W.; Johnson, S. 1998. Colorado Forest Health Report 1992–95: a baseline assessment. Colorado State Forest Service, Fort Collins, CO, and U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT, and Rocky Mountain Region, Denver, CO. 44 p.

Spiegel, L.; Rogers, P.; Frank, M.; Atkins, D. 2001. Wyoming forest health: a baseline report. In press. Wyoming State Forestry Division, in cooperation with U.S. Department of Agriculture, Forest Service, State and Private Forestry, Denver, CO and Forest Service Research, Ogden, UT.

Stolte, K. 1997. 1996 National technical report on forest health. FS-605. Washington, DC: U.S. Department of Agriculture, Forest Service. 47 p.

U.S. Department of Agriculture, Forest Service. 1996. Status of the Interior Columbia Basin: summary of scientific findings. Gen. Tech. Rep. PNW-GTR-385. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; U.S. Department of the Interior, Bureau of Land Management. 144 p.

RMRS
ROCKY MOUNTAIN RESEARCH STATION

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 National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals.

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