Defining Mature and Old-Growth Forests

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USDA Forest Service and USDI Bureau of Land Management have requested input on development of a definition for old-growth and mature forests on Federal Lands and provided a series of five questions. We have organized our input around these five questions followed by recommendations for an inventory to identify those forests.

What criteria are needed for a universal definition framework that motivates mature and old-growth forest conservation and can be used for planning and adaptive management?

It is not possible to develop a single definition of mature and old-growth forests [hereafter referred to as "older" forests] because the nature of older forests varies markedly with forest type and region. Much of this diversity is encompassed by two broad categories of older forests that differ in their natural disturbance regime and, consequently, in their fundamental structure. These are: 1) older forests developed on sites characterized by infrequent (episodic) severe wildfire and 2) older forests developed on sites characterized by frequent (chronic) low-severity wildfire. We will refer to these as Moist and Dry Forests, respectively. Examples of Moist Forest include coastal Douglas-fir, many eastern hardwood forests, and most western subalpine forests. Examples of Dry Forests include ponderosa pine forests in the Intermountain West and longleaf pine in the southeast. Wind can be a significant disturbance in either of these two categories of forest but we emphasize wildfire here, because frequent (chronic) wildfire is what produces the distinctive composition and structure of Dry Forests.

These two categories of older forests share some common attributes including the: 1) Presence and often dominance of large old trees, large snags, and large down logs, with the definition of "large and old" varying with the forest type and other considerations; 2) Irregularity in the distribution of trees and other vegetation (spatial heterogeneity or patchiness).

Otherwise, the structure of older Dry and Moist Forests in their natural states contrast greatly. Older Moist Forests have high tree densities with diverse tree sizes (including large old trees) and dense canopies that are either continuous or multi-layered. Older Dry Forests commonly have low density stands composed primarily of older trees and relatively open high canopies, except in regeneration patches.

The recognition of two fundamentally different types of forests helps motivate mature and old-growth forest conservation and can be used for planning and adaptive management. Policy in episodically disturbed forest types needs to focus on retention and protection of mature and old-growth forest stands. Policy in frequent-fire forests needs to accommodate and encourage active management to restore and maintain these forests during which existing mature and old trees are retained and their populations are rebuilt.

What are the overarching old-growth and mature forest characteristics that belong in a definition framework?

The overarching (i.e., common) characteristics of older forests are: 1) large old trees of one or more species and the dead derivatives of those large old trees – large snags and large down logs; and 2) spatial heterogeneity in the distribution of trees and other vegetation, often evident as patchiness in density and canopy cover, gaps, and clustering of trees.

An origin-date threshold of the oldest cohort (for example, 1920) is perhaps the best single attribute for defining the forests and trees for consideration in an initial inventory. Stands that have had past partial cutting should be considered if they otherwise meet the definition of mature or old-growth forest. Use of an origin date would ease analysis and implementation. Use of origin date also reduces the potential for future conflict in growing managed forests that incorporate mature and old trees that may be subject to eventual harvest. A mature and old-growth forest policy should encourage foresters to grow mature and old-growth trees as part of their managed forests and not discourage them, which a ban on harvesting any tree over a given age, regardless of origin, would do.

How can a definition reflect changes based on disturbance and variation in forest type/composition, climate, site productivity, and geographic region?

First, there must be at least two different general definitions to deal with the fundamental differences in forest structure between older forests on sites that were historically frequently disturbed and older forests on sites historically subject to infrequent or episodic disturbances. That will deal with the major (fundamental) differences in older North American forests related to disturbance regime. Otherwise, the differences recognized among sites, types, etc., in defining mature and old-growth forests should be largely quantitative rather than qualitative.

How can a definition be durable but also accommodate and reflect changes in climate and forest composition?

An adaptive approach to older forest definitions as well as policies for the management of these forests should be utilized. Periodic assessments (monitoring) of these forests will be necessary to identify any fundamental changes in biota, structure, and function and to adjust management approaches needed to maintain the ecosystem functions of older forests in a changing world.

What, if any, forest characteristics should a definition exclude?

Dense, high-biomass forests are not a desirable characteristic that should be included in a definition for older forest on landscapes that were historically subject to frequent fire (Dry Forests). Such forests were, under their natural disturbance regime, dominated by open forests of older and larger trees. Many of these forests have become dense as a result of past management practices including exclusion of fire. Dense Dry Forest stands that still have significant populations of older trees do need to be included in the inventory. However, policies for such Dry Forests need to allow for restoration with the proviso that the older trees must be retained as stand densities are reduced. A policy that does not allow restoration of older Dry Forests will doom the older tree populations; they will be lost through fire, drought, and/or bark beetle attack.

A Process for Identifying Older Forests on Federal Lands

We view mapping older forests as a multi-step process. An initial map developed from remote-sensed data will need to undergo significant ground checking if the intention is to use it in implementing policy rather than simply indicating the general location of older forests. A process involving agency field personnel would be appropriate to determine the accuracy of any map to deal with potential errors of both inclusion (forests initially identified but prove not to be older) and exclusion (i.e., older forests that the mapping process failed to identify). In fact, it may be necessary to finalize locations of older forests as local management plans are developed and implemented.

Age of the oldest forest cohort present in candidate forests is an important criterion. For many of the important functional attributes of older forests, it is the old trees, with their distinctive features, that have special functional significance. Large younger trees are not capable of fulfilling many of these functions so presence of large young trees is, by itself, not a useful criterion for identification of older forests. A brief summary of some of the unique attributes of older trees is attached (Attachment #1) .

Characterization of older Moist Forests has been most successful using multiple structural and compositional attributes integrated into a numeric index of “old growthedness.” This, with an aging of older trees in the stands, has been successfully used by the Washington Department of Natural Resources to identify older forests on lands that they administer in western Washington (see below). Avoid focusing on maximal values of a single attribute (e.g., biomass) in these definitions.

On the other hand, identification of older Dry Forests simply requires the identification of stands with a significant population of older trees. The majority of the Dry Forests have been drastically modified from their historic condition by grazing, logging, and elimination of periodic wildfires. Presence of some of the attributes characteristic of older Moist Forests, such as a high density of large younger trees and multiple canopy layers, are not desirable characteristics of older Dry Forests and should not be utilized to identify mature and old growth Dry Forests in the upcoming inventory; they are primarily a consequence of modern human activity.

Objections sometimes are raised to using age to identify older forests and trees as we propose above on the basis that that will require extensive increment boring of trees. Our experience in the Pacific Northwest is that, with training, the majority of older trees can be accurately determined from external features of trees, such as the bark and canopy structure.

Distinguishing between areas historically subject to frequent fire and those subject to episodic fire (i.e., between Dry and Moist Forests) is an essential step in inventorying older forests. As noted earlier, older forests developed under a frequent fire regime are fundamentally different in their structure from older forests developed on sites subject to infrequent wildfire (Attachment #2). Policy and management ultimately need to reflect those differences. The best way that we have found to distinguish between sites of Dry and Moist Forests is by using forest vegetation zones based upon plant association or habitat type classifications. Such classifications exist for all federal lands, at least in the west and we have attached a map of such zones for the range of the northern spotted owl (Attachment #3). Such classifications were utilized to distinguish the two categories of older forests (Moist and Dry) in recent legislation proposed for conservation of old-growth forests by Senator Wyden, for example, demonstrating their practical use in policy and management.

Washington State Department of Natural Resources successfully used a mapping exercise and evaluations of stands using an old-growth index based on multiple structural attributes to identify old-growth Moist Forests on lands that they manage. This was followed by field checking, which included visits to the relatively few stands that could not be successfully classified without an on-site examination. Identification of older Dry Forests was done by determining whether or not there were significant populations of mature and/or old trees present in stands. It was not necessary for stands to have a dominance of older trees for them to be identified as the older Dry Forest.

they occupy (Figure 2.5). Species other than trees, such as shrubs and forbs, also contribute to structural complexity. The tall and decay-resistant tree life form makes much of this structural complexity possible; few other ecosystems exhibit such large, complex, and persistent structures of biological origin, although coral reef ecosystems would be another example.

Of the three major categories of ecosystem attributes (biodiversity, function, and structure), structure has special significance for forest managers and stakeholders for three reasons. First, structures are typically the objects that we manipulate to achieve management objectives. Second, some of the structures—the trees—are often a major end product of our management, such as logs for harvest. Third, structures are often used as surrogates for processes (e.g., productivity) and species (e.g., habitat) that are difficult to observe or measure directly.

Forest structure is multidimensional—i.e., it includes consideration of (1) the variety and abundance of individual structures, such as trees, snags, and logs as well as (2) the spatial arrangement of the structures and structural conditions within the forest (Table 2.2). Both of these dimensions are important in forest management. In production forestry the focus is exclusively on live trees and uniform

Box 2.3 **Ecological significance of old trees**

Old trees differ greatly from young trees in some of the roles that they play in forest ecosystems, and this is not just related to their generally larger size, the principle being that ***old trees are not simply enlarged versions of younger trees.*** Particularly in long-lived species, older trees accumulate significant idiosyncratic features as a result of injuries and infections and responses to those injuries (e.g., reiterated tops) and as a consequence of altered light and temperature conditions (e.g., epicormic branch systems). Even to very old ages, trees commonly retain an ability to grow and repair themselves in response to both damage and improved environmental conditions, although such capacities (and inherent longevity) do vary widely with species.

Large old trees have larger branches, often of both primary and secondary (epicormic) origin, which are important to many canopy organisms and processes. For example, large branches can accumulate massive epiphytic communities and provide essential sites for the nests of large birds, such as eagles, or, alternatively, egg-laying sites for birds that do not create nests, such as marbled murrelet (*Brachyramphus marmoratus*). Older trees have time to develop larger primary branches and to experience stimuli (e.g., breakage) that generate secondary branch systems. Canopies of old trees may also be deep, extending close to the ground—even after undergoing extensive natural pruning as younger trees—as a result of secondary (epicormic) branch development. On the other hand, canopies of old trees in frequent-fire ecosystems are likely to be elevated, reducing the potential for fire to ladder into the crown.

Old trees have larger percentages of heartwood than younger trees of the same species, which results in more durable snags, logs, and other coarse wood structures. Heartwood decays differently than sapwood so it plays different roles as habitat; elements of heartwood may be very persistent in litter and soil systems. Heartwood also behaves differently as a fuel because of its greater content of resinous material.

In many species, older trees develop thick and complex (e.g., furrowed) bark, which create niches for invertebrates that are, of course, potential food sources for other species (e.g., Carey, 2009). Thicker barks make older trees more resistant to wildfire and increase their probability of surviving such events and functioning as foci in ecosystem recovery. Some species may produce masses of loose and stringy bark that are important habitat for invertebrates: e.g., *"Bark streamers provide habitat for a wide array of invertebrates, such as spiders and predatory wingless tree crickets . . . [which] are, in turn, prey for several species of marsupials . . . and birds"* (Lindenmayer, 2009, p. 75).

The decadent features of older trees are among their most important from the standpoint of habitat for biological diversity. Cavities and other pockets of decay are essential for a wide array of cavity-dependent species (e.g., see (Lindenmayer, 2009; Hunter & Schmiegelow, 2011). Multiple tops provide complex canopies as well as thick vertical branches that are broad, stable platforms, which can accumulate thick mats of organic matter. The epicormic branch systems mentioned earlier may also be the consequence of crown damage and loss. Brooms of various types may also develop as a result of diseases or mistletoes; these can be important nesting, resting, and hiding habitat for birds, mammals, and other animals.

Old trees also represent a distinctive genetic resource, particularly in landscapes that are now dominated by managed forests. These trees not only represent diverse germ banks but also include genotypes that can be viewed as long-term "winners"—i.e., they are trees that have survived diverse climates, attacks by fungi and insects, and possibly intense storms and fires!

Finally, it is important to recognize that large and old trees may continue to accomplish significant net growth. An outstanding example of this has been documented for old coast redwood (*Sequoia sempervirens*) and giant sequoia (*Sequoiadendron giganteum*) trees. After a comprehensive analysis of growth patterns in a large sample of such trees, investigators found no evidence of negative growth–age relationships in either species and concluded that, *"Except for recovery periods following temporary reductions in crown size, annual increments of wood volume and biomass growth increase as redwoods enlarge with age until extrinsic forces cause tree death"* (Sillett et al., 2015, p. 181).

Wildfire is an important disturbance element in some deciduous hardwood forests, particularly near the boundaries with prairies and in the transition to boreal regions. In both of these cases, conifers become important components of the stands. Examples would be the mixed hardwood–conifer ecosystems of the Lake States, where red pine and eastern white pine are important conifer associates (Figure 3.27), and, more generally at higher elevations and latitudes, where true firs and spruces become important stand components. However, even where fires occur, crown fires are unusual in hardwood forests due to "relatively (compared with many conifers) high foliar moisture content, low bulk density of the canopy and possibly low content of flammable extractives" (Frelich, 2002, p. 25).

Wildfire does generate developmental patterns that contrast with those from wind disturbance events, since fires tend to kill from below. Consequently, significantly less regeneration from vegetative legacies occurs following wildfire in comparison with windstorm events, whether sprouts from surviving larger trees or advance regeneration. Regeneration following fire in this archetype is much more dependent upon seed dispersed from lightly burned or unburned sites. One consequence of this is that the PFS is likely to be both more species rich and persistent following wildfire than after a windstorm.

The lenga forests found in Tierra del Fuego are a very simplified example of the deciduous hardwood archetype (Figure 3.28); they have few or no other tree species present and low overall higher plant diversity. Lenga is a relatively shade-intolerant species, which has infrequent mast years but usually sustains a seedling bank in the understory. Creation of canopy gaps by wind provides the opportunity for seedlings to develop into dense sapling patches (Figure 3.28), which undergo intense competition but eventually produce individuals that move into the upper canopy. The wind-generated gaps display a classic log-normal distribution with regard to patch size with many small gaps and very few large patches (Rebertus, Kitzberger, Veblen, & Roovers, 1997). Some larger wind events can result in very large patches of windthrow with nearly 100% of the overstory affected. Large amounts of CWD are characteristic of the lenga forests (Figure 2.9), which partially may be a consequence of the dominance of brown-rots in wood decay rather than white-rots, which are more characteristic of deciduous hardwood forests.

Natural Forest Archetypes Characterized by Frequent Fire

Forest ecosystems that experience frequent-fire disturbance regimes have highly distinctive structural and compositional features that differ dramatically from the two stand-replacement archetypes that we have just described. In fact, we are amazed that the profound distinction between frequent-fire and essentially all other temperate forest types has not been more consistently and emphatically recognized by foresters and forest ecologists. In a forest dichotomy the differences between frequent-fire forests and all other closed-canopy temperate and boreal forests are more significant structurally and functionally than the differences between coniferous and hardwood-dominated forests! Perhaps the fundamental uniqueness of the frequent-fire forest has not (in our opinion) been adequately appreciated for several reasons. First, after much initial high-grading and some selective management by landowners, management in the mid-20th century moved toward conversion of such forests to plantations; also, many foresters and stakeholders may not have recognized that fire was an essential feature of a stable and productive forest ecosystem.

Figure 3.27 *There are forest types that regularly experienced significant disturbances from both wind and wildfire, such as this mature red pine-hardwood forest in central Minnesota. Such forests could provide the basis for an additional archetype in which both types of disturbances are interacting to produce unique outcomes from interactions of both types of disturbances and joint dominance by both conifers and hardwoods (Cutfoot Experimental Forests, Chippewa National Forest, Minnesota, USA).*

Fire is unique among the most common natural disturbances in several features, including its tendency to kill "from below" rather than "from above," when it occurs at low to moderate intensities; consequently, fire tends to kill smaller trees while the larger dominants and codominants have a high probability of surviving. ***Frequent fire also operates selectively in favoring species adapted to survive fire and against species that are easily damaged or killed by fire.*** Fire adaptations may relate to structural features of either the reproduction (e.g., seedlings that have fire-resistant features that aid in their survival) or adult trees (e.g., thick fire-resistant bark and pruning of lower branches).

Another unique attribute of fire compared to most other disturbance agents is that humans have the capacity to directly influence this disturbance agent—i.e., either to limit or eliminate it from a site (for at least a period of time) or to systematically introduce it to sites. Significant changes have occurred in most frequent-fire forest ecosystems as a consequence, most profoundly as a result of the historical and initially very successful efforts to eliminate fire in these ecosystems.

The common natural outcome of the powerful selective force of frequent fire is a predominantly low density forest dominated by larger, older trees (Figure 3.29) regardless of the inherent productivity of the site (e.g., Christensen, 1981, 1988; Glitzenstein, Platt, & Streng, 1995; Hagmann, Franklin, & Johnson, 2013, 2014; Peet & Allard, 1993; Ware, Frost, & Doerr, 1993) (Color Plate 3.5). Frequent fire often overwhelms the influences of other environmental variables, such as productivity. Both of the two primary examples of this archetype that we discuss here—ponderosa pine in western North America and longleaf pine in the southeastern United States—often exhibit classical savanna-like architecture, even though they otherwise occupy very different environments. Ponderosa pine forests are found

Figure 3.28 *Monotypic forests of lenga* (Nothofagus pumilio) *in Tierra del Fuego provide a highly simplified example of a deciduous forest in which wind is the primary exogenous disturbance regime. (a) The forests are relatively simply structured. (b) Canopy gaps are required for successful regeneration as lenga is a relatively shade-intolerant species. Regeneration can be heavily grazed by families of guanaco—a native camelid—but woody debris created by windthrow events confers some protection to the regeneration.*

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primarily in seasonally dry climates and often on sites of relatively low productivity due to moisture limitations; hence, they are sometimes referred to as the ***dry forests*** (Franklin & Johnson, 2012, 2013). Longleaf pine forests, on the other hand, lack a regular dry season and can be highly productive on better soils. Yet, frequent fire produces similar architectures in both types (Figure 3.29).

Ponderosa Pine Ecosystem Frequent-fire forests dominated by ponderosa pine were arguably one of the most extensive forest formations in North America prior to European settlement, but the majority of these forests have been modified by fire suppression and harvesting. Ponderosa pine was the only significant tree species on many sites, although it often was associated with various species of juniper (*Juniperus* spp.) and oak, Douglas-fir, white or grand fir (*Abies concolor* and *grandis*), lodgepole pine, and western larch (*Larix occidentalis*). Western larch largely replaces ponderosa pine as the major fire-resistant tree dominant in portions of the northern Rocky Mountains. In the Sierra Nevada Range of California, sugar pine (*Pinus lambertiana*), Jeffrey pine (*Pinus jeffreyi*), and incense-cedar (*Calocedrus decurrens*) are significant associates.

The archetypical ponderosa pine ecosystem is predominantly a fine-scale mosaic of patch types largely reflecting mortality processes (fire and bark beetle) that kill individuals and small clusters of trees (Figure 3.30). Consequently, the diversity of patch types—openings (PFS) and patches of

Figure 3.29 *Natural forests of ponderosa pine (top) and longleaf pine (bottom) have similar savanna-like architectures despite their significant differences in environment and productivity and in the frequency of fire that is required to sustain these structures. Ponderosa pine forests are often found on dry, low productivity sites and their savanna-like structures can be sustained by fires at relatively long intervals (e.g., 10–25 years). Longleaf pine forests occupy environments that are generally moist throughout the growing season and can be highly productive; sustaining these forests requires fire at relatively short intervals, such as one to three years.*

Figure 3.30 *Profile of a well-developed ponderosa pine forest illustrating the mosaic of conditions, from openings to groves of old trees that are characteristic of such forests. Drawn from transect in Bluejay Springs Research Natural Area, Fremont-Winema National Forests, Oregon, USA. (Illustration by Robert Van Pelt)*

saplings and poles (YFS), mature trees (MFS), and groves dominated by large old trees (OFS)—as well as patches that are mixtures of these conditions are simultaneously present in the mosaic (Franklin & Van Pelt, 2004) (Figure 3.12). While the spatial arrangement of these patches changes over time, the collective forest ecosystem is very stable as long as it continues to experience frequent fire (see Color Plate 3.6). For an ecologically complete forest ecosystem all patch conditions need to be present.

Tree densities in the frequent-fire archetype are typically low with the basal area primarily composed of older, large-diameter trees (Hagmann, Franklin, & Johnson, 2013, 2014; Noss et al., 2006). Diameter distributions are often relatively flat or exhibit bulges in the larger diameter classes; the classic reverse J-shaped diameter distribution found in the stand-replacement archetypes is not characteristic of frequent-fire ecosystems. Tree spatial distributions are often highly clustered rather than uniform (Figure 3.31) (Churchill et al., 2013; Larson & Churchill, 2012). The clumped spatial arrangement of trees has important ecological consequences, such as in its effects on the behavior of wildfire and bark beetles and vertebrates' use of the habitat.

Historical ponderosa pine forests also had high levels of landscape continuity; distinct edges or vegetative boundaries were generally encountered only when environmental conditions shifted sufficiently to alter site potentials, such as to grassland or riparian habitat. The lack of traditional "stands" was partially due to the infrequency of extensive high-severity fire events, which would generate distinctive larger patches with well-defined boundaries. Mixed- and high-severity fire behaviors now occur with increasing frequency as the result of the greatly increased intervals between fires.

As moisture conditions improve along environmental (e.g., elevational) gradients ponderosa pine forests shift from nearly pure forests of ponderosa pine to forest ecosystems that include greater mixtures of other species, which are often referred to as mixed-conifer types. In much of the western intermountain North America, species such as

Figure 3.31 *Tree spatial distributions are often highly clumped or clustered in frequent-fire forest ecosystems, which has important consequences in the functioning of these ecosystems, including their response to wildfire and other disturbances.*

Douglas-fir, white or grand fir, and western larch are typical additions. Common associates in the Sierra Nevada mixed-conifer forests are sugar pine, incense-cedar, white fir, Douglas-fir, and California black oak (*Quercus kelloggii*). In the mixed-conifer forests fires can be less frequent, and mixed-severity fires are more common than in the pure ponderosa pine forests.

Although we have used the present tense in these descriptions of the ponderosa pine and mixed-conifer forest ecosystems, most of these forests have been highly modified as a result of Euro-American colonization. Elimination of frequent fire has been the most important change, but this is only one of many disruptions. One of the earliest and nearly universal impacts of Euro-American colonization was grazing by immense herds of cattle and sheep in the second half of the 19th and beginning of the 20th centuries; this eliminated most fine fuels, which were important in sustaining frequent fire, and also competed with tree seedlings. (Noss et al., 2006). Another early and widespread impact was destruction of Native American cultures, many of which had utilized fire. Active fire suppression has been the most important impact during the last 100 years. Finally, logging has dramatically altered many of these forests such as by selective logging of larger trees, clearcutting, and establishment of plantations.

The outcome of all of these impacts has been the conversion of the majority of frequent-fire forests to dense, fuel-rich stands dominated by species intolerant of fire and drought (Figure 3.32) with the further consequence that large, uncharacteristic stand-replacement wildfires are now the dominant disturbance regime (Figure 3.33). Unexpectedly, the impacts of fire elimination generally have been much greater in the mixed-conifer forests than in the pure ponderosa pine forests. Factors responsible for this faster response of mixed-conifer forests to elimination of fire are related to their significantly greater productivity (more available moisture) and the regeneration and rapid growth of species, such as white fir, which produce highly flammable fuel ladders. This more rapid shift in forest fuels on mixed-conifer sites is often overlooked because it usually involves many fewer "missed" fire intervals than on drier sites. There are significant efforts underway to restore many of the pine and mixed-conifer forests to more resistant conditions (see Chapter 4).

Longleaf Pine Ecosystem In order to maintain its composition and structure, the longleaf pine ecosystem requires fire at very frequent intervals (one to three years), which makes it the "bookend" ecosystem of the frequent-fire forests. At longer fire intervals competing hardwoods become established and have the potential to increase their dominance, eliminating the potential for frequent fire and successful reproduction of longleaf pine. ***The longleaf pine ecosystem is the most finely tuned to its disturbance regime of any forest ecosystem we know.***

A second exceptional attribute of the longleaf pine ecosystem is its very high biodiversity, which is composed of both plant and animal species; in fact, ***we believe that the longleaf pine ecosystem is the most biologically rich temperate forest ecosystem in the world.*** Understories in longleaf pine ecosystems may include 300–400 vascular plant species. The bunchgrasses, such as the widespread wiregrass (*Aristida stricta*), make critical contributions to the quantity and structure of surface fuels required to support the very frequent fires (Mitchell, Hiers, O'Brien, & Starr, 2009). The rich vertebrate diversity includes birds, amphibians, reptiles, and mammals; notable species include gopher tortoises (*Gopherus polyphemus*) and red-cockaded woodpeckers (*Picoides borealis*) (Figure 3.34). A comprehensive treatment of the longleaf pine ecosystem and its management is provided in *Ecological Restoration and Management of Longleaf Pine Forests* (Kirkman & Jack, 2017).

The architecture of the archetypical longleaf pine ecosystem is very similar structurally to that of ponderosa pine (Figure 3.29). Savannas dominated by larger-diameter trees are characteristic. Lightning fires generate openings in the forest where patches of longleaf pine reproduction can

Figure 3.32 *Many ponderosa pine and mixed-conifer forests have undergone dramatic change with the removal of fire, including increased densities, dominance of fire- and drought-intolerant trees, and greatly increased fuel loadings, including abundant ladder fuels. Old ponderosa pine are now surrounded by young and mature Douglas-fir and grand fir that have grown up around it as a result of fire suppression (land managed by the Washington Department of Natural Resources near Ellensberg, Washington State, USA).*

develop (Figure 3.35), but regeneration is not necessarily confined to openings. Diameter distributions are relatively flat under the frequent-fire regimes.

Longleaf pine forests once covered 80 million acres in a crescent extending from Virginia across the Southeast to eastern Texas. Today only about 3% of these forests remain and much of that is on federal military reservations. Some of the original longleaf pine acreage has been converted to agricultural and other domestic uses. Of the area remaining in forest cover, the vast majority of the longleaf pine has been converted into plantations of other southern pines, such as loblolly and slash pine, which are more amenable to intensive forest management. Interest in restoration and management of longleaf pine is increasing, however, with much of it based on ecological forestry approaches (see Chapter 4). Social concerns over smoke from prescribed burns are one of the major challenges to sustaining this ecosystem in the future.

Other Frequent-Fire Forest Ecosystems The pitch pine–hardwood forests found in New Jersey (known as the Pine Barrens) are a distinctive type of frequent-fire forest (see Chapter 4). Pitch pine (*Pinus rigida*) is capable of reproducing vegetatively after being subjected to severe wildfire. The hardwoods associated with it, which include several species of oak, also are capable of regenerating themselves vegetatively. Hence, forests composed of pitch pine and hardwoods are capable of experiencing a severe canopy-consuming wildfire, but many of the trees, including the dominants, will survive such events by abundant sprouting.

Frequent-fire forest ecosystems composed of pine or mixtures of pine and oak species are widespread in North America and the world (O'Brien et al., 2008).

Applying Principles from the Forest Archetypes

So, what is the value of these archetypes? Do they represent the real world of the natural forest? Is this what we are likely to see when we visit unmanaged forest landscapes? Are they what we are trying to emulate in ecological forestry practice?

The archetypes that we have presented here are simplified models of how forest ecosystem development may proceed in unmanaged forest landscapes. As we have presented them, the two episodically disturbed landscapes are linear, segmented, and predictable, and the frequent-fire archetype does not experience a stand-replacement disturbance event! Of course, the natural (or seminatural) world is never that simple!

The complexity of the real world begins with the complexity and stochastic nature of disturbances themselves.

Figure 3.33 *Large, uncharacteristic stand-replacement fires are now common in many frequent-fire forest landscapes of the western United States; the fore- and mid-ground areas in this photo of part of the B&B fire of 2008 are examples. More distant high-elevation areas (subalpine forests) are portions of the landscape characterized historically by stand-replacement fires (Deschutes National Forest, Oregon, USA).*

Attachment #3. Potential forest vegetation zones and physiographic provinces in the range of the northern spotted owl. (Adapted from Reilly et al. 2018. "Climate, Disturbance, and Vulnerability to Vegetation Change in the Northwest Forest Plan Area." IN Spies, et al. *Synthesis of Science to Inform Land Management within the Northwest Forest Plan Area*, PNW-GTR-966, Volume I.) Dry Forests are generally in warm colors—reds, oranges, and yellows. Moist Forests are generally in cool colors—blues, purples, and greens.