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COVER STORY

The spectacular cover photograph was taken by Sam Chase, an oil-industry employee, on a work-related flight from Sacramento to Bakersfield, California, the morning of December 20, 1977. In the photo, an enormous plume of dust sweeps out of the Tehachapi Mountains and rises 5,000 feet above the southern San Joaquin Valley. It vividly illustrates how natural forces extend human disturbances on arid lands, resulting in severe erosion. In this case an extreme wind storm was stripping overgrazed lands, unprotected farmlands, urban developments, and dirt roads and tracks. All are especially vulnerable to wind erosion.

When the small plane took off from Sacramento, Bakersfield Airport's pre-recorded weather report spoke only of morning fog and light winds. The storm's violence had kept airport workers at home, unable to change the recording. Approaching Bakersfield, everyone on the plane could see the futility of trying to land there. Sam took the photograph after the plane turned east to Tehachapi—apparently he and the pilot were the only ones who hadn't lost their stomachs.

The incredible record left by this storm is unparalleled in the geologic literature, and we are grateful to Sam for making this unique photograph available.

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We dedicate this work to our family—Ruth and Dave, David, Paul, and Collette, Ben, Owen, and Scé, and our grandchildren David Hiroshi and family, Ayako, Amanda, Ann, Jacob, and Daniel Miyahara; and Madalyn and Nathaniel Wilshire—and to their futures. It is also dedicated to our students, who give us hope that the western United States and the world can support the communities of living things that support us all.

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Our intent in preparing this book was to open the scientific knowledge of environmental issues to nonscientists, especially to citizens concerned about environmental problems in their own communities, and to lawyers and reporters trying to make sense of competing legal and political claims. Taking a leaf from the popular-science guides of our beloved former U.S. Geological Survey colleague N. King Huber, we sought out chapter critiques from many nonscientists of our acquaintance. Their influence on the writing has been profound. We owe very special thanks to Dee Cope, a skilled technical editor and dear friend, who critiqued all chapters, including the most difficult subjects. Among the many others who shared their time and thoughts on how to explain technical information to nonspecialists, we especially thank independent environmental and science film makers Doug Prose and Diane LaMacchia; citizen-activists Ernest Goitein, Claire Feder, Olive and Henry Mayer, and H. R. Downs; ecologist-activists Edie and Jim Harmon;

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Above all, we salute the many devoted public servants at all levels of government, who try earnestly to make sure that federal, state, and local policies are based on valid scientific data and analyses, against political pressure and on slim funding. We also salute the land managers in the field, who continually must contend with angry citizens expressing many different viewpoints about how they should be doing their jobs. We once toiled among you, and we recognize your desire to do what is best for the environment, while facing the demands of a growing population and the need to feed yourselves and your families.

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Introduction Obeying Nature

Science…does not compromise.…[It] forces ideas to compete in a dynamic process. This competition refines or replaces old hypotheses, gradually approaching a more perfect representation of the truth.…The natural process of a bureaucracy…tends to compromise competing ideas. The bureaucracy then adopts the compromise as truth and incorporates it into its being.
John M. Barry, *Rising Tide*

This book focuses on the human-caused environmental woes of America's 11 contiguous western states, its mostly arid western continental frontier. In the nineteenth century, penny pamphlets and dime novels mythologized the American west, making icons of its prospectors, "cowboys," northwestern loggers, and wide open spaces. The west was free of encroaching neighbors and government controls, open to fresh starts. As Robert Penn Warren wrote, in *All the King's Men*, "West…is where you go when the land gives out and the old-field pines encroach…when you are told that you are a bubble on the tide of empire…when you hear that thar's gold in them-thar hills.…" But the "West" was more than gold and oil bonanzas—it was also a land of rich soils, bountiful fisheries, immense, dense forests, desert wonders, and sparkling streams. It is no myth that the western states were America's treasure house.

The romantic myths related to "winning" the west tend to obscure both its basic objective of resource exploitation and the huge public expenditures that supported every aspect, bestowing fortunes on a few. Western resources supported U.S. industrial growth and affluent lifestyle, but now they are highly depleted or largely gone, and the region is in danger of losing the ability to sustain an even moderately comfortable future. Much of what we have done to these magnificent lands opened them to devastating erosion and pollution. Today, whole mountains are being dismantled to produce metals from barely mineralized zones. Entire regions may be devastated in the attempt to extract the last possible drops of petroleum. We soon could cut down the last remnants of ancient western forests, along with the possibility of ever again seeing their like. Large-scale farming has opened vulnerable western soils to erosion by water and wind, perhaps inviting another dust bowl era. Irrigating vast crop acreages has converted many of them to salt farms, perhaps resembling the conditions that spelled doom for the ancient Babylonian Empire.

The how and why of these risks—the past and impending losses—are the theme of this book, along with proposals, strategies, hopes, and even *fantasies* about how to salvage what is left and rebuild western lifelines. Most chapters describe land uses that degrade and deplete this slow-healing, mostly arid region—and especially its public lands. Each one explains how natural forces spread the negative impacts of forest clearings, farming and grazing, mining, roads and pipelines, all aspects of military training and weapons manufacturing and testing, urbanizing sprawl and excessive water developments, recreation, waste disposal, and energy extraction and use—resulting in severe erosion and flooding, reduced and compromised water supplies, and degraded air quality. We address manufacturing impacts under most of these headings. The final chapter explains the basic natural processes themselves, and a glossary defines scientific terms and concepts.

The authors expect that environmental science and analysis teachers and students may use this book, but also intend it for a guide for lawyers, journalists, other researchers, and people with environmental problems in their own neighborhoods. To help our audience understand the technical issues, we have endeavored to present them in terms that the general reader can understand. Clearly, no single book could possibly cover all the issues, case studies, and implications of these topics—some have whole libraries devoted to them. Each chapter is supported by detailed references for deeper exploration, which support the text and provide resources for the reader's class projects or local issues. Additional references, and an alphabetical bibliography, can be found on the Web site www.losingthewest.com.

The scientific information we rely on is backed by the best and most highly validated research and analyses that we could find, free from the influence of special interests. Most of it was performed by government or academic scientists at public expense. Many of the studies are published in peer-reviewed journals, but a very large component exists in academic and governmental reports that most citizens barely or never hear about, let alone see. The prose in these limited-distribution reports often features intractable jargon that would defeat nonscientist readers. Many chapters lean heavily on our own observations or detailed geologic research in nearly every western state—in particular, lead author Howard Wilshire's many published studies on human surface impacts.

Seeing the television images of Neil Armstrong's footprint on the soft lunar surface in 1969—so much like dry desert soils—Howard wondered how long that print would last in the Moon's airless and rainless environment. A colleague's calculations suggested that it will be recognizable more than a million years from now, setting Howard to examining his own tracks on desert streambeds and dark pebble-mosaic surfaces. Immediately, he realized they were no different from the marks of the burgeoning and abrasively noisy off-road motorcycles and dune buggies that were shattering his prized desert silence. He then began investigating the fate and durability of human imprints on the Earth under the eroding, transporting, and depositing processes of gravity, rain, and wind.

Since then, Howard has studied the impacts of motorized off-highway recreation (chapter 11), coal mining and mine reclamation projects (chapter 4), mountaintop wind farms (chapter 12), roads and pipelines (chapter 5), and the recovery of old mining ghost towns and military camps, including still-visible tank tracks and trampled base camps from World War II troop training (chapter 6). With colleagues from the U.S. Geological Survey, he also critiqued the site-selection procedures for a proposed nuclear waste dump (chapter 10). Along with Howard, Jane

Nielson and Richard Hazlett have performed geologic studies for evaluating the mineral resources of proposed wilderness areas and have performed numerous environmental reviews of proposed developments, required by state and federal environmental laws. Jane and Rick also bring to this book strong backgrounds in forestry, groundwater, energy, agriculture and grazing, and environmental toxicology issues. All the authors have helped journalists, lawyers, and concerned citizens comprehend research bearing on a multitude of environmental issues, and all have taught university-level courses in addition to performing research for the U.S. Geological Survey.

The host of valid scientific investigations that we cite, and many others, strongly indicate that preserving as much of the natural world as possible is essential to sustaining human health and safety, as well as the future food supply. Like many or most Americans, we once uncritically accepted the inevitability of human "progress" and ignored its Earth-degrading aspects. We expected to find that past and current human land uses do not preclude a prosperous future, but finally have accepted that most data point the other way. As Shakespeare's contemporary Sir Francis Bacon reputedly put it, "Nature, to be commanded, must be obeyed." That being the case, an understanding of Earth processes, and the significance of their biological connections, is a critical frame for societal and governmental attitudes toward the Earth and natural processes—and, in particular, for framing national land-use policies. These connections inevitably lead science into the murkier realms of bureaucratic stasis and political conflicts.

Land uses always have political implications. The federal government funded nineteenth-century western exploration, including many scientific investigations. The government also supplied the conquering armies that secured the west for Euro-American settlement and exploitation and gave away lands and support for settlers in all directions. Many federal policies have contributed and still do contribute to degrading the west and depleting its resources. Sadly, some government science has been done very badly, to the detriment of all Americans and at the hazard of many lives. In the following chapters, we discuss many past and current political conflicts over western land uses and the environmental consequences, and try to expose the misguided science that supported some very bad outcomes. The issues do not necessarily pit environmentalists against landowners or named political parties against each other, nor do they invoke right versus left splits. Some draw all these strands together. The policies and laws that we espouse are ones that good science and practical experience indicate can help us obey nature and better protect us from nature's worst ravages.

In 1968, University of California Professor Garrett Hardin published "The Tragedy of the Commons,"[1] a now-famous essay on the tendency of people to overuse and destroy any finite resource that anyone can access without restriction, especially under growing population pressure. Hardin likened such resources to the New England town commons, which were open grazing lands for many generations. It is easy to compare those commons to America's overused public lands, but Hardin pointed out that the atmosphere and water bodies, which nobody owns—including rivers, lakes, groundwater, and oceans—also are commons. Their ability to absorb all our waste is finite in terms of human life spans. Continuing to use them as dumping grounds is what destroys these life support systems for us as well as for wildlife. The multiple threats from human-accelerated global climate warming, only now becoming obvious, vividly illustrate the severe consequences of using the environment for a dumping ground.

Hardin and others have pointed out that overusing these common resources has allowed businesses to keep profits high. By not having to pay royalties for using up resources, or for cleanup or disposal, industries can raise their bottom lines. Misuses of public lands and private crop lands represent the "externalized" costs of doing business. But someone always pays, and in the United States, taxpayers suffer from polluted air and waterat the same time that they subsidize private farmers, public lands graziers, and the private companies that log and mine the public's lands. More recently, Paul Hawken and colleagues[2] have noted that natural resources—and the natural processes that create those resources—are the support for industrial economies. The functions of nature have substantial financial values that are ignored at great peril. They should be considered "natural capital" and factored into industrial balance sheets.

More than a century ago, a rising public consciousness began to recognize the value of preserving and protecting natural lands. That conservation movement gave rise to national parks, national forest preserves, and other land-conserving political movements. It also created land management roles and conservation and preservation mandates (figure I.1) for a number of federal agencies, including the U.S. Department of the Interior's Bureau of Land Management, Fish and Wildlife Service, Bureau of Indian Affairs, Bureau of Reclamation, and National Park Service; the U.S. Department of Agriculture's U.S. Forest Service; and even the U.S. Department of Defense. Many states created management agencies for state lands in the same time frame; however, broader agency mandates include such diverse and sometimes irreconcilable agendas as national security, economic enterprise, and local resident interests.

Since the early 1960s, national environmental laws—notably the Wilderness Act, the National Environmental Policy Act, the Endangered Species Act, the Clean Water Act, and the Clean Air Act—have reached beyond public lands to preserve or restore a clean and safe environment *virtually everywhere* in the United States. Again, many western states followed suit. These noble and ambitious laws are based on valid scientific principles, drawing especially on the fields of chemistry, hydrology, and ecology. They have taken America a long distance toward clearing our air and water natural capital sectors, and protecting native species and natural lands for the economic and other benefits that they provide to humankind. It would be hard to overestimate how much worse off our environment would be without them.

National and state bureaucracies do not always implement or rigorously enforce the landmark environmental laws and regulations as the framers had envisioned, however. There is still a long way to go before America's rivers and streams are "swimmable and drinkable" as envisioned by the Clean Water Act, for example. And certainly many good-seeming laws have unintended negative consequences.

Since 1980, the very idea of regulating land uses, and air and water quality, has come under attack—along with attacks on the very existence of public lands and the credibility and relative neutrality of science itself. Rejecting regulation, the anti-public lands movement has warped Garrett Hardin's concerns to suggest that all lands should be in private hands. Public relations "sound science" campaigns tout alternative information or trumped-up "controversies" that support a favored project, and question valid data that could obstruct a dump, resort, or expanded

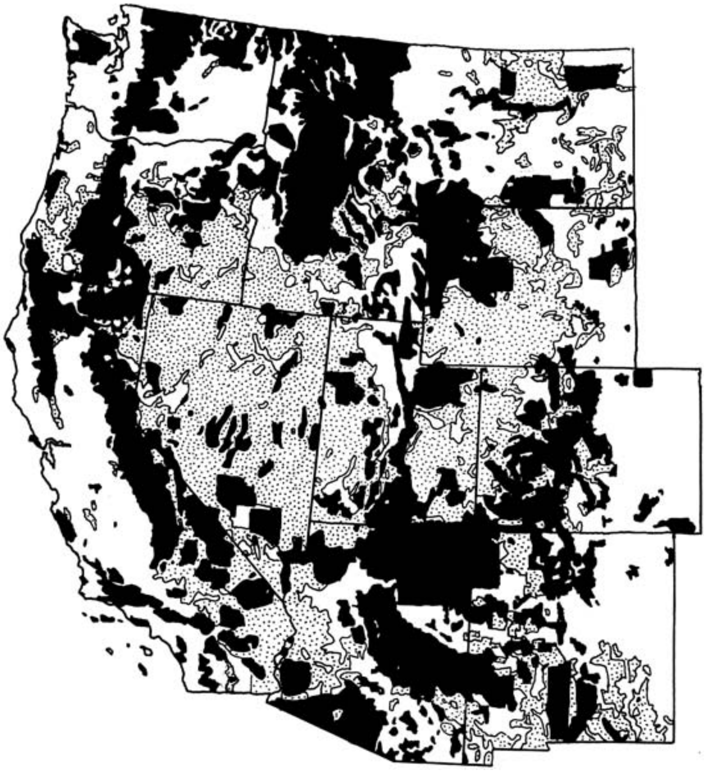

Figure I.1 Map showing public and private lands in the 11 western states. The U.S. Department of the Interior Bureau of Land Management oversees the largest public acreage by far (stippled), and the rest (shaded black) is managed by the Department of the Interior's National Park Service, Bureau of Indian Affairs, Bureau of Reclamation, and U.S. Fish and Wildlife Service; by the U.S. Department of Agriculture Forest Service; and by the U.S. Department of Defense. Private lands are shown in white.

bombing range "only" to protect fish, birds, insects, lizards, or the habitats that support them. Many scientists are poor at public relations and have had a difficult time defending their research from false charges of poorly framed studies, of overly alarmist conclusions, or, ironically, of bias. And some scientists fear seeming strident or less than objective, even in defense of natural systems, preventing them from speaking out for better policies at federal and state levels. Tragically, some of the best government scientists have come under more and more political control and have seen the hearts cut out of their data-based technical reports in order to support the policies of one federal administration or another.

Western U.S. public lands, about 47% of the region, are this nation's patrimony—the bulk of its remaining natural capital. As Garrett Hardin pointed out, allowing free use of them will mean utter destruction. There is still a lot to save, and much of the damage can be reversed. But utter destruction is the risk that the nation is taking, and what we authors hope to avoid. Theoretically, the west's public lands belong to every American citizen, and we all have a stake in how the public lands are managed and how our food is grown, especially since so much public money goes into it. Environmental laws give the public the most say about land uses on both public and private lands, and our democratic form of government also gives the public a say about how the public purse is managed.

Citizen engagement is the first step on the trail toward working with, instead of against, nature. The lack of an ongoing discourse between scientists and the public obscures many critical issues, however, and most are not easily generalized for public consumption. Print journalists still produce excellent investigative reports on scores of environmental hazards and their effects on our lives, but apparently fewer people are reading them. The broadcast media is less patient and less focused, so it cannot explore the scientific nuances. Television and radio reports often highlight apparent controversies instead of investigating what may lie behind conflicting presentations, even when one side has an obvious bias.

But we authors find that Americans overwhelmingly want to protect their environment. More than half the public understand viscerally that wildlife and wild lands are important to their well-being and want to know more about how these connections are made. Although national park use may be down, Americans cherish the existence of parks and public forest lands and understand the need for wilderness protection. They cherish and even identify with their local natural areas. It is the authors' hope that this book will help to increase and broaden public awareness of the risks from overuse and misuse of America's western lands, and help citizens to better address national and local land use issues.

Not surprisingly, we have failed to come up with many easy fixes. Most of the ideas are practiced and practical but take a long time to bear fruit. Some of our fantasy solutions, or approaches to solutions, may be our readers' nightmares. If you don't like our solutions, please invent some of your own—just be sure that they obey nature.

1 Once and Future Trees

Forêts précèdent les peuples, et les déserts les suivent. (Forests precede civilizations and deserts follow them.)
Chateaubriand (1768–1848), quoted in Aldous Huxley, *The Human Situation*

I am trying to save the knowledge that the forests and this planet are alive, to give it back to you who have lost this understanding.
Paulinho Paiakan, Kayapo Leader, Brazil, 1990

Along the Colorado Plateau's high-standing Mogollon Rim in northern Arizona's Coconino National Forest stands a small patch of big trees that matured well before Europeans came to North America. Massive ponderosa pines, and even pinyon pines and western junipers, tower above the forest floor, shutting out all but the most shade-tolerant competitors. Few places like this one still exist anywhere in the United States, even on national forest lands. A tourist hoping to see all the diversity that earliest European arrivals found commonplace in the western landscape must seek out a wide scattering of isolated enclaves across the region.

Western forests no longer contain the grand glades and lush thickets that our forerunners encountered because most woodlands, especially those owned by the public, largely serve a wide variety of human purposes, as campsites or home sites, board-feet of lumber, potential jobs, recreational playgrounds, and even temples of the spirit. We also rely on forests to maintain habitat for endangered species and seed banks for restoring depleted biodiversity—and to provide us with clean air and water, stable hillside soils, and flood control in wet years. Forests must perform these roles while being consumed, fragmented by roads, and heavily eroded. But there is no guarantee that these most beloved and iconic of natural resources can sustain such a burden.

Federal, state, and local government agencies oversee and regulate western U.S. forest lands and their uses, trying to manage the complex and only partly understood biological interactions of forest ecology to serve public needs. But after nine decades of variable goals, and five decades of encroaching development, western woodlands are far from healthy. Urban pollution and exotic tree diseases, some brought by humans, are killing pines, firs, and oaks. Loggers have more than decimated the oldest mountainside forests—most valuable for habitat and lumber alike—with clearcutting practices that induce severe soil erosion. Illegal clearings for marijuana farms are increasing. Drought, following a long history of too much fire prevention, promotes widespread, devastating fires. Salvage logging follows the fires, promoting more erosion and habitat losses.

As these stresses converge toward a crisis, rapid climate warming is reducing the survival potential of many tree species, if not of entire interdependent plant and animal communities (ecosystems). If the climate warms too fast and droughts stretch out, many of our highly logged and trampled and driven-over western forests could perish, depriving us of all their critical services.

Preserving Forests for the Trees

Trees have served humanity's economic and spiritual needs and wants as long as people have lived on the Earth. Before and after the rise of civilizations, people cleared woods for farming, cut trees for building shelters, and burned them to cook food and keep warm.[1] Over the last 10,000 years, extensive and pervasive human uses, for firing pottery and smelting metals; making tools, paper, and other equipment; and building communities, boats, roads, and vehicles have radically transformed the world's forests. While ancient Mycenean and Greek cultures venerated trees and preserved many sacred groves for religious rituals,[2] their unregulated forest cutting also denuded hills and mountains. Severe erosion followed, stripping upland forest soils and flooding huge sediment loads into rivers. The eroded forest soils choked harbors and pushed coastlines seaward from important coastal cities such as Ephesus, Troy (Illios), and Mytelene,[3] which ended up landlocked or buried under sediment.

Like the ancients, European civilizations long depended on forests for their primary energy source—as critical then as petroleum and coal are to us now (see chapter 12). Ships made of wood were essential to navigation and economic expansion until the latter nineteenth century. By the seventeenth century, farmland clearings and massive construction projects, including whole navies, had severely reduced the size and quality of northern Europe's timber resources—a classic illustration of Garrett Hardin's 1968 "Tragedy of the Commons." A worldwide search for ship masts ensued, dictating both foreign policy and military actions from the Baltic to the New World.[4] Once global explorers discovered vast Asian and American timberlands, Europe's rulers established colonies to exploit them, among them the founding settlements of these United States.

The European settlers moved into forests of the temperate zone, between the Tropic of Cancer and the Arctic Circle. These forests covered about a billion acres of what is now the contiguous United States. Native Americans had made impacts upon the woods, yet mature stands of large to giant trees from several hundred to several thousand years old were abundant and widespread. To avoid words laden with scientific controversy and legal confrontation, we refer to these pre-Columbian North American woodlands as "heritage forests."

Although mostly arid, the west harbors dense, undulating stands of trees hugging the northwestern coast—still the world's most impressive stretch of temperate rain forest. Interior forests grow mostly in the mountains, the islands of moisture punctuating dry prairies and deserts. The largest, tallest, and oldest trees on

Earth—the great groves of coast redwoods and stately Douglas firs; monumental giant sequoia; gnarled, weather-beaten timberline bristlecone pines; and dark, coastal fog-moistened spruce and yew—all grow in the west.

Few of the heritage forests are left today. The remaining scraps cover less than 63 million acres, around 6% of the original.[5] North America's earliest settlers saw no reason to preserve forests that could harbor hostile Indians and predatory animals. Wrote one, "Upon first glance, the woods gave . . . the impression of a 'wild and savage hue. . . .'"[6] For many generations, most Americans accepted clearing forests as virtuous activity. Except in a few early forest reserve areas, they indulged in unchecked cutting and logging until the early twentieth century. Forests representing almost all major ecosystems have been logged over at least once, or converted to myriad human uses.[7]

By 1907, agricultural clearings, mostly in the eastern states, had shrunk U.S. woodlands some 28%,[8] raising the possibility that rapacious lumber companies and railroad interests could denude America of its forests. Leading foresters and politicians of the day seemed to understand that forest processes were important "natural capital"—predicting that the nation could be facing not only a timber famine, but also the loss of precious topsoils similar to what happened in Mycenean Greece, along with depleted groundwater supplies and degraded water quality. They also feared that loss of evapotranspiration from trees—the process of drawing water from the ground through plant roots, upward through stems or trunks, and releasing it through leaves or needles—might even dry the climate.[9]

As it turned out, formally classified U.S. forest land declined only 2% after 1907 even though the global demand for wood products increased fivefold between 1900 and 2000. This was due to a combination of social forces and enlightened government regulations, which helped the United States avoid timber famine and complete forest denudation. Fossil fuels replaced wood (see chapter 12), and plastics manufacturing from petroleum (see appendix 3) began shifting the world toward substitutes for many wood products. Meanwhile, the federal government enacted nationwide forest management policies that allowed American forests to recover, also preserving many heritage forest remnants in national parks and forest reserves. Millions of farmers moved from low-quality or degraded farm lands to find work in cities (see chapter 2), and forests regrew on those lands, as well. Also, after World War II, the United States imported foreign lumber in tremendous quantities.

Forests of predominately native tree species still occupy about 70% of the 1620-era woodlands nationwide.[10] But the overwhelming majority of American forests now mostly contain small-diameter trees, no more than 30 inches across, from the second or third regrowth cycle. Only about 7% of American forests are protected in national and state parks, wilderness areas, and other conservation reserves.[11] And large forest regions are in the process of conversion to other uses as you read these pages.

Most western forests are on federal public lands, variously under the supervision of the U.S. Department of Agriculture's Forest Service (USFS) and two U.S. Department of the Interior agencies, the National Park Service (NPS) and Bureau of Land Management (BLM). State and county preserves protect some heritage forest stands, especially in California, and environmental groups have purchased a number of others.

The national forests, under USFS management, were born in the early twentieth century after the most productive and accessible forests, generally on lowlands, had come under private ownership. The remaining timber stands mostly were in steep remote terrain, which private landholders had spurned as less accessible and generally less productive. Up to WWII, the abundance of private timber, and the difficulty and expense of logging mountainsides far from any road, protected the trees in national forests. But when demand for forest products surged after the war, logging severely depleted the private forests, leaving national forests the nation's largest timber resource.

Although the remaining groves of great old trees are only a few percent of the nation's remaining harvestable timber acreage, they contain greater volumes of relatively unblemished wood than equivalent acreages of regrown timber. The old forests also are principal habitat for dwindling native North American wildlife. Campaigns for preserving them are intended largely to save the life support of threatened and endangered species. Nature worshipers and recreating urbanites—a vocal and active segment of the citizenry—also campaign to preserve heritage groves as monuments of the spirit. Some of the preservation campaigns have turned into mystical experiences. Perhaps the apotheosis of modern tree worship is Julia Butterfly Hill, who lived high in the branches of a coast redwood for more than two years, developing a close personal relationship with the tree named "Luna."

Julia Hill's tree-sitting campaign succeeded in saving just one heritage forest remnant, while commercial companies still get permits to cut in and around thousands more.[12] Ironically, many people hope to preserve heritage forests *and* continue consuming high-quality lumber for their homes, boats, and decks. The conflict between these disparate goals, both within individuals and across the culture, continues to inflame tensions over western U.S. forests.

Most people do not realize that there are even better reasons for saving forests—that trees' natural functions are just as important to human lives as to wildlife. *We need to save forests for the services that trees provide.* Trees are Earth's main source of airborne oxygen, absorbing carbon dioxide (CO_2) and releasing oxygen for people and all other animals to breathe. This same process of forest respiration also reduces the atmospheric greenhouse gas concentrations that drive rapid climatic warming. Trees also help purify surface and underground water. The clean water that forests provide is nearly as important for human survival and health as oxygen—and clean water is a critically declining resource (see chapter 9).

Former USFS chief Mike Dombeck has

> worried that we may, as a society, lose our appreciation of what the land does for us; why open space is important.... The fact that a single tree sequesters about 13 pounds of carbon each year. That a single tree produces enough oxygen for a family of four to breathe. The water filtration functions of the vegetation on the landscape. It's important for people to appreciate and connect to the land.[13]

Since extensive tree cutting on hill slopes commonly results in severe soil erosion and siltation, Dombeck might have added that trees add essential nutrients to the soils in which they grow, hold soil on slopes, and help prevent catastrophic floods (see chapters 5, 8, 9, 13). These are the top six reasons for humans to preserve forests and worship trees.

The Nature of Forests

USFS and BLM aspire to take over forest management from nature. So far, however, they have not proved that people can manage heritage forests to preserve natural ecosystems while extensively and intensively producing lumber, paper, and other commodities. Some conservationists clamor for the agencies to protect the old woods in their presettlement state or, slightly more realistically, return them to that state. To reach either goal requires better knowledge of the actual state of both the presettlement and today's forests, and also expertise in how to stabilize small remnant glades that are surrounded by clearings and second- or later growth woodland. The most difficult challenge is preserving the whole diversity of forest ecosystems, particularly in heritage forest remnants outside of parks and preserves. The first, most critical step is finding out how forests grew and thrived before intense human occupation.[14]

Woodlands are shaped by climate and the soils that they grow in. The old temperate forests of North America matured in temperate-zone soils, which resist degradation and erosion better than do soils in the tropics, where rainfall levels are extremely high. The temperate zone's lower rainfall and cooler climate make temperate soils good nutrient storehouses.[15] But understanding how temperate woodlands grow, what makes them thrive, and how best to preserve a forest or any other ecosystem, whether stressed by humans or by natural forces, remains the subject of considerable research efforts.

Biogeographer F. E. Clements[16] proposed that forests develop through broadly predictable plant succession processes, with intimate links between all the plant and animal species. Widespread-seeding, fast-growing "pioneer" trees easily colonize an unforested area, increasing shade and moisture as they mature. This critical first stage helps longer lived "successor" species spread their seeds, grow, and eventually take over. Clements demonstrated that a natural forest generally transitions through one or more successional stages (or "seres") over 100–500 years, eventually reaching a "climax" mix of forest species that may not change for millennia. The climax community's CO_2 absorption is more stable and sluggish than that of younger forests because the older forest promotes less new growth. A climax forest must age several centuries before achieving the full maturity of old growth (table 1.1).[17] The total soil nutrient and water use of old growth forests generally equal the combined weight of vegetation and animal life (biomass) in the ecosystem.

Plant succession processes create much of the biological diversity (biodiversity) in natural ecosystems. A typical succession pattern in western temperate forests starts after one or more of the natural destructive forces—high wind, natural fire, flood, drought plus beetle infestations, disease, landslide, volcanic eruption, and even meteorite impacts—open a clearing or a series of clearings. Pioneer grasses, wildflowers, and shrubs sprout very quickly in the clearing, and then successor

Table 1.1 Forest Successional Stages

Stage	Age Range (Years)
Young forest	1–70
Mature forest	70–150
Early old growth	150–250
Mid old growth	250–500
Late old growth	500–750

"Young," "mature" nomenclature based on figure 4 in: J. F. Franklin and T. A. Spies. Composition, Function, and Structure of Old-Growth Douglas-Fir Forests. In L. F. Ruggiero et al., eds. Wildlife and Vegetation of Un-managed Douglas-fir Forests. *USDA Forest Service* General Technical Report PNW-GTR-285, 1991;71-80. Available: www.humboldt.edu/~storage/pdfmill/Batch%205/unmanaged.pdf. Ends of ranges are not to be taken literally.

aspens, willows, and lodgepole pines grow up to replace them. If nothing else changes, these successors yield in turn to climax-stage firs, which dominate the forest until they die from old age, or until another disturbance clears them away and resets the ecological clock. The strongest support for Clements's succession model is the broad geographical extent of uniform forest communities across many mountain ranges in the American west, and even at common elevations and latitudes worldwide.

Ecologist A. S. Waitt's forest dynamics concept modified Clements's long-term successional model by accounting for the effects of short-term changes. Waitt showed that frequent events, such as fires and windfalls, down to and including the natural aging and death of individual trees, continually open up gaps in natural forests and create an ever-changing "gap-mosaic" architecture (figure 1.1).

> Following the death of a large tree and its fall, a canopy gap forms. The area below this gap becomes the site of increased regeneration and survival of trees. Trees grow, the forest builds, the canopy closes, and the gap disappears. Eventually, the mature forest in the vicinity of the former gap suffers the mortality of a large tree and the new gap is formed and the cycle is repeated.[18]

The gaps offer a large variety of habitats, maximizing forest biodiversity.

H. A. Gleason's contrasting "individualistic community" concept[19] proposes that a forest is simply a collection of individual trees, plants, and animals without significant codependent relationships, only coincidentally requiring similar ecologic conditions. The well-documented interdependence of plant and animal communities favor Clements's successional model, but this individualistic community concept is useful for understanding exotic plant invasions (see chapter 3), which can radically alter the survival prospects of native species.[20]

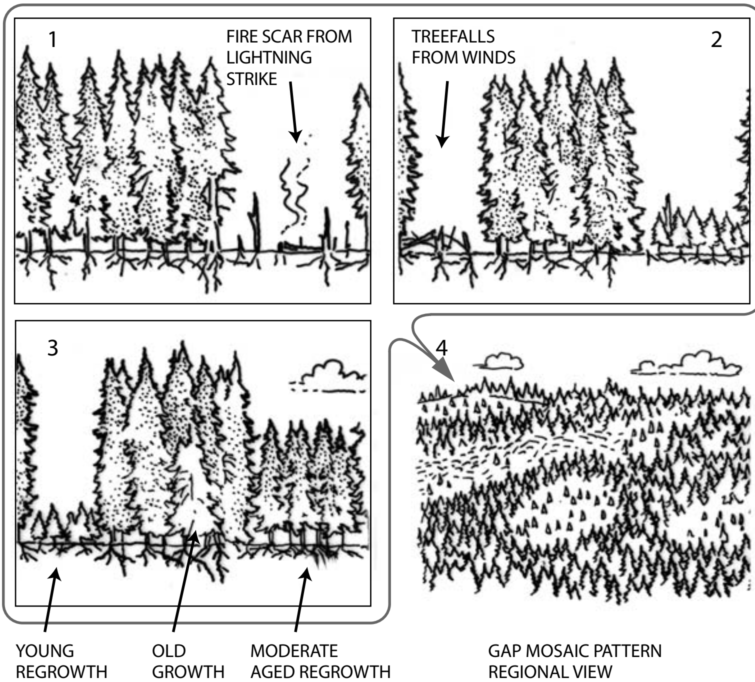

Figure 1.1 Evolution of gap mosaic structure in natural forests. Gaps periodically open from lightning strikes (1) and strong winds (2), as well as insect infestations, landslides, flooding, and trees dying of old age. Successor plants colonize gaps as they form (3), leading to a mosaic of differently aged trees and successional ecosystems (4).

Cataclysms

Climatic forces, along with other natural forces driven by gravity, the sun, and Earth's own internal heat engine, modify the land surface in many ways (see chapter 13). When a tree falls, a volcano erupts, or a vehicle impacts a hill slope or stream, natural forces start transforming the site through erosion, siltation, biological decomposition, and the like. All the forces operate continuously and interrelate complexly. Fossil tree leaves and branches, found in some sedimentary rocks—including thick coal seams (see chapter 12)—testify that natural forces periodically devastated forests before humans or their axes appeared on Earth.

One immense cataclysm, the Chicxulub meteorite that slammed into what is now Mexico's Yucatán Peninsula some 65 million years ago, destroyed vast tracts of North American forest. Natural processes reestablished plant cover and added animal species over about the next 10 million years. The resulting ecosystems were entirely different communities than before the meteorite impact.[21] Natural climate changes are much more common than meteorite impacts, or even volcanic eruptions or landslides, and pose the most serious long-range challenge to the survival of temperate-climate forests worldwide.

Climate variations have kept North America's forests in a state of continuous flux for at least five million years. Over the past two and a half million years, western North America was mostly moister and cooler than it is now. A number of times, glaciers—sheets of ice, some as much as two miles thick—emerged from far northern latitudes and blanketed the North American landscape as far south as Kansas. Glaciers also emerged from high mountain ranges, carving sloping river canyons into steep-walled valleys with broad, marshy floors, thus creating the topography of Yosemite, Glacier, and Rocky Mountain National Parks. During ice ages, warm intervals like the present occurred less than 10% of the time. Today's rapid warming, aided by human burning of fossil fuels, is much higher than would have been achieved by natural climate changes at this point in Earth history.

North American forests started adjusting to the warmer conditions when the most recent ice age ended, about 10,000 years ago. As the glaciers retreated, forests began to spread northward into areas that had been ice-covered for a hundred thousand years. This northward reforestation is still taking place. All this means that America's heritage forests developed in a relatively short period of climate and geologic stability within a much longer history of harsh, erratically changing conditions. At present, the basic mix of species in forest communities is changing on thousand-year time scales in many places—and in a few locations, the adjustments are happening much faster.[22]

Human factors

During ice ages, glaciers tied up such large volumes of water that ocean levels declined by hundreds of feet, turning shallow ocean floor into dry land bridges between continents and connecting areas that now appear as islands. As the last ice age ended, North America's Indian forerunners came from Siberia on a land bridge that now lies under the Bering Sea, together with large mammals such as the grizzly, moose, buffalo, and elk. Eventually, most of America's pre-Columbian human population lived in forests and cut trees to make lodges or tipis, canoes, and much more. Geographer Thomas Vale explained, "Pre-European peoples humanized areas on the North American continent, including parts of the American west. . . ." But these are minor human imprints that do not fundamentally modify the natural world.[23]

Some of the highly civilized native cultures built permanent communities, even cities, and did significantly degrade the local ecology with irrigated agriculture (see chapters 2, 9). By one estimate, all forest within six to nine miles of the prehistoric metropolis of Cahokia, near modern-day St. Louis, was cut down to make way for farming. Tree cutting for fuel and construction lumber extended much farther.[24] These effects were ecologically significant to a much lesser degree than those of later settlers or the present.[25]

So European colonists moved into forest-mosaics shaped both by nonhuman and by human forces. Deep forest areas were not uniformly dense and did not all consist of giant trees. Instead, groves of sparse mature trees, accompanied by ground-level grasses, ferns, and small shrubs, alternated with sunny openings of meadow grass punctuated by seedling trees and bushes, or with zones of densely packed younger trees and understory shrubs. At irregular intervals, human- or lightning-sparked fires burned the forests, prairies and other grasslands, and even wetlands.

Native Americans were sophisticated land managers. They manipulated plant species to sustain food and fiber supplies, often deliberately setting forest fires to promote growth of their favorite food plants and clear away brush and litter (see chapter 3).[26] The fires they set rarely were severe—they improved forage and habitat for game animals, opened hunter pathways, and made hunting easier, particularly of deer and other game that prefer feeding in open forest understory. The fires also enhanced biodiversity and opened up niches for saplings and healthy young trees.

Forest Health

Forest managers need a way to assess the health of forest ecosystems to guide their management practices. Otherwise, they—and we—will not know whether forests are thriving now or if they can thrive in the future under our relentless pressures. First and foremost, sustaining forests requires preserving stable slopes and soils. All human clearings destabilize slopes and soils, which in turn increases floods and lowers water quality, oxygen production, and biodiversity. Clearings also reduce the forests' CO_2 absorption.[27] The number and size of human clearings have vastly expanded over the past 50 years, breaching forest integrity, soils, slopes, and streams on scales that natural processes rarely accomplish, short of cataclysms.

In the western United States, 64% of exploitable timber grows on public lands, most of it in the Pacific Northwest states under USFS jurisdiction, or in the arid Great Basin and southwestern states under BLM management.[28] Other significant unprotected forest tracts are state owned, or privately held and governed by state forestry regulations.[29] Regulations and guidelines vary by agency and category of land ownership.

Effectively, the USFS is the largest timber supplier in the United States. It plans and prepares "timber sales"—actually, sales of permits for logging timber on federal lands—offers the sales for bidding, awards the contracts, and administers the eventual harvest of trees belonging to all U.S. citizens. In addition, agriculture and grazing (chapters 2, 3), mining (chapter 4), reservoirs (chapter 9), military training (chapter 6), utility corridors and roads for oil and gas exploration and production (chapters 5, 12), plus urban–suburban developments (chapter 8) all encroach on western regrown and heritage woodlands. Large-scale recreational developments on national forest lands (chapter 11) and increased suburban settlements at the forests' edges tend to influence national forest management policies.

Federal and state land managers and elected officials have a duty to evaluate the sustainability of logging practices and lumber yields and to enforce laws protecting endangered species. At the same time, they must also respond to appeals from other commercial forest users and address the public's sometimes conflicting demands for access and fire suppression. Both USFS and BLM must manage federal lands to reconcile the often incompatible goals of "multiple use"—fostering economic and recreational uses while trying to preserve natural resources. The agencies tend to allow extensive clearing in and around western U.S. forests for myriad consumptive human uses.

Sustaining harvests

More than 90% of all the world's wood products come from natural forests, primarily in the northwestern United States, Russia, and rainy equatorial countries.[30] Logging takes place in eight of the 11 western states, principally the Pacific Northwest states plus California, Idaho, Montana, Wyoming, Colorado, and parts of northern Arizona and New Mexico. The timber mostly supplies construction lumber, and wood for paper and biomass fuel. All by itself, the United States uses 20% of all the world's produced wood—nearly 50 cubic feet per year for every American. This is more than three times the global average, and double the lumber consumption of most other industrialized countries.[31]

Many of the people who call for endangered species protections also demand abundant forest products, with little idea of the paradox or environmental consequence. Globally, the consumption of wood products is rising, driven both by world population growth and by many developing countries' goals for economic expansion. By 1999, fuel wood and charcoal consumption grew to just over half of all wood cut.[32] Paper accounts for another 20% of the global annual cut. Worldwide wood consumption is likely to reach more than 77 billion cubic feet per year by 2010—roughly equivalent to cutting down 77 million trees of 50–65 foot height. Only about a third of wood products are recycled.

An agreeable climate and healthy soil are the most vital factors supporting the long-term sustainability of a forest. Under ideal natural conditions, changes from human exploitation may do little ecological damage to a forest that grew and will regrow, but where conditions have severely deteriorated, the same changes can force ecosystems decline or extinction. Given optimal soil and climate combinations, plant and animal associations can resist substantial stresses from drought, insect infestation, logging, or grazing. An ecosystem is much more vulnerable under less than optimal conditions.[33] But even under optimal conditions, frequent repeat harvests ultimately render a forest incapable of recovering from logging impacts. At each cut, the soil loses nutrients, its layered structure degrades, and the overall erosion potential increases (see chapter 13).

There are appropriate and inappropriate ways to cut a forest, depending upon the landscape and forest type. To avoid overcutting and devastating soil losses, timber-dependent economies must harvest timber under sustained-yield principles, continuously producing wood from the same areas for indefinite periods. Selective cutting can be the least damaging approach to logging. To achieve sustainability, the rate of forest cutting must never exceed the growth rate of harvestable trees. Roads must be correctly placed, preferably high on a slope, and care taken to limit the surface disturbances from cutting and hauling. For example, highly conserving Switzerland has long restricted timber cutting in its mountain cantons to selected trees scattered through a forest tract. This practice of selective cutting preserves the stability of wooded slopes, prevents floods from increasing in number and height, and protects vital ecological services, to the benefit of villagers and graziers living in the valleys below. Low Swiss population pressures keep timber demands well within sustainable limits.

In practice, foresters cut forest patches on rotation, allowing adequate intervals for regrowth depending on the type of tree. A stand of Australian eucalyptus may yield marketable products once every ten years, but plantation pine, a major source of pulpwood and paper, commonly needs to grow for at least 20 years between harvests. To sustain the yield from a pine forest, only 5% of the timber can be cut each year. On the other hand, eastern U.S. oak and beech forests require 200-year rotation periods, which partly explains high oak and beech lumber prices.

Unkind cuts

The USFS records estimate that more than 60% of western U.S. logging is selective,[34] but the large per capita U.S. demand for wood products makes loggers prefer clearcutting. Unlike selective cutting, clearcuts utterly eradicate a patch of forest (figure 1.2). Heavy machinery fells and extracts only the larger trees while crushing smaller trees and shrubs and overturning soil layers that typically take thousands of years to develop (see chapter 5, box 5.1; and chapter 13). Clearcutting allows logging companies to extract large amounts of timber in short periods of

Figure 1.2 Forest harvesting techniques. *Selective cutting* removes relatively few carefully selected trees of top value and leaves forest structure mostly undisturbed. *Shelterwood cutting* removes large valuable trees piecemeal in two to three cuts over a period of 10 years and largely preserves forest diversity and habitat. *Seed tree cutting* leaves a few large trees to provide seed stock and shelter for regrowth. *Clearcutting* removes all commercially valuable timber and mostly destroys forest structure and habitat. *Coppicing* cuts trees able to regrow through root sprouts, with no need for reseeding. *Salvage logging* removes valuable timber from forests killed by fire, insects, or other natural processes.

time, and to replant more easily. It is the simplest and, in terms of profit margins, most efficient way to harvest a forest on a rotational basis.

Individual clearcuts are variably sized and shaped, ranging from a few to several hundred acres. Removing logs from clearcut areas requires abundant roads and skid trails for removing the cut trees, which are even more damaging than the cuts themselves. Road reclamation is feasible and desirable but rarely happens on western public lands (see chapter 5). The roads open forests to off-road vehicles, which exacerbate the damage (see chapter 11).

Seed tree harvesting, a less abrasive form of clearcutting, typically leaves 5–12 mature trees standing per acre to help reseed logged areas. Other practices that encourage rapid forest regeneration include shelter wood harvesting, which removes only mature trees, and coppicing—a highly productive alternative to clearcutting, which leaves stumps behind to sprout new trunks and regenerate another crop (figure 1.2). Coppicing is best for growing tree varieties with short rotation intervals (5–10 years), but unfortunately, it requires particularly intensive herbicide, insecticide, and synthetic fertilizer applications to suppress undesired plants and give the sun exposure to preferred tree species.[35]

Various skidding alternatives depend upon costs and the slope of cut-over land. Dragging the logs out with motorized equipment, such as tractors, significantly disturbs the soil on low slopes of less than about 57% (30° angle). For dragging logs to loading points across steeper hillsides, loggers set poles and string metal cables between the poles and remaining trees—but even this technique can critically disturb soil. On steeply sloping land, some loggers use helicopters, and even balloons, to remove high value logs without damaging soils. In recent years, some environmentally concerned loggers have reverted to hauling logs with mules and horses, because they correctly perceive that animal haul paths are narrower and cause less soil disturbance than do machine-made trails.[36]

Tree roots hold the soil on slopes. As the Myceneans discovered, tree roots help keep the rainwater runoff to a minimum, thereby minimizing erosion and soil losses that can choke streams, prevent fish from spawning, and bury farmlands in flood times (see chapter 2). Conversely, cutting trees severely diminishes the effect of living roots that hold soil on a slope against the pull of gravity. Wholesale root decay after intensive logging may take 5–10 years, depending upon climate, soil type, and the kinds of trees. But even if new plants can establish seedlings and restore some root systems in that time, the slope's strength still tends to decline.

Slopes held in place only by dead, weakening roots are open to severe mass wasting processes—everything from gullying to large-scale landsliding—that deliver loads of sediment into streams (see chapter 13). Soil creep, the slow, gravity-induced, downslope movement of soil masses on steep slopes, is a very widespread phenomenon on both cleared and uncleared forest slopes (chapter 13). The sediment shed from clearcuts can far exceed what soil creep delivers in uncut forests, however. When trees are suddenly removed, their evapotranspiration stops, letting soil moisture and shallow groundwater levels suddenly rise toward the surface, which further increases the slope's failure potential. Denuded slopes become particularly vulnerable to debris flows, which are thick slurries of mud and debris that surge downslope, picking up trees and other rubble and flattening everything in their paths (chapter 13).[37]

Shallow landsliding increases dramatically on steep clearcut slopes, as much as two to three times normal rates.[38] Landslide inventories in Oregon's Cascade Range recorded significantly higher soil mass movement rates in clearcuts compared to surrounding forests.[39] In Siuslaw National Forest, Oregon, about three-quarters of all rain-triggered landslides in one 1975 storm came from clearcuts.[40] A 1999 study on a part of the Humboldt County, California, Headwaters Forest reported that the highest proportion of landslides occurred in areas that had been clearcut over the previous 15 years.[41] Landslides move sediment and logging slash, plugging up road culverts and diverting streams and their tributaries. In some landscapes, the water diversions led to severe gully erosion in forests (see chapter 13).[42] In wet years, the increased rainwater coming off clearcuts increases eroded sediment loads. Carried into fast-running streams, the sediments aid in lowering stream channels and undercutting stream banks, potentially inducing more landslides and reactivating old ones.[43]

Many loggers formerly removed clearcutting residues and slash to reduce fires, leaving mountainsides bare and highly prone to erosion. The presently accepted best practice is to leave some deadwood and forest litter on the ground to trap moisture and provide nutrients for forest regrowth. But erosion levels still are high, especially on slopes. After cutting, many loggers burn the piles of slash left in clearcuts and even have dropped napalm on them from low-flying aircraft. The high heat of napalm sterilizes the remaining soil to depths of several centimeters, eradicating any surviving organic layers and baking the surface to a hard crust that cannot absorb rainwater. Compared to undisturbed forested hillsides on similar slopes with equivalent landslide potential, stormwater runoff is higher from the compacted, torn, mixed, and baked soils, yielding 3–30 times more eroded sediment.[44]

Plant losses take away shade and increase evaporation, which dries out upper soil layers and reduces the internal cohesion between soil particles. Groundwater rising at deeper levels from evapotranspiration losses may not balance these soil drying effects. On slopes steeper than 10% (6° angle), noncohesive dry soils release streams of loosened mineral bits and other soil matter, termed "dry ravel." In the first 24 hours after a 1980s fire in the Oregon Coast Range, clearcut areas on slopes steeper than 60% (31° angle) lost between 2 and 16 dump truck loads of eroded sediment per acre, more than half in the form of dry ravel.[45] Moister areas are much less likely to produce dry ravel. Even in southern California, the less sunny north-facing slopes tend to retain more soil moisture than do south-facing ones, so burn scars in chaparral vegetation on north-facing slopes release 10 times less dry ravel than do the south-facing slopes.[46]

Hillside logging requires roads, but roads on slopes are highly destructive. National forests contain nearly 450,000 miles of roads, mostly in the western states, built at taxpayer expense for timber cutting and fire control (see chapter 5).[47] Even accounting for clearcuts, erosion from roads is 10 times greater than the erosion directly associated with logging in the western United States.[48] The study of a steeply sloping California clearcut showed a shocking increase of more than 200% of eroded sediment in the first six years after the operation had constructed roads low on slopes or near watercourses, and used tractors for skidding logs downslope to haul-trails built in stream channels.[49] Clearcuts in northern Idaho yielded 770 times more eroded sediment over the six-year period following logging road construction compared to equivalent unlogged forest slopes. Landslides produced 70% of the measured sediment.[50] More than half of all landslides in northern Idaho forests come from roads carved into slopes, and a further 30% originated in areas combining roads, fire burns, and logging scars.[51] An air photo study of Vancouver Island indicated that more than a third of all landslides in logged areas were somehow related to roads.[52]

Forest–water connections

The stream and spring water in natural forests is remarkably pure, and the streams coming from them transport very small sediment loads even in steep terrain. These filtering services are provided by forest soils and leaf litter—the natural filters that remove suspended solids and dissolved compounds from rain runoff (figure 1.3). The forest understory of branches and smaller undergrowth, plus litter on the ground, also cushions soils against pounding raindrops. Where water collects on the mat of forest litter, various chemical processes and animal activities create openings that let the water rapidly seep underground, replenishing the groundwater that many cities and rural dwellers depend upon (see chapter 13). Cutting forests and stripping or paving over woodlands and other natural habitats limit the areas where groundwater may be naturally replenished. Not surprisingly, groundwater supplies are steadily diminishing all across the naturally arid western United States (see chapter 9).

Flat lands are obviously less vulnerable to slope and soil stability problems than is hilly country, although flat lands bear the flood burdens of extensive silt deposits and water pollution. But forested watersheds protect developed areas downstream from severe flooding in all but the worst storms. The leaves, branches, soil, and

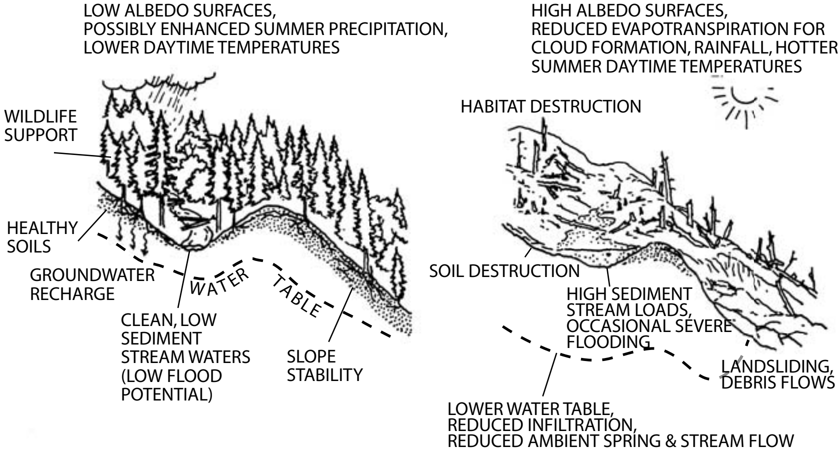

Figure 1.3 Diagram showing the ecological services a healthy forest provides on slopes, contrasted with the damage from excessive clearcutting and severe fires.

roots that obstruct and retain running water in a forest also capture and divert much of the precipitation falling on forests, and take up large amounts in plant evapotranspiration processes. These diversions lower the amount of rain that runs off and slow flow rates, particularly on slopes (see chapter 13). During a downpour, the water flows coming out of forests are much less intense than the drainage from poorly vegetated or unvegetated areas. Streams from forested areas also take a much longer time to reach flood levels and fall back again and so produce less damaging floods than do streams from less vegetated and developed areas (see chapter 8, figure 8.7).

Soils eroded from partly logged to denuded slopes pollute water supplies, clog filtration systems, and promote heavy silt accumulations in downstream waterways. Removing that sediment is one of the most expensive treatments required for purifying municipal water supplies, for both reducing wear on pumps and, even more important, removing toxic chemicals attached to sediment particles.[53] Water purification costs are high for municipalities and their consumers, but forests do it for free. New York City's former mayor David Dinkins understood these facts when he advanced a plan in July 1993 to upgrade management and reinforce protection for 2,000 square miles of forests and farmlands around the city's 19 reservoirs. The protected areas, as far away as the Catskill Mountains, have provided New York with water since 1842. Dinkins's plan for improving and maintaining the system cost $720 million—much cheaper than the billions it would cost to build new water treatment and purification systems, let alone find ways to dispose of treatment plant wastes.[54]

Gases for life

The normal respiration of trees, taking up CO_2 and releasing oxygen to the lower atmosphere, is a critical forest ecosystem function that supports human life and helps regulate greenhouse gases. The oxygen that trees release is the main source of the oxygen that people—and all other animals—have to breathe. Trees retain CO_2 in their wood and leaves, making forests a critical factor in regulating the global carbon cycle and worldwide atmospheric temperatures. Cutting forests eliminates their role in removing CO_2 from the atmosphere and so helps to warm the climate. Once the forest has been cut, soils degrade and release substantial amounts of CO_2 to the atmosphere, further adding to climate warming.

Sustaining diversity

The concept of biodiversity describes the wide variety of plants and animals in ecosystems, which maintain competitive or collaborative interactions of many kinds, providing food and shelter and performing myriad other services mutually necessary for all species' survival—including humans. This diversity of plants and animals in ecosystems provides natural "factories" that break down wastes of all sorts, clean up polluted groundwater, and support complex food chains. A few of the life forms in any ecosystem perform vital, keystone functions, meaning that many other animal or plant species could not survive without them.[55] The catastrophic biodiversity reductions worldwide since the end of WWII largely correspond to destroyed or degraded forests and tropical marine ecosystems.

Human clearings and roads subdivide habitat and reduce diversity. Such clearings, especially logging clearcuts, are becoming more abundant and pervasive in forests than are the gaps produced by natural fires and other natural clearing processes. And natural gaps also continue to open. The clearings constitute barriers, subdividing forests into many small segments and making some too small to function as ecosystems (see chapter 5). The effects of forest fragmentation have been especially devastating to habitat.[56] Unfortunately, current government policies are promoting roads and vehicular recreation in unfragmented lands with wilderness values, while allowing many more clearings for development in national forests.

Forest fragmentation markedly increases the amount of edge habitat, transitional to clearings, at the expense of denser forest interior zones. This change reduces life support for many songbirds and other animals of the forest interior, exposing them to edge habitat predators, parasites, and disease, and so decreasing their survivability. A few small forest clearings in a large forest stand may affect biodiversity very little, while the same-size clearings could be devastating to ecosystems in a small forest. Adding numerous human clearings to natural openings—the deep canyons, sand dunes, and mesas or buttes—that already subdivide western forests can disrupt plant succession and disproportionately reduce biodiversity even in large forests.

Large predators and migratory herbivores, such as the red wolf, elk, and grizzly bear, need to roam across hundreds of square miles of unfragmented inner forest. As interior habitats decrease in size, the numbers of animal and plant species they support also decline: the species-area effect. A 90% reduction in habitat area can cut biodiversity by half.[57] Reduced biodiversity impedes future forest regrowth, especially from the loss of pollinating birds and insects, while obstructing the maintenance of balanced, healthy forest ecosystems. Heavy logging, with heavy soil losses, also opens a woodland to bioinvasion, letting nonnative species take over and preventing native ecosystems from reestablishing themselves (see chapter 3).

Western forest fragmentation already has contributed to the disappearance of predatory animals that need extensive unfragmented forest habitat, while encouraging cowbirds, mockingbirds, hawks, ravens, and rats to expand into human residential areas. All these species can easily adapt to rapidly changing conditions and thrive in unstable environments, supported by garbage dumps and open neighborhood dumpsters. Ravens have become the dominant bird species in woodlands adjoining many California and Arizona population centers.

Burning Issues

What foresters regarded as a "healthy forest" in 1891 is far different from our understanding of healthy forests today. The federal mission to serve multiple public interests in managing public woodlands has become progressively more difficult to work out, given both the increase in population pressure and a much deeper scientific understanding of our negative impacts on forest ecosystems. Scientific studies show that healthy forests are diverse ecological systems, ever-changing on extended time lines that greatly exceed ordinary human economic interest. To support diversity, and what may be regarded as a truly healthy forest condition, federal and state land managers must look beyond timber harvests and factor in the natural changes that modify forests, especially fires.[58]

Ecological studies reveal that fires are natural and common in most ecosystems. Over millions of burning and regrowth cycles, most plants have adapted to fire, some developing a thick bark, rich in fire-retarding tannin, some storing food in roots to sustain themselves after a burn, and others resprouting vigorously. A number of fire-adapted trees, such as lodgepole pine, produce cones that can release seeds only after intense heating. Heat and flame return some nutrients to the soil even while depleting others, so that surviving plants and seedlings—especially pioneers—often thrive on burned ground.

Fire-prone plant communities are "self-reinforcing: The type of plants that grow on a burn determines the nature of the fuel complex…[which] determines the intensity and frequency of [the next] fire and its future biological effects."[59] Thus, changing numbers and locations of plant communities influences future fire patterns, which influence future landscape development, the whole grand cycle operating in a time frame of thousands of years.

Experience also shows that human land uses force such rapid changes on natural ecosystems that they cannot recover easily, and sometimes not at all. Natural processes never stop, and always amplify ecological disruptions. If human disruptions exceed natural thresholds, the ecological response can be devastating. These are serious challenges to such agencies as the USFS and BLM and are forcing significant changes to forest management.[60] Fire control is an area where natural thresholds have been crossed. On no issue of forest management have attitudes changed more.

Crowning blows

Woodlands burn in three different ways:

- Ground fires burn root structures and oxygen-rich soil.
- Surface fires burn in underbrush and downed dead logs and branches, called deadfall.
- Crown fires burn the forest canopy, its upper tree branches and leaves.

Although unspectacular and slow moving, from the human point of view ground fires are among the most destructive because they kill the roots of trees and are very difficult to control. Surface fires commonly move slowly enough for firefighters to contain them at the fire front, but may spread into forest canopy as they advance. Ground and surface fire are called "cool" fires because maximum temperatures remain between 500°F and 1,000°F. High summer temperatures, wind, and rising air drafts from the heat of a ground fire, can whip flames upward into the canopy, generating crown fires.[61]

Crown fires move more or less independently of the surface but can set surface fires as they spread, moving as much as 10 miles per hour under gusty conditions. Temperatures may be as high as 2,000°F, enough to melt glass and soften steel beams so much that they bend like a pretzel. Far-spreading hot crown fires do more to destroy valuable stands of timber than do smaller burns, and usually defy firefighters' attempts to contain them until the weather changes to less windy or higher humidity conditions.

Prior to Lewis and Clark's western expedition, fires were relatively cool and did not often develop into crown fires that burned the larger trees. The fires were relatively frequent, cleaning out leaf litter and deadfall and reducing the fuel available for subsequent burns. Frequent cool fires reduced the number of crown fires. Intervals between crown fires in presettlement times sometimes can be deduced from studying the number and appearance of growth rings in a tree's wood, which show its age.[62] Prehistoric fire-charring in some Oregon tree ring records suggest that large crown fires might have swept a typical patch of western Oregon Douglas Fir forest an average of once every 200–400 years.[63] Yellowstone National Park's major 1988 fire supports this conclusion, since the most recent previous conflagration of similar size occurred in the 1700s, an interval of about 200 years. Outside Yellowstone, several crown fires have occurred each decade since 1970—a disturbing trend.

Until the later twentieth century, the U.S. government policy was to fight forest fires. The policy started with the "Peshtigo Blow Up" fire of October 1871, the most destructive forest fire in North American history.[64] Ignoring the contribution of clearcut slash that the loggers had left on the ground, an influential 1899 U.S. Geological Survey report quite unscientifically concluded that wildfires are "always evil, without a single redeeming feature."[65] Propping up the "evil fires" notion, the 1910 Great Idaho fire, also partly fueled by clearcut slash, destroyed three million acres of pine woods in the northern Rocky Mountains, killed more than 80 people, and carried wood ash as far north as Greenland, about 3,000 miles away.

Protected from burning for decades, forest litter and undergrowth began accumulating both in logged and regrown woodlands and in unlogged heritage forests. Cattle grazing on USFS and BLM meadows and clearings eliminated grasses and wildflowers, permitting the growth of small, weak trees in dense ("doghair") thickets (see chapter 3). Historical photographs, especially in the substantial photo coverage of California's Sierra Nevada range, show general increases in forest density and cover throughout the west since the mid-nineteenth century. Between 1866 and 1961, forest cover on the floor of Yosemite Valley increased approximately 20%. Photos of Lake Tahoe's Emerald Bay area show even greater increases between 1873 and 1994.[66]

Post-1910 forest fire suppression may have helped reduce human-set fire frequencies for a time. But over the succeeding decades, thick undergrowth and deadfall accumulations began to alarm fire specialists. As the densely crowded trees matured, insect infestations and plant diseases flourished. Weakened and dying timber stands covered thousands of acres, and some whole woodlands suddenly perished, greatly increasing the load of highly flammable dead wood. In 1970, the NPS faced rising firefighting costs, increasing numbers of hot crown fires, and rising losses of private property and human life in forest-fringe suburbs. To address these problems, the NPS began allowing some natural fires to burn freely in remote parklands and inaugurated controlled burning to remove deadfall and increase biodiversity.[67] Eventually the six-million-acre 1988 Yellowstone fire, a literal backcountry firestorm in the national park's densely overgrown lodgepole pine forest, drew public attention to the problem. That fire underscored the new policy's wisdom and added controlled burning to national forest management tools.

But the NPS's burn policies came too late and accomplished too little. NPS and BLM had to continue fighting major fires on national forest lands to protect property interests. Meanwhile, studies of controlled burn areas showed that they can increase erosion,[68] and both environmental groups and forest-margin residents have challenged them for impairing air quality. Additional concerns attach to the use of fire retardants and foams, both to contain controlled burns and to fight fires in remote areas. The chemicals are toxic to both terrestrial and aquatic native animals and plants, and encourage weed invasions, thereby reducing species diversity.[69]

Restoration or salvage

Trying to understand the density of presettlement forests, Arizona forestry researchers mapped the 1890 distribution of trees in northern Arizona's Ponderosa pine forests.[70] Their "restored forest" model is the expected mosaic of predominantly large, old pine trees and dead snags, punctuated by meadows and aspen groves. It suggests that the region's presettlement forests had supported 10–50 trees per acre (averaging 23 per acre), interspersed with patches of ground-level grasses and shrubs. By contrast, northern Arizona's human-managed forests today average 851 trees per acre. To determine whether the model forest can promote cooler fires, the researchers cut 50–90% of trees in overgrown experimental forests[71] and later burned the same areas to promote grassy growth. They planned to observe the experimental area over a decade or more to evaluate the restoration model.[72]

Before restoration theories could be fully tested, extensive hot fires burned huge western woodland areas in the summers of 2000–2003, fulfilling decades-old fears. Excepting the costly 2000 Los Alamos, New Mexico, fire, which started as a controlled burn, the fires swept across lands where prescribed fires had been blocked for years. The year 2000 fires utterly denuded some forest lands, wiping out their capacity to "recover" through natural processes—meaning produce harvestable timber—for more than a century to come. The 2002 wildfires covered more than 300,000 acres, and the 2003 fires consumed 400,000 acres of scrub and forest. In southern California alone, the 2003 fires took 1,500 houses and 13 lives.

The fires attracted political attention that promoted a version of the yet-unproved "forest restoration" model. Largely throwing science out the window, the untested idea of removing "excess fuel through controlled burning and thinning" suddenly became the favored approach to managing forests.

In 1995, President Bill Clinton had anticipated something like forest restoration when he opened recently burned national forest areas to two years of "emergency salvage" logging. Legislation promising thousands of new jobs and increased timber industry profits allowed commercial loggers to remove burned, diseased, and insect-infested trees, as well as trees downed by wind and other causes, ostensibly to prevent future fires. For convenience, the loggers also could remove some living trees. In the northern Rocky Mountains alone, 318 woodlands, including 25 heritage forests, were proposed for salvage logging.[73] The provisions required salvage projects to observe all applicable environmental laws but suppressed public reviews and input.

Since 2001, the George W. Bush administration has conflated "salvage logging" with "restoration" as "hazardous fuels reduction" measures, meant to mitigate future severe forest fires by removing "excess" dead, dry wood from regrowing forests. In 2003, the USFS supervised the Red Star Restoration Project to salvage still-usable trees from a fresh 2,000-acre burn 15 miles west of Lake Tahoe. Both the Clinton and Bush salvage logging operations failed to live up to promises that they would create jobs and produce greater financial return than the normal timber sales process. Meanwhile, they opened burned forests and heritage forest areas to logging of viable standing trees.

Paradoxically, salvage logging does not necessarily reduce fire hazards, and may actually *increase* them. Fires often begin when lightning strikes dead snags, but the main fuel that feeds a conflagration is the finer material on or near the forest floor, including brush, pine needles, small trees, and other debris of no value to logging operations—especially when partly burned. Removing larger snags and logs alters local conditions: wind, sun exposure, and evaporation all increase, along with the fire hazard. Large moisture-retaining logs are not left on the ground to slow advancing fires. Disturbances caused by salvage logging also reduce seedling regeneration by 71%.[74]

The law of healthy forests

Following the 2002 fires, Congress declared that "throwing billions at fire fighting is fruitless without sweeping restoration" and adopted the Healthy Forests Initiative (HFI), loosely based on the ideas behind forest restoration. Voted into law and signed by President George W. Bush in December 2003, HFI mandates selective tree cutting and prescribed or carefully controlled low-level burning, and deadfall log and underbrush removal. These measures aim to reduce the density of trees and tree debris in national forests to "pre-twentieth century status," ignoring both the lack of information on the pre-twentieth century status of any western forest ecosystems other than ponderosa pines in northern Arizona,[75] and the too-short time lapse for evaluating the restoration experiments. At the same time, the government proposed substantial changes to such mainstay environmental laws as the National Forest Management Act, the National Environmental Policy Act (NEPA), and the Appeals Reform Act.[76]

HFI emphasizes cutting instead of burning for fire control and would sanction forest cutting projects, including salvage logging, for "fuels reduction." At the same time, HFI allows the projects "categorical exclusions" from formal environmental impact studies under NEPA to assess potential adverse impacts. Not surprisingly, the amounts of proposed "restoration" cutting appear extreme in many cases.[77] HFI also reduces the time required for issuing forest clearing permits, in some cases by trimming or relaxing existing environmental regulations. In essence, HFI puts the benefits of cutting trees for fire reduction far above threats to soil stability and endangered species.

The industry-friendly Bush administration previously had tried to streamline environmental reviews of logging proposals, easing the way for "approval to thin underbrush and small noncommercial trees as well as conduct some 'thinning out of commercial grade wood' [i.e., large trees] in areas at high risk of fire." All the proposed regulations increase the difficulty of mounting citizen appeals against abusive logging plans, and extend the assault on forests into roadless natural areas.

Many of the roadless areas include heritage forest stands, which potentially could obtain wilderness status.[78]

Environmental groups understand the need to thin forests for emergency fire control but tend to view the HFI proposals as a rerun of the 1995 fire-salvage project, aimed at opening national forests and critical endangered species habitats to unregulated commercial cutting.[79] A proposal to apply HFI to Alaska's lush Tongass National Forest, too wet ever to have sustained a significant wildfire, only increased suspicions of government deceit and duplicity. The suspicions seemed to be confirmed when the USFS produced a brochure promoting HFI, which featured a 1909 photograph purporting to show sparse large trees in an unlogged part of California's Sierra Nevada. Environmental groups quickly discovered that the actual scene was a freshly logged forest in Montana.[80]

Cutting Costs

The USFS often has appeared willing to sell timber at any price, even in its normal timber harvest process. Salvage logging programs may be even less remunerative.[81] Criticisms of the agency's financial performance generally focus on below-cost timber sales, common in Rocky Mountains states, which yield revenues lower than the costs of preparing and administering them.[82] The yearly distribution depends on market strengths or weakness, and also varies with accounting methods. According to the U.S. General Accounting Office, the 1992–1994 timber harvests eventually returned to the Treasury less than a quarter of the funds Congress had appropriated for the USFS to use in preparing timber sales and administering harvests. The timber sale program often has required annual congressional supplements to break even, using taxpayer subsidies to cover losses from below-cost sales. Clearly, below-cost timber sales are a drain on the public purse.

Environmentalist critics charge that the USFS's Emergency Salvage Logging Program actually costs the U.S. Treasury more than $50 million,[83] representing yet another below-cost logging operation on federal lands. Revenue from the Red Star salvage contract, supposed to help sustain the commercial logging industry, proved insufficient even to support the USFS's management operations or help pay for cleaning up the debris, which remained on the ground in highly flammable piles.[84] Part of the revenue shortfall has been blamed on the late 1990s drop in lumber prices, which sent the logging industry into decline—ostensibly from Canadian competition, imported lumber, and lumber mill closures in the western United States.[85] But western lumber industry organization data indicate that the west's lumber oversupply from the late 1990s into 2003 was due more to increased plant efficiencies and the competitive globalized economy than to strident conservationist lawsuits and the much maligned Endangered Species Act.[86]

Timber sale proceeds tend to get kicked back to states and into USFS programs, rather than to the U.S. Treasury. The U.S. General Accounting Office has reported that the Treasury received only 10% of total USFS timber sale receipts for fiscal years 1992–1994; the rest went to special payments and accounts.[87] For example, a 1908 law directed the USFS to return 25% of receipts to the states for building county roads and schools in national forest areas, because they do not generate state tax revenues. These payments exceed cash timber sale receipts for many forests, making them extreme cases of below-cost sales.[88] To keep the revenue-sharing payments high, many western counties have become timber sale advocates, often ignoring potential adverse environmental impacts and negative economics.

Timber sales receipts feed so many special internal USFS accounts and trust funds that critics charge USFS managers can keep themselves and their staffs employed with timber sales funds. The sale revenues can be used for projects to mitigate logging damages to wildlife habitat, potentially providing some wildlife managers an incentive to support damaging logging projects.[89] One example is the so-called "K-V Fund,"[90] which can receive any amount from timber sale receipts for reforestation and timber stand improvement projects, as well as for timber sale activities. The economic calculus of salvage logging is similarly complicated by mandated payments to states and deposits to special funds. Salvage profits are added to the Timber Salvage Sale Fund, another special account, instead of returning to the U.S. Treasury. But the Timber Salvage Sale Fund does not cover total costs of salvage logging, which must come from additional congressional appropriations (taxpayer money). The USFS does not audit its own accounts, and the actual financial costs or benefits of lumber sales on national forest lands are unknown.[91]

Other financial fiascos are outright frauds, including timber theft and abusive logging practices that contribute to deteriorating forest health. Fraudulent bidding and related practices are long-term problems, particularly in the Pacific Northwest.[92] To ensure profitability, some bidders have pushed the plethora of USFS standards to the limits, or even beyond. The USFS has altered bidding practices to curb the worst of the abuses, but the public cannot scrutinize completed contracts, and the USFS does not compare actual harvest returns with estimated sale revenues, so the effectiveness of those alterations is unassessed and unknown.[93]

Real costs

Salvage logging is supposed to improve forest health,[94] but like other logging, it actually exacts a steep environmental price. The machines and process of skidding overturn and destroy charred and vulnerable forest soils, remove nutrient-rich organic matter, and destroy ecological habitats that had survived earlier fires or insect infestations. Following a large fire, the salvaged forests are slower to regrow because the soils recover more slowly than in unlogged burns. And both the economically marginal 1995 and Red Star salvage projects attracted bids by allowing loggers to extract large living trees. USFS forest salvage proposals for watersheds that provide urban drinking water supplies to cities, such as Phoenix, Arizona, and Durango, Colorado, have raised concerns over the likelihood of increased erosion with increased sediment loading and turbidity in streams.[95]

In addition to paying many costs of cutting forests, taxpayers bear the "externalized" costs of deteriorating forests. Possibly because loggers cut mostly the large pines in western forests, firs—and especially Douglas firs—have become dominant in the cut-over areas.[96] Firs are more easily damaged by drought, insects, and diseases and contribute disproportionately to catastrophic wildfire risks. The many thousands of miles of roads, built and maintained for timber cutting and fire control at public expense, also degrade U.S. national forests (see chapter 5). USFS accounting makes timber sales appear more profitable by showing roads as assets, when in reality the roads on hill slopes generally contribute even more to erosion and flooding than logging clearcuts.

To regenerate cut woodlands, the USFS plants and seeds cut-over acreage, *also* at taxpayer expense. Regeneration costs from 1977 to 1994 added up to nearly $2.5 billion,[97] which works out to $314 per acre planted—a total of about 1.2 billion taxpayer dollars.[98] Only about half of the planted acres could be certified as successful; that is, they regenerated timber. But USFS accounts misleadingly lumps both successful and failed plantations into the single category of new plantings.

Future Forests

In 2001 USFS reported that about half of U.S. timber is less than 50 years old, and two-thirds of the west's lumber volume resides in regrown trees less than 21 inches in diameter. Only a fifth is in older trees with diameters of 29 inches or more. Only 16% of western U.S. potential lumber volume is in 21- to 29-inch trees as much as 50 years old.[99] These statistics explain why regrown woodlands yield less timber per acre than do heritage forests, and why loggers so desire to cut the old forests. As a reminder, the remaining heritage forests grow on a mere 7% of all wooded U.S. lands.

In the 1990s, environmentally aware citizen groups endorsed the Sierra Nevada Forest Plan Amendment, called the "Framework," for managing Sierra Nevada national forests on the bases of science-based ecological principles and regionwide concerns about fire and clean water supplies. By 2004, environmental groups were facing logging proposals under HFI, also supposedly based on healthy forests concepts, but likely to give commercial loggers access to large, old trees in roadless reserves and perhaps even in national parks. Matching science and environmental law against politics and economic interests, these struggles illuminate the contradictions inherent in trying to both preserve natural functions and allow multiple human uses.

A growing demand for lumber in developing countries, especially China, sent timber prices skyward in 2004, a trend that could revive the west's lumber industry. Increasing paper consumption and a turn toward alternative biofuels also will add demand for regrown forest wood. New federal regulations to expedite tree cutting in national forests, while preventing public-interest lawsuits or appeals of logging permits under environmental laws, surely would fuel a logging revival targeted at the last of America's oldest trees. Agroforestry, cultivating and harvesting trees on plantations, might either add new lumber sources or supplant natural regrowth.[100]

Sierra Nevada heritage

The fiercest battles over managing and preserving heritage forests center on California's 400-mile-long Sierra Nevada range, the longest unbroken mountain belt in the lower 48 states. The Sierras and more northerly Modoc Plateau embrace 11.5 million acres of publicly owned forest, slightly more than 10% of the state's territory, including two national parks and 11 of the 155 national forests under USFS management. Forest types vary from foothill oak woodland to alpine trees.

During the 1970s and 1980s, many acres of Sierra Nevada forest outside the national parks and other preserves had lost their oldest and largest trees to either clearcutting or selective logging. Habitat losses to logging, fire, grazing, and spreading human developments threatened many species, including several spotted owl species.[101] In 1993, Congress acknowledged "growing recognition among scientists, land managers, conservationists, and other citizens that the Sierra Nevada was in deep ecological trouble." Both in 1995 and in 1996, the USFS tried to design a sound management plan based on a scientific review of the entire region, the congressionally commissioned and funded Sierra Nevada Ecosystem Project. These attempts proved futile and "[i]n the end, both plans proposed doubling the amount of logging in the range while offering little in specific protection measures for the owl" and other threatened species.[102]

By 1998, the USFS recognized that forest management throughout the Sierra Nevada needed redirection and had begun developing the Framework both to save habitat for endangered and threatened wildlife and to reduce wildfire potential. When publicly unveiled in May 2000, forest and biological scientists, lawmakers, business leaders, and citizens hailed the Framework for incorporating the best available science into forest planning. The Draft Environmental Impact Statement chose the most protective of eight proposed alternative regional management strategies for preserving wildlife and habitat. It combined strategies for defending habitat and research to improve protections for sensitive and endangered species with fire hazard reduction through selective tree cutting, log and underbrush removal, plus prescribed burning—all guided by likely impacts on wildlife. This scheme would have protected trees more than 20 inches in diameter from logging, thereby dropping timber production to as little as 200 million board feet from as much as 700 million board feet in the 1990s.[103]

Assuming that balancing extremely different and intense forest uses is even possible, the Framework certainly seemed like the right way to go about it. But everyone could see that it would severely limit logging in heritage forests. Barbara Boyle, Sierra Club's regional representative, proclaimed, "Basically the [Sierra Nevada] commercial logging program is not going to exist."

The 2000 presidential election replaced the Framework's political sponsors in Washington. In 2001, Dale Bosworth, the new USFS chief, received 276 appeals from land developers and commercial forest product interests. While praising the plan's sound foundation and "the hard work and dedication of the interested citizens, government agencies and many others who came together to help develop the Sierra Nevada Framework," Bosworth called for further review. The review and subsequent revision refocused plans for Sierran forests away from habitat and endangered species concerns and onto timber harvesting.[104]

Bosworth's review elicited much skeptical commentary from district rangers, the officials directly charged with implementing land management policies.[105] Nearly two-thirds of rangers' comments labeled the Framework's standard goals and guidelines as top-down management, likely to limit their responses to a continuously changing, complex, and dynamic forest environment. One wrote,

> Place more emphasis on the desired condition over landscape and be very limited on prescribing how to achieve that desired condition…leave it up to us in the field to achieve that condition.…Nothing in nature is exact and uniform and when you try to apply standard prescriptions across…the Sierra Nevada, you are bound to run into problems.[106]

An even higher proportion of rangers worried that agency funding would be too low to support the Framework's complex management system, and another third noted that the restriction on clearing to no more than 10% of total area per decade would conflict with the emerging HFI. A few fretted about the region's timber industry and revenue and job losses for some mountain communities, but most agreed entirely with the wildlife protection and fire mitigation objectives of the Framework, affirming that "how to" rather than "why" is the issue.

Inevitably, the Framework did collide with HFI. In 2004, Regional U.S. Forester Jack Blackwell set the maximum diameter of Sierra Nevada trees to be logged at 30 inches—10 inches larger than the Framework limit. This policy would allow cutting of large trees on all 11.5 million acres of the Sierra Nevada's national forests, tripling the Framework's allowance.[107] Despite protests that heavily logged forest areas are fire prone, Blackwell also announced that the USFS would spend $50 million to promote logging in heritage forests on 700,000 national forest acres, ostensibly to protect trees, wildlife, and human settlements against large, intense wildfires.[108] When Blackwell opined that the Sierra Nevada Framework "was overly cautious," former Chief Forester Mike Dombeck retorted, "The original plan had input from our best scientists both inside and outside the Forest Service. Apparently now the efforts are due to commodity extraction."

The management policy for Sierra Nevada forests still is making feathers fly. Both HFI and the discarded Framework plan, plus similar state and local programs, have become lawsuit targets for massed environmental organizations. So far, political agitation has kept national and environmental laws in place, and courts have disallowed clearcutting in and near protected heritage groves. In 2006, a federal judge ruled that the USFS cannot allow commercial logging in California's Giant Sequoia National Monument, and a federal appeals court upheld the public right to review forest plans under NEPA. A 2005 suit against the USFS for omitting essential scientific information from the Framework revision still was pending in early 2007.

The new plantation

Modern agroforestry generally grows just one hybrid tree species per plantation (monoculture), hybridized by traditional protocols to enhance lumber yields and reduce rotation intervals. Ideally, plantations would allow previously logged areas to regrow throughout the west, but they tend to replace rather than augment natural forest stands. Monocultures starkly reduce the biodiversity necessary to preserve forest habitat for animal species. Monocultures might not threaten biodiversity overall if the total plantation area remained small, but replacing too many natural forests would considerably impoverish regional ecosystems. However, species monitoring, under Endangered Species Act constraints, could govern the pace of conversions. This would become yet another land management challenge.

In addition to traditional hybrid trees, agroforestry researchers also are bioengineering tree varieties. Potlatch Forest Industries is experimenting with cloning poplars from hybrids that can grow 60 feet tall in six years and can be harvested every six years.[109] Plantations of the fast-growing hybrids and clones take up water quickly, lowering water tables and potentially drying up springs and creeks. Compared to natural species' 15- to 20-year rotation, the anticipated six-year cutting intervals likely will cause greater erosion and greater sediment pollution, especially on slopes. Plantation road networks as dense as, or denser than, the clearcutting roads in natural forests inflict the same severe erosional damage of all other roads (see chapter 5).

Natural forests provide their own fertilizers, while fast-growing plantation trees rapidly deplete soil nutrients, requiring large fertilizer applications. Erosion carries fertilizer nitrate and phosphate into streams and ponds, promoting algal blooms that consume all the oxygen and kill fish and other animals (see chapter 9). Plantations of cloned monocultures eliminate the protection of tree species biodiversity. Since every tree contains the same genetic material, the artificial forests are highly susceptible to disease and insect attacks. They also require heavy pesticide and herbicide applications, which compound their pollution potential.

Plantations of genetically modified (GM) trees, created through directly altering a plant's cellular genetic material (DNA), pose many of the same threats as cloned hybrids. GM tree varieties under commercial development include Scotch pine, Norway spruce, silver birch, teak, apple, and cherry. GM Douglas fir plantations in western Washington State can grow to cutting sizes in half the time of wholly natural stands[110] and yield more useful wood and paper per tree than do their natural counterparts. The downside is that they probably use up soil nutrients even faster than the clones and so will need even more fertilizer.[111] Some GM trees are designed to make harvesting less energy consumptive, although more frequent harvests could offset that advantage.

Agroforestry proponents suggest the fast-growing cloned and GM trees might use even larger amounts of CO_2 than natural ones, helping to slow the rate of greenhouse warming. This is a spurious argument: Cutting forests releases large amounts of CO_2 from both soils and trees. And the CO_2 sequestered from regrowing them does not adequately compensate those losses.

Many environmentalists contend that agroforesters and government regulators have not adequately investigated potential bioengineering consequences, or taken them seriously, and that proposed safeguards are insufficient. GM poplars, pines, and fruit trees have a gene from the *Bacillus thuringiensis* (*Bt*) bacterium inserted into their cellular DNA, for example. They express insecticidal *Bt* toxin in all their tissues, including the edible parts,[112] which might be lethal to beneficial insects, such as bees and butterflies. *Bt* may kill the larvae of monarch butterflies and could threaten other beneficial insects. Herbicide-resistant GM trees have the potential to become noxious weeds. The environmentalists contend that these genetic modifications could spread to the natural gene pool and disrupt entire ecosystems in wholly unpredictable ways—akin to past "good-willed disasters" from diseased foreign plants.[113]

Supposedly, the *Bt* trees are engineered to be sterile, but "sterile" aspens growing in field trials in Germany began to flower after three years.[114] Pollen from *Bt* plantations could spread the genetic modification to natural trees, and their

Bt-bearing seeds could directly threaten the future of natural forest habitat. Another issue is an aspen variety with low lignin content in wood, developed to need fewer chemicals for making paper. Lignin is the main strengthening agent in tree trunks, and no one knows how lignin-poor trees will withstand winds. The effect the low-lignin characteristic might have on ecosystems if it spreads to natural aspen and related species is unknown.

Hot trees

North America's heritage forests endured the ice ages, but today's forests must adapt to rapid global warming to survive. Rapid climate change seemed like a science fiction scenario until 2000, but the reality is showing up in extreme weather patterns, unusually warm winters and broiling summers, melting ice caps, and rapidly eroding shorelines in far northern latitudes. Heat stress has visibly weakened the underpinnings of subarctic ecosystems, forcing both plants and animals to look for more comfortable conditions. Many climate scientists now believe that a new era of rapid climate change is already upon us and that future human generations will face worsening problems.

North American forests have responded to environmental shocks many times in just the past 60 million years. Pollen samples from the last glacial interval in what is now New York State indicates rapid temperature fluctuations about 12,000 years ago, jumping as much as 7°F over only 50 years. The sudden shift nearly eradicated such cold-adapted trees as birch, fir, and spruce. Between 12,000 and 7,000 years ago, mean 5–9°F global temperature increases forced white spruce and lodgepole pine species to shift their ranges by hundreds of miles. Over time, oak and white pine replaced tree species that could not adjust, and which simply disappeared.[115]

Global warming models now predict a similar temperature increase within the next *hundred* years, and this time the radical temperature change adds to all the human stresses on our woodlands. In the face of rapid climate change, intensive forest fragmentation, soil depletion, and groundwater decline, many or most forest ecosystems may not be able to reestablish themselves naturally (see chapters 9, 13). Under these kinds of pressures, the future may bring large-scale die-offs of many tree species and extinction of large stands of western temperate forest.

At advanced stages of global warming, severe, prolonged droughts are possible to likely. Droughts are fundamental causes of forest fires. A run of drought years is the immediate cause for the devastating 2000–2003 western fire seasons in southern California and the interior western United States, contributing to the nation's worst fire seasons on record (table 1.2). Dried-out trees, bark beetle infestations in weakened trees, and withering summer heat fed the disastrous, record-setting fires.

Globally, 95% of all wildfires are set by humans, and humans set about 50% of all fires even in lightly populated western states (about 75% in crowded California).[116] As the years grow increasingly warm, with human populations poised to rise another 50% over the next 50 years—perhaps far more in the tinder-dry, lightning-prone west—forest fires are likely to increase dramatically. Increased catastrophic crown fires will be the likely result of forest management practices that do not effectively thin forests because of funding issues, economic concerns, and political controversy.

Table 1.2 Recent U.S. Wildland Fire Acreage Statistics

Year[a]	No. Fires	Acres Burned
2000	82,071	6,891,292
2001	63,737	3,265,574
2002	67,889	6,657,464
2003	50,022	3,161,924
2004	61,625	7,733,023
2005	54,051	8,175,432
2006	84,333	9,080,628
2007	74,031	8,245,535
5-Year Average: (2003–2007)	64,812	7,279,308
10-Year Average: (1997–2007)	67,557	5,736,924

National Interagency Fire Center Fire Information. Available: ww.nifc.gov/fire_info/nfn.htm.

[a] Data for years 2000–2007 compares fire statistics between 1 January and date of inquiry (7 October 7 2007) for each year, plus five-year and ten-year averages.

Both historically and currently, forest managers resist letting ground and understory fires burn and spread for fear of losing timber crop and the public's demand that governments protect private residences. Nothing creates raging controversies more than limiting where Americans can build homes or find playgrounds. But in 2003, newspaper editors questioned the wisdom of building subdivisions in forests, in much the same way that frequent floods have raised questions over home and town sites on river floodplains and coastal barrier islands. As global warming and droughts increase fire dangers, insurance companies may impose limitations over public and politicians' objections.

Forests in the Balance

A century and a half ago, the geographer and explorer Alexander von Humboldt realized that human sustenance is inextricably tied to forests: "By felling the trees which cover the tops and sides of mountains, men in every climate prepare at once two calamities for future generations: want of fuel and scarcity of water."[117] We have felled our mountain forests, opening them to soil erosion, adding habitat fragmentation from roads, urban developments, and recreational sites, and high fuel loads due to counterproductive fire suppression. Our high fossil fuel consumption has induced higher than natural global warming, which may be advancing too fast for either forest or human comfort (see chapter 12).[118]

Nobody knows how old forest remnants will respond to continual human fragmentation and human-caused extinctions, added to the inevitable natural disruptions from high winds, earthquakes, volcanoes, and fires. Many biologists and ecologists fear that old forests cannot survive rapid climate change without radical protection. Accumulating a few centuries of continued soil losses could, in addition, devastate even younger forests. The small, isolated forest remnants of the interior west will be especially challenged. Lending a sense of urgency, some ecologists warn that a variety of plant species could disappear across hundreds of thousands of square miles over the coming century.[119] While the oldest individual trees will die off naturally as time goes on, preserving their dynamic ecosystems is the best hope for preserving and extending North America's biodiversity. Each of the American west's heritage forests will need its own ecological management plan, on the lines of the Sierra Framework.

Given the predominant national outlook and the antiregulatory climate favoring commercial interests, there is no easy solution to the forest dilemma. Establishing forest management policies and practices that better preserve biodiversity will take a long time—longer than political cycles and climatic change allow. They would have to be sustained no matter what political party holds power. Any move toward better forest management must begin with widespread and fundamental changes in national and regional attitudes and awareness. Public pressure is needed to drive reforms from a broad-based consensus that ecosystem services are important natural capital, and that ignoring or compromising them too much will have disastrous consequences.

Achieving adequate USFS implementation would require strong political support for sound ecological management[120] and tough oversight of logging and replanting practices. Maintaining such a system requires public education and determined political leadership. State and federal forestry agencies would have to enforce laws conserving old trees, hill slope soils, and plant and animal species. Environmental organizations would have to finally reach agreement on goals. If asked, we would advocate a shift away from absolute preservation or restoration of an assumed "natural" state, likely an unsustainable goal in any case, toward reducing the human footprint and preventing impacts on natural processes that maintain well-functioning ecosystems.

To reach such a national consensus for saving our western forests, Americans would have to concede that, after decades of experimentation with negative results, the best way to manage forests may be to simply leave them alone, fires and all. Nature has been in the business far longer than we have, after all. We may need to accept a human retreat from forests on the basis that burgeoning residential and business developments are ultimately harmful.

We definitely will have to take conservation and consumption issues more seriously and more personally, and this is where individuals have the greatest power. Do we really need to consume so much wood? In addition to our very high lumber use, on average, each American uses almost 900 pounds of paper per year, more than double western Europe's per capita paper consumption (351 pounds per year). The U.S. paper consumption far exceeds the minimum amount essential for literacy and communication (80–120 pounds per year).[121] Much of the excess is in packaging and advertising.

We might need to accept some minor inconveniences to achieve big environmental payoffs. In many parts of Europe, shoppers routinely carry reusable cloth bags to reduce the wood demand for paper bags, and so could we. To address climate change as individuals, we might lobby for urban community and school gardens, plant or "adopt" small teaching forests to offset carbon emissions, and revive National Arbor Day with a new and greater sense of purpose. Getting children involved in all such programs would help to build conserving practices into the body of American traditions.

Most of these ideas clearly are incompatible with our consumer culture and deep political disagreements on values. But should rapid climate changes severely limit the forests' ability to adjust and regrow, they also could limit the free-oxygen–producing, carbon-dioxide–sequestering, water-purifying, and other critical life support services that forests provide us. Water scarcities already occur throughout the arid west, jeopardizing the future for thirsty, rapidly growing populations and industries (see chapter 9). Drought conditions linked to climate warming are likely to increase the potential for destructive crown fires.

We may have a limited window of opportunity to forestall a future of severe and rapid climate alterations made even worse by the destruction of our forest ecosystems, which are a key element of the west's natural wealth. Julia Butterfly Hill's tree-sitting, and political movements to preserve all remaining old trees in California, may seem radical, but if we Americans cannot reduce our resource demands, future generations will face an impoverished and dangerous future.

2 Harvesting the Future

We lose our health—and create profitable diseases and dependencies—by failing to see the direct connections between living and eating, eating and working, working and loving.
Wendell Berry, *The Unsettling of America*

For most of two centuries, the United States was a nation of small farms and many farmers, raising much of their own food along with one or more cash crops and livestock for local markets. Today, farms run by families of weatherbeaten farmers, pie-baking farm wives, and earnest 4-H offspring are disappearing. Americans live on supermarket or take-out food, mostly produced on extensive, highly mechanized and chemical-dependent industrial-scale "conventional" farms, raising single-crop monocultures or single-breed livestock. The larger farms cover tens of thousands of acres, too much for single families to manage. It is not agriculture, but agri*business*—an industry run by corporations.

Conventional industrial agriculture is highly productive, and supermarket food is cheap. So why should anyone worry about growing food with chemical fertilizers, expensive equipment, pesticides, and pharmaceuticals? The reasons, acknowledged even by the industry, are that agribusiness "saddles the farmer with debt, threatens his health, erodes his soil and destroys its fertility, pollutes the ground water and compromises the safety of the food we eat."[1]

Croplands presently encompass some 57 million acres in the 11 western states (table 2.1). Giant plantations consume huge amounts of natural resources—soil, fertilizers, fuels, and water.[2] Synthetic fertilizers keep overused soils in production, until they become too salty (salinated) and must be abandoned. Industrial farming has taken over large areas of wildlife habitat, including forest, scrub, desert, or prairie, to replace degraded croplands.[3] The clearings and massive pesticide applications threaten or endanger large and increasing numbers of plant and animal species in the western United States.[4] Pesticide exposures sicken family farmers and agribusiness workers in the fields, and add environmental poisons to our diet. Pesticides and other problematic agricultural chemicals accumulate in our bodies.

Agribusiness consumes especially huge amounts of increasingly costly, nonrenewable petroleum. "Every single calorie we eat is backed by at least a calorie of

Table 2.1 Cropland in the 11 Western States and the United States, 1997 (Thousand Acres)

State	Cultivated Cropland: Irrigated	Cultivated Cropland: Nonirrigated	Noncultivated Cropland: Irrigated	Noncultivated Cropland: Nonirrigated
Arizona	905	77	229	1
California	5,090	1,130	3,191	224
Colorado	1,908	5,659	1,038	164
Idaho	2,822	1,719	624	352
Montana	929	11,598	1,234	1,410
Nevada	71	50	578	2
New Mexico	636	753	454	34
Oregon	829	1,848	851	234
Utah	329	376	922	51
Washington	1,022	4,556	757	322
Wyoming	448	530	886	310
Total Western United States	14,989	28,296	10,764	3,104
Percentage[a]	35%	65%	78%	22%
Total United States	48,878	277,906	13,253	36,962
Percentage[a]	15%	85%	26%	74%

U.S. Department of Agriculture. *Summary Report, 1997 Natural Resources Inventory* (revised December 2000), table 3.

[a] Percentage of total cultivated or noncultivated land.

oil, more like ten"[5] to run fleets of immense plowing, planting, cultivating, harvesting, and processing machines, plus countless irrigation pumps. Growing a pound of American beef consumes half a gallon of petroleum. A top executive of the giant agriculture-chemical corporation Monsanto has admitted that "current agricultural technology is not sustainable."[6] High-tech agriculture, such as cloning and genetically modifying crops, does not help conventional agriculture become more sustainable.

We taxpayers support these unsustainable farming practices, both at the grocery store and through our taxes. Especially in California's Central Valley, many large-scale farms irrigate crops with federally subsidized water, originally intended for small- and medium-sized farms. Huge dairies, cattle feedlots, and mass hog and poultry operations replicate this water-depleting pattern throughout the west. Tax money also goes directly to corporate farmers in the form of heavy federal payouts and price supports that destroy family farms.

A return to more traditional farming practices, especially small, ecologically balanced, local organic farms, supported by local communities, offers a way to rebuild healthy agricultural soils—the keystone component of America's natural capital—and a more sustainable future. If government programs shifted to encouraging smaller organic farms, we could begin repairing nutrient-depleted soils, restoring economic viability to small- and medium-scale farming, and improving American diets.

We Are What We Eat

We in the United States are predominantly urbanites or suburbanites who grow lawns, not vegetable gardens. In contrast to even citified Europeans, who tend to know how their food is grown, relatively few Americans understand the importance of nutrition or care to inquire where supermarket food comes from or how it gets there. Most of us get all our food information from television commercials or diet books. Some studies suggest that more than half of Americans eat mostly processed food—principally pasta, pizza, TV dinners, breads (and cakes), plus red meat and dairy products. Their main vegetables are onions and potatoes.[7]

Even those of us who vary their diets may lack access to fresh garden produce, unaware that the mass produced fruits and vegetables in standard salad bars or shrink-wrapped packages lack the succulence, texture, and flavors of garden-ripened produce. They may never have tasted the juicy sweetness of vine-ripe tomatoes or crunch of fresh garden lettuce, packed with vitamins and iron. Routine U.S. Department of Agriculture (USDA) reports show that the nutritional contents of fresh, conventionally grown, supermarket vegetables have declined from 1975 to 1997. But the USDA never publicized this information, so critical to public health, nor addressed the causes.

There's a simple reason we all need to know more about food than its taste and calorie content. What we eat, breathe, and drink—the substances that we take into our stomachs and lungs—link us directly to our environment. Each of us consists of more than a trillion cells, which are constantly dying and being replaced. "Living" means that bodily functions literally re-create all our organs, inside and out: skin, bone marrow, kidneys, livers, stomach linings, brains, reproductive organs—all the time. The air, food, and liquids that we consume are the raw materials, the building blocks, for this constant process. What is in them becomes part of us. Good food sustains health, and poor or contaminated food can undermine our minds and bodies, and even kill us.[8]

Both junk food junkies and people trying to "eat healthy" on the grains, fruits, and vegetables from large supermarket chains unknowingly swallow low levels of pesticide residues with every bite. The residues accumulate in fat cells, reproductive organs, and other body tissues—a process called bioaccumulation. A constant diet of chemical residues from conventionally grown foods can bioaccumulate in body tissues to concentrations many times greater than the amounts on foods or floating around in the environment.

Dairy and meat products contain detectable levels of hormones and antibiotics that industrial factory farms feed to livestock. Hormones can disrupt the body's critical endocrine systems, which run reproductive and other functions. Many pesticide formulations contain chemicals that imitate natural hormones. Bioaccumulation processes can build up excess hormones and other endocrine-disrupting chemicals, stored mostly in fat cells. The endocrine disrupters can impair adult reproduction, and new research suggests that they can disturb children's growth and sexual development.[9] Overusing agricultural antibiotics threatens the effectiveness of many antibiotic drugs that we rely on to control human diseases.

Corporate Farms at the Public Trough

Almost all U.S. farmlands are privately owned, yet large corporate farmers receive massive federal support. State and local government programs also pour money into private farms. In 2005, federal farm support payments totaled more than $25 billion—nearly 50% more than federal welfare payments. Farm support programs began in the New Deal, as loans to farmers facing low crop prices. The system kept grain prices from collapsing in the face of huge surpluses and "helped both to pay for the farm programs and smooth out the…swings in price."[10] Most farmers eventually repaid the loans and kept on farming.

Successive Republican administrations attacked the loans system. Ultimately, the 1970s corn sales to the then-Soviet Union drove food prices up, to a chorus of national discontent. Earl Butz, Secretary of Agriculture under Richard Nixon, hurried to lower prices and enacted programs that morphed government farm programs into flat-out handouts for large farmers growing defined commodities. The conservative Heritage Foundation contends that these farm subsidies overwhelm market forces, causing overproduction, low prices, and continual demand for more payouts. The low prices drive small- and medium-scale farmers out of business.[11] The subsidies also have increased total pesticide and fertilizer use, ruining natural lands downstream.

In the 1996 "Freedom to Farm" bill, and again in 2002, Republican-dominated conservative Congresses tried to wean farmers from government handouts and accustom them to free market risks and rewards. Both attempts failed. The 1996 bill awarded more than 70% of total tax-based farm subsidies to only about two-fifths of the nation's farmers, mostly running large operations in 12 states and growing wheat, corn, cotton, rice, and soybeans, with smaller amounts for sugar beets, peanuts, and livestock and dairy farm operations. Reported the USDA, "In real numbers, the top ten percent took home $48 billion out of $60 billion over a five year period."[12]

The 1996 law also changed the system from subsidies based on acres planted in qualifying crops to direct payments without restrictions. To give farmers flexibility in the face of shifting market trends, they now can decide what to plant, and even to not plant a crop in bad years. But somehow the law attached previously subsidized crop types to farm*lands*, independent of current use. This provision has put farms under houses—in particular, Texas rice farmers have made millions from selling their lands for housing developments.[13]

At the end of 2001, President George W. Bush instructed Congress to pass a farm bill based on free market principles as a way to expand international trade. An odd alliance of farm groups, free-market political groups, and environmentalists supported a draft Senate bill that capped farm payouts at $275,000 for any one recipient and increased funds for saving small farms as well as for soil conservation and pollution cleanups. The final bill earmarked less than a quarter of total farm spending—$12.9 billion over six years—for conservation programs that especially benefit small to medium farmers and farm owners.[14]

Agribusiness lobbyists carved up the draft, however, deleting the low subsidy cap that directed support to small farms, and dedicating most of the conservation money to cleaning up factory farm messes. The Environmental Quality Incentives Program (EQIP), originally intended to help farmers protect drinking water, became "a multi-billion dollar giveaway to a few industrial-type livestock companies" that "accelerates the consolidation of the livestock industry, harming family farmers and consumers." Most subsidy payouts went overwhelmingly to the same large operations growing the same set of overproduced crops. And payout amounts tripled.[15]

Agricultural census data show that fewer than 40% of U.S. farms, and only a fifth of farms in the 11 western states, grow any of these crops. Only 9% of farms in California, the largest farming state, get any support. Rather than address the bias of a system that has awarded subsidies to Fortune 500 companies, celebrities Ted Turner and David Rockefeller, basketball idol Scottie Pippen, and 14 members of Congress, the bill amended the Freedom of Information Act to restrict public knowledge of who gets these subsidies. Turning farm payments into state secrets sets a dangerous precedent of exempting federal programs from public disclosures to avoid embarrassing public officials and influential citizens.

Urging a veto, the Heritage Foundation calculated that the 2002 bill would pay out $30 billion annually in "guaranteed incomes and constant bailouts to a few of the wealthiest farm operators, unparalleled by those of any other industry...." Guaranteeing a minimum income of $32,652 for a family of four to every full-time farmer in America would be much cheaper—only $4 billion per year.[16] Farm payouts may keep farmer profits low, but they ratchet up grocery and restaurant prices. The Heritage Foundation estimated that the 2002 legislation will cost an average American household both $1,805 in higher taxes and $2,572 in inflated food prices over the 10 years the law is in effect, extracting at least $200 from every American household per year.

The 2002 bill also has had international repercussions. Brazil cotton growers' complaint to the World Trade Organization (WTO) resulted in a 2005 judgment against U.S. cotton subsidies—the first against a wealthy nation for domestic agricultural subsidies. In 2006, poor and developing nations' resistance to cheap subsidized U.S. crops flooding their markets threatened to undercut previous WTO agreements. In early 2007, Canada launched a WTO complaint about "trade-distorting" U.S. corn subsidies, which undercut corn prices for farmers worldwide.

Small farm squeeze-out

Writes *Metrofarm* author Michael Olson, "[C]ompetition for the consumer dollar is between the very big and the very small [farms]. The middle ground...is being squeezed into oblivion."[17] The main pressures are conventional farming's heavy costs for nonrenewable fuels, fertilizers, pesticides, and irrigation supplies—not to mention hugely expensive machinery. Crop prices have fallen under the pressure of subsidies, giving small-scale conventional farmers a crushing debt burden, which increasingly renders their operations uneconomic. One or two bad years in a row can force severely mortgaged farmers into bankruptcy.

Federal support goes to immense farms that can balance seasonal losses with income from other corporate divisions. Then the corporate farms buy out smaller neighbors with their federal payouts. Closing the circle of ruin, they then apply for additional support to compensate for low crop prices. The Heritage Foundation called it the "plantation effect," in which "family farms with less than 100 acres are…bought out by larger agribusinesses, which then convert them into tenant farms." "Freedom to Farm" flexibility destroys tenant farmers, however. The tenants collect support payments for their crops, but landowners take the money when land goes out of production. The owners get more from the government than from renters, so they kick tenants off the land. In 2006, the *Washington Post* reported that Texas rice-growing acreage has shrunk nearly 66% since 1981, with most rapid declines starting in the late 1990s.

Many small- and medium-scale farmers have to contend with low land prices and lower standards of living, pointing to the need for directing federal subsidies to those sectors instead of agricultural giants. Other pressures come from imported foreign produce, raised by low-paid labor under conditions unacceptable in the United States, which undercut both U.S. food safety standards and farm prices. California grape farmer John Baranek protested, "America demands that we farm clean and produce the highest quality food under the most strict standards in the world, and now we have our corporations buying crops from foreign countries using pesticides we banned 20 years ago."[18]

The small-farm squeeze also reduces farming efficiencies and contributes to degrading agricultural lands. Contrary to the widely held idea that bigger is more efficient, Institute for Food and Development Policy studies show that small farms actually produce far more per acre than do large ones. Compared to a large monoculture farm, smaller "integrated" farms generally raise more than a dozen crops and various animal products and so may have a lower yield per acre for one or several crops. But "the total production per unit area [on a small integrated farm]…can be far higher…[and] the commitment of family members to maintaining soil fertility on the family farm means an active interest in long-term sustainability not found on large farms owned by absentee investors."[19]

Small U.S. farmers also have a better conservation record than do the larger-scale farmers—they "devote 17% of their area to woodlands [compared to only 5% average for large farms]…and keep nearly twice as much of their land in 'soil improving uses,' including cover crops [to prevent soil erosion] and green manures [to add nutrients]." Factoring in the environmental costs of conventional farming enhances the significant economic benefits of medium- and small-scale organic farming alternatives.

Conventional Degradation

Throughout human history, farming inroads probably are most to blame for reducing forests and wildlife habitat to isolated remnants. Plowing fields always leads to soil erosion and degraded farmlands. In ancient Greece, the philosopher Plato lamented, "Once the land was enriched by yearly rains, which were not lost, as they are now, by flowing from the bare land into the sea. The soil was deep, it absorbed and kept the water in loamy soil, and the water that soaked into the hills fed springs and running streams everywhere." Agrees modern farm philosopher

Wes Jackson: "[T]he plowshare may well have destroyed more options for future generations than the sword."

America's late 1940s transition to modern "conventional" farming methods takes agricultural impacts far beyond erosion. Chemical agriculture and animal factory farms are the top dispersed sources of air and water pollution and major contributors to the 75,000 polluted miles of rivers and 4.5 million acres of polluted lakes, estuaries, and wetlands in the western United States (table 2.2).[20] In the words of Douglas Tompkins, founder of North Face sporting goods:

> Our conversion from agrarian, local, fully integrated food [raising] systems to industrialized, monoculture agricultural production has brought a staggering number of negative side effects, many of them unanticipated [including] soil erosion, poisoned ground waters, food-borne illnesses, loss of biodiversity, inequitable social consequences, toxic chemicals in food and fiber, loss of beauty, loss of species and wildlife habitat. . . .[21]

The bad effects extend to all western lands—and to everybody who eats conventionally grown food or who breathes the air or drinks water from agricultural areas. Adds Tompkins, "To make the crisis even worse, we continue to export this destructive industrial system of food production around the earth."

Soil ruin

Practices that degrade soil, our least appreciated and most undervalued resource, destroy farmlands' fertility. Decades of abusive farm management have led to widespread

Table 2.2 Polluted Waters in the Western United States, 1998

State	Rivers and Streams (Miles)	Lakes, Estuaries, Wetlands (Acres)
Arizona	1,780	29,840
California	13,720	3,367,170
Colorado	1,750	11,080
Idaho	11,160	233,980
Montana	29,550	1,470,300
Nevada	2,600	109,340
New Mexico	2,330	66,340
Oregon	6,040	116,830
Utah	3,560	132,360
Washington	550	14,910
Wyoming	1,410	9,690
Total	74,450	4,461,900

U.S. Environmental Protection Agency. *Atlas of America's Polluted Waters* (EPA 840-B-00-0002, 2000).

soil erosion, stripping of western U.S. croplands, and growing numbers of abandoned farms. By the end of the twentieth century, eight million acres of degraded U.S. agricultural land either had been abandoned or taken out of production under the federal Conservation Reserve Program.[22]

Soil is the main medium in which most plants grow. Before plows broke the rich but fragile arid western soils, the land maintained its health by growing a vegetative mix, some plants adding nutrients as others extracted them. Farmers today plow constantly and grow the same set of nutrient-extracting crops every year. This is the best way to exhaust soils and open them to erosion.

Natural geological and biological processes developed soils over many hundreds to thousands of years. Rainwater interacts with carbon dioxide (CO_2) to release minerals from rock debris, and soil biota—abundant bacteria, fungi, algae, and other microscopic organisms from decaying living things—process the minerals into the nutrients that plants need to grow and thrive (see chapter 13). In undisturbed soils, the actions of earthworms, insects, bacteria, and fungi constantly process and exchange nutrients. Eventually, most natural soils develop a layered structure (profile), capped with protective and stabilizing biotic surface crusts. Upper soil layers develop openings that hold water and air, absorb raindrops, retard erosion-causing runoff, and enhance water seepage to natural groundwater-storage aquifers (recharge). Soil organisms, including plant and tree roots, remove natural waste substances, purifying the water (see chapter 1).

Rainstorms and windstorms shape the land in complex and continuous processes of soil erosion, transportation, and redeposition (see chapter 13). Soil crusts, plant covers, and other natural soil stabilizers minimize erosional effects, while human disturbances open soils to erosion. Topsoil, the upper layer that most effectively feeds plants, is the first to go and carries the nutrients with it, along with decayed litter and biota (figure 2.1). Removing topsoil also undercuts plant roots and kills the plants, exposing lower soil layers to faster oxidation and leaching by water. As erosion proceeds, the soil eventually loses all of its nutrients and larger biota.

After plowing, even gently sloping and flat lands undergo accelerated erosion—even where farmers employ erosion control techniques. Erosional effects and rates are much greater on slopes, because sheets of running water quickly carry soil away and cut shallow rills into the hillside. If not stopped, the rills develop into deep gullies (arroyos). Crawler tractors, developed in the early twentieth century, eased plowing on steeper slopes but greatly increased erosion rates—especially in fields of corn, cotton, and leafy vegetables.[23] A common modern tendency is to plow straight up a slope, increasing runoff and erosion even more.

Erosion turns in-place soil to unstable sediment and a costly problem. Conventional-farm soils store fertilizer and persistent toxic pesticides, but eroded sediments carry off significant amounts of the chemicals and deposit them downstream (see chapter 13). Sediments can bury undisturbed fertile soils and crops and damage equipment and trees. Overloading streams with sediment inevitably generates more and larger flooding episodes downstream. Sediment deposits are more easily eroded than the soils themselves and can continue polluting streams, rivers, lakes, and ponds for many years in succession.

Contour plowing and terracing reduce the worst erosion effects from rain runoff. But contouring slopes with huge machines can be dangerous, and terracing

Figure 2.1 A huge dust plume rises 5,000 feet above the southern San Joaquin Valley, California, at the height of the 24-hour December 1977 windstorm. Dust streams from canyons in the Tehachapi Mountains foothills (lower left). Before local wind-speed gauges failed, some had recorded winds up to 194 miles per hour, which uprooted or toppled powerline towers, destroying orchards, vineyards, and other crops. Photograph by Sam Chase.

restricts the planted acreage. Terracing also is costly and adds to a conventional farmer's huge debt burden. Neither technique can lower soil erosion on plowed lands to natural levels. No-till farming, which presses seed into the soil with mechanical drills, has less erosive potential and is gaining popularity.

Dust to dust

Wind storms carry dust particles thousands of miles, spreading pollution around the globe. To the 1930s economic depression, drought and strong winds added the Dust Bowl, which stripped soil from intensively farmed wheat fields on the plains of Kansas, Oklahoma, and Texas.[24] Some of the blinding and choking dust and sand storms buried crops still standing in nearby fields, severely abrading trees, houses, cars, and animals. Other windstorms rained Texas soils on Chicago or blew midwestern dust across New York City and Washington, DC, spreading pathogenic bacteria and fungi that cause severe respiratory problems and other illnesses.[25]

Acknowledging the threat of soils massively on the move, the 1930s federal government prescribed and funded soil-conserving practices, such as contour plowing and planting trees and bushes for windbreaks. But the Dust Bowl's hard lessons now seem forgotten on America's arid plains. Farms across the west yield dust abundantly, and windstorms again destroy soil fertility and threaten health and safety.[26]

Windbreaks are out of favor because they impede today's supersized farm equipment and popular center-pivot irrigation systems in rectangular fields. Temporarily increased wheat prices in the 1970s prompted farmers to tear out tree lines and hedgerows and plant every square inch of land. Taking out the windbreaks also eliminated valuable habitat for wild animals. By 1977, huge stretches of California's San Joaquin Valley lacked barriers to wind erosion altogether. When a spectacular wind storm swept down, it completely removed the soil, subsoil, and even underlying weathered bedrock across extensive tracts (figure 2.1). The soil fungus *Coccidioides immitis*, common in southern California, Arizona, and New Mexico, spread valley fever, a severe respiratory disease, in the dust. One fatality was a gorilla in the Sacramento zoo, some 300 miles away. The dust storm severely denuded areas on the ground, which still are visible barren patches. They are unlikely to return to full biological productivity unless left alone for thousands of years.[27]

Few data reliably estimate the extent of current erosional problems. The theoretical universal soil loss equation (USLE) and wind erosion prediction system (WEPS; see chapter 13, box 13.1) could be useful, but the data for making those calculations are inadequate. For 1992, the USDA conservatively guessed that a total of 2.1 billion tons of soil was lost to wind and water erosion, excluding gully erosion and mass wasting (see chapter 13). If piled on a single football field, that much soil would form a heap 200 miles high. The USDA figure was the most conservative of several soil loss estimates for that year—an unbelievable 1.1 billion tons less than the 1982 estimate.

Fertilizing and polluting

Such critical soil properties as thickness, layering, water storage capacity, and surface crusts cannot be restored in a human time frame (see chapter 13). To keep on growing crops in degraded fields, farmers add expensive fertilizers and other amendments. Assuming available resources and affordable fuel costs, fertilizers can restore plant nutrients and acid balances to upper soil layers, but nothing can restore subsoil acidity, soil textures, water storage capacity, or biota. In fact, synthetic fertilizers tend to kill the biota. Rising fuel prices also increase the costs of making fertilizer and mining already-depleted fertilizer raw materials, inevitably raising farming costs (see chapter 12).

Fertilizers are principally nitrogen (N), phosphorus (P), and potassium (K) chemicals.[28] Every year, U.S. industrial agriculture applies close to 30 million tons of NPK fertilizers to farmlands, about 13 million tons of nitrogen fertilizers—nine million tons are synthesized domestically, and the rest is imported. Agriculture in the United States largely depends on nitrate compounds made from ammonia, a nitrogen–hydrogen chemical (NH_3). The ammonia is synthesized in two laboratory processes from atmospheric nitrogen. One highly energy-consuming process generates hydrogen at temperatures as high as 660°F and pressures 3,000 times higher than at sea level.[29] About 38% (three million to four million tons) of annual U.S. hydrogen production goes to making fertilizer. Most of the hydrogen comes from natural gas, so fertilizer supplies are increasingly limited by natural gas costs and availability (see chapter 12).

Nitrogen-rich fertilizers also include animal manures. The United States produces approximately 1.6 billion tons of domestic animal manure annually; about half is used for fertilizing pasture and grazing land. In general, plants are able to absorb only about one-third to one-half the nitrogen in applied fertilizers, a wasteful and environmentally harmful excess.[30] The nitrates that plants cannot absorb go back to the atmosphere as ammonia gas or nitrous oxide, a potent greenhouse gas,[31] or they wash into streams or leach into groundwater. If manure is not buried but simply laid on the ground, it loses about half its nitrogen content in 24 hours. Overfertilizing has turned vast tracts of organically rich and fertile soils into a sterile compound that does little but hold plants upright.

The phosphorus and potassium in fertilizers come from nonrenewable phosphate rock and potassium-rich salt deposits, resources of uncertain availability. To make the fertilizers, phosphate rock and potassium salts are mined and treated—although potassium salts also can be manufactured in the lab from other potassium chemicals. Phosphate fertilizer consumption in the United States is about five million tons per year. Paradoxically, the United States supplies most of the world with phosphate fertilizers but also annually imports about two million tons of raw phosphate rock from North Africa and the Middle East for making the fertilizer. Economic geologists estimate that the United States will become a net importer of phosphate rock in 20–40 years. Since the world's remaining phosphate deposits come from politically and economically unstable regions, they probably are the fertilizer resources with highest potential for shortage shocks.

Potassium-rich salts are mined from "evaporite" salt beds, deposited as ancient lake or subsurface brines progressively dried up. The United States consumes about 11.5 million tons of potassium fertilizer annually and imports about nine million tons from Canada.[32]

Phosphate rock and fertilizer contain potentially toxic natural trace elements such as cadmium, selenium, and others that can harmfully concentrate in vegetable crops and in the animals that eat them, including us.[33] Other commercial fertilizers can be worse. Unbeknownst to farmers, urban back yard gardeners, and golf course and cemetery groundskeepers, until about 1997 many packaged fertilizers contained unidentified recycled hazardous wastes or mixed fertilizer and hazardous waste. Mining wastes can be packaged as fertilizer because federal laws uncritically exempt them from hazard labeling. "Ironite" was one such lawn and garden fertilizer product, consisting of mine tailings laced with high arsenic and lead concentrations from a Humboldt, Arizona, proposed Superfund site (see chapter 10). Revelations about the fertilizer plus wastes concoction inspired both Washington State and California to pass laws limiting heavy metal concentrations in fertilizers.

About 1.6 million tons of waste chicken manure, annually produced on megascale chicken farms, also wind up fertilizing croplands. The manure contains arsenic from chicken feed additives for controlling infections and increasing weight.