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Chapter 3

Science of Old Growth, or a Journey into Wonderland

THOMAS A. SPIES

Old-growth forests often are valued for their apparent stability—they are often perceived to be ancient but ageless, unchanging through millennia. This notion of inherent stability is at least in part responsible for our desire to preserve such forests. Paradoxically, however, the scientific value of old growth really lies in helping us understand how forests change across in time and space. Old-growth forests are rich in history and constantly changing in subtle or not-so-subtle ways. Understanding the ecological complexity behind the old-growth icon may better prepare us to conserve forest biodiversity and old growth in the future.

In this chapter, I make the following points:

- Old growth is dynamic, resulting from the opposing forces of biological growth on one hand and disturbance and decay on the other.
- The scientific value of old growth lies in several areas: (i) providing controls for measuring the effects of human activities; (ii) shifting our focus to relatively long timeframes to help us understand how and why forests change; (iii) helping us identify the unique contributions of all forest stages to biological diversity and ecological processes; and (iv) opening our eyes to the importance of structural

complexity in providing habitat for organisms and the foundation for ecological processes.
- The conceptual and methodological challenges in the study of old growth include scale dependence, complexity, reification (making abstract concepts concrete), and the difficulty of conducting centuries-long controlled experiments.
- Our scientific understanding is evolving from simple models of forest development to more complex ones that do a better job of representing the dynamic maze that defines forest development. As our scientific understanding improves, it becomes increasingly clear that an old-growth icon—based on a well-defined, finely focused snapshot of stable forest conditions—is inadequate. It may even be a conceptual trap that keeps us from more broadly understanding the variety of ways in which forests develop, thus eroding our ability to provide for forest diversity in the long run.

My overall thesis is that in following our curiosity about tall, massive old-growth Douglas-fir forests we have been led down a rabbit hole into a world of ecological complexity filled with paradoxes (e.g., disturbance is needed to maintain old forest diversity) and visions defined by the different scales at which we view old growth. In this new world, old growth is only one part of the story of forest complexity, and in some views of the forest it may disappear except for the legacies of dead wood it leaves, like the smile on the disappearing face of the Cheshire cat in Lewis Carroll's *Alice in Wonderland*. Old growth remains vital to biological diversity, but our continuing investigation of it reveals that it is only one part of a complex and changing web of forest diversity.

Definitions

"Old growth" has almost as many definitions as "forest." In recent years forest ecologists have defined *old growth* as a forest in the later stages of development characterized by the presence of old trees and structural diversity. Of course, those later stages occur at different time points for different tree species, further complicating our attempts at definition. A second and somewhat older meaning is a forest that has developed without evidence of human impacts such as cutting or grazing. This second meaning, which also is associated with the words *virgin* or *primary*, is problematic from a scientific standpoint because it often is difficult to determine the human

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history of a forest and many seemingly virgin forests, have been influenced directly by aboriginal people or indirectly by industrial-age people through fire suppression or other activities. One ecologist aptly noted that "in forestry virginity is relative" (Clark, 1996).

Of course, the term *old growth* has its own history of meanings and values. Coined as early as 1891 by Bernard Fernow, an early leader in American forestry (Busby, 2002), old growth was simply a forest of old trees—not unlike the core meaning today. The addition of "growth," which is not really essential to the term's scientific meaning, may have occurred as a convention of a time when forests were primarily viewed as a crop to be harvested. When T. T. Munger, the first director of the U.S. Forest Service's Pacific Northwest Research Station, published a paper in 1930 on conversion of old forests to young, he did not include the term *growth*, but he did refer to the big trees of the region as "colossi of the vegetable kingdom," a choice of words that conjures up images of pumpkins, as old ponderosa pine are sometimes called by foresters (Munger, 1930).

Old-Growth Science in the Pacific Northwest

The science of old-growth forests in the Pacific Northwest was advanced in the late twentieth century by the publication of two important synthesis volumes. The first, which focused on the dry forests of the Blue Mountains of Oregon (Thomas, 1979), identified old growth as one of several successional stages that were important to wildlife species. Old growth was defined structurally in terms of live trees, standing and down dead trees, and presence of cover and canopy layers. Prior to publication of this book some wildlife biologists viewed old growth as a biological desert, because it was perceived to lack the habitat for game species.

The second synthesis (Franklin et al., 1981) characterized the composition, structure and function, and management options for old-growth Douglas-fir forests in the relatively wet western Cascades. This work called attention to the conservation status of old-growth forests—they were protected in only five percent of the landscape in parks and wilderness areas at that time. Franklin et al. (1981) also laid out a fundamental scientific question: How are old-growth forests (and their streams) distinguished from second-growth forests that follow fire or timber management?

This publication made sixteen major conclusions, including the following:

1) It takes 175–250 years for Douglas-fir forests to develop the range of structures associated with old growth;
2) Few plant and animal species are confined to old growth, but some may be dependent on it;
3) Net forest growth slows to near zero in old growth because mortality of trees is generally balanced by growth of surviving and new trees;
4) Old-growth forests hold on tightly to nutrients, and losses of nutrients such as nitrogen are low;
5) The structure of old forests is more heterogeneous than that of young forests;
6) The most distinctive features of old growth are large live trees, large snags, and large fallen trees on land and in streams;
7) The live and dead structures of old-growth forests provide specialized habitats for a variety of vertebrates, invertebrates, mosses, lichens, and fungi on land as well as in streams;
8) Conservation of old growth should be based on protecting entire old-growth watersheds from logging and, where timber management is practiced, leaving stream buffers, old trees, and dead wood within the managed forest.

These statements, which were not initially based on a large body of empirical science, are still largely valid after twenty-five years of subsequent research. However, many questions remain unanswered. For example, we still do not fully understand why the gross growth or production part of the forest ecosystem declines as forests age (Binkley, 2004), or why some species are more common in older forests than in younger ones.

Challenge of Scale

Two fundamental questions lie at the root of the ecological science of old-growth forests: (i) How do forests change in structure and species as they mature? (ii) What are the causes of those changes?

I will examine these questions further, but first, it is important to point out that the answers to them, like many in ecology and other sciences, depend on temporal and spatial scale. For example, the trees species that constitute the old-growth forests of the western Cascades appeared together for the first time only about 6,000 years ago—making old-growth Douglas-fir–western hemlock a *young* forest association in geological time. If we take a more limited view, say the 1,000 years prior to 1850, the species

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composition of these forests has been relatively constant but the amount of young and older forest has fluctuated over time as fires (some of them set intentionally by Native Americans) and other disturbances occasionally killed the canopy trees (fig. 3.1).

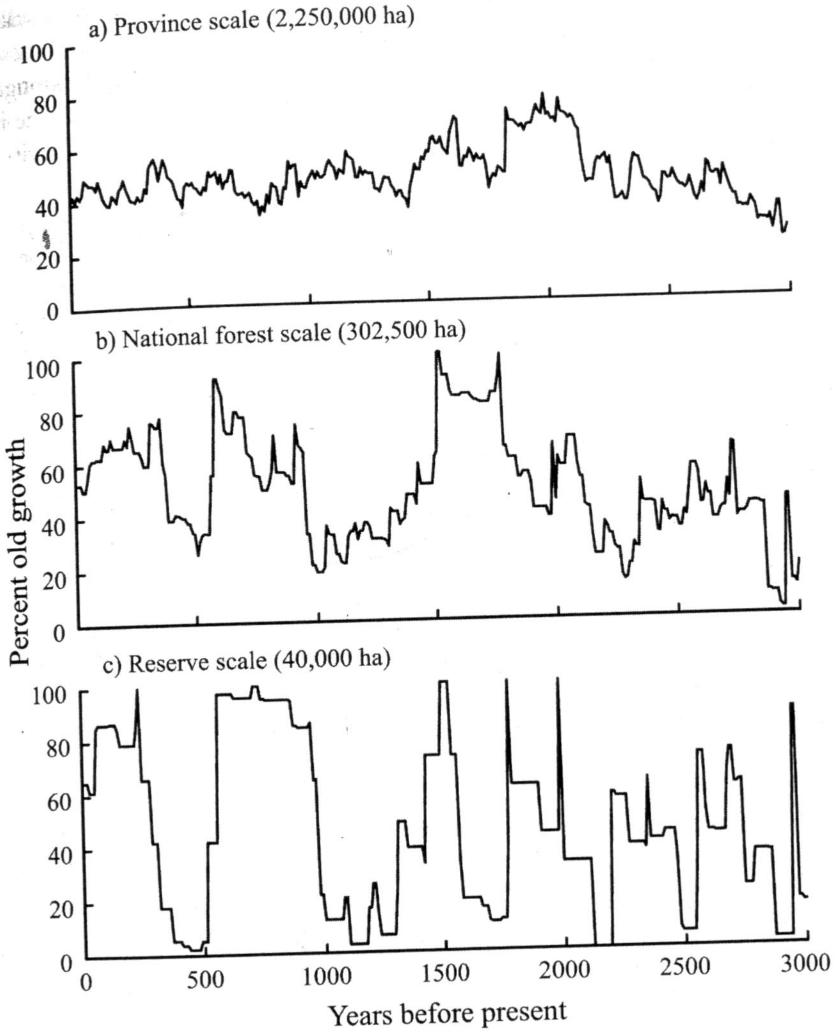

FIGURE 3.1. Modeled variation in historical percentage of old growth in the Coast Range at different spatial scales: (a) the area of the entire Coast Range physiographic province, (b) an area the size of a national forest, (c) an area the size of a old-growth reserve. (Wimberley et al., 2000)

During the past 100 years, forest change has been more unidirectional as the area of forests declined, replaced by open land or relatively uniform younger forests as a result of widespread land clearing, logging, and human-caused wildfires. During this same time in dry landscapes of the region, cutting of large old pine and suppression of fire has created denser, more fire-susceptible stands with fewer of the large fire-resistant pines.

Unfortunately, science cannot determine the "best" space or time scale at which to view forests. No single scale is sufficient to understand these natural systems. Forest patterns and dynamics are always varying (although not uniformly) across time and space. Our choice of a reference frame is driven by the scale of species or ecological processes, economics, institutional mandates, and personal interests.

Scientists have long struggled with scale. For example, early research in Oregon used small sample plots (less than one-tenth of an acre)—about half the size of a tennis court—to characterize the structure and composition of old growth. The plots were subjectively located around big old trees and avoided patches of recent disturbance from wind and fire. The scientists quickly realized that the scale of the old-growth forest phenomenon was larger than a small patch of big, old trees. With a small plot the death of single big tree could change the forest from old to young. Over the years, the size of forest sample plots has increased more than twentyfold to greater than 2.5 acres, the area of two football fields.

At the next scale up, foresters and ecologists often use the term old-growth *stand*. The concept of a forest stand, a relatively uniform area of forest typically ten to 100 acres in size, does not come from any scientific analysis or theory, but from the practical needs of foresters and scientists who needed relatively homogeneous units for logging, planting, and experimental study. At the stand level the death of a single tree is not very noticeable by most measures.

More recently, the geographic extent of the study of Pacific Northwest old growth has increased to more than 25 million acres—all of western Washington, Oregon, and northern California—using inventory grids and satellites orbiting hundreds of miles above the earth. At the regional level, the loss of an entire stand of trees to fire or logging is not very noticeable.

Applying the Scientific Method to Study Old Growth

The application of the scientific method to the science of old growth also is challenged by the long timeframes and diversity of environments and for-

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Method to Study Old Growth

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es and diversity of environments and forest types. Some determined scientists have begun to investigate how old-growth logs decay through experiments that are designed to run for 200 years. In general, however, centuries-long experiments are not feasible, not only for reasons of funding and institutional memory but also because the very subject of the study—a whole forest or study plot—may be destroyed by fire, wind, or other forces. Consequently, scientists are forced to use other less-powerful scientific methods, such as manipulative experiments that run a few years or decades, retrospective studies of ecological phenomena created by past natural or human disturbances, and computer simulations, which allow scientists to study how forests *might* change over long times or large areas. These methodological limitations do not make the science of old growth less of a science—geology and astronomy, for example, have done very well without being able to use controlled manipulative experiments.

The science of old growth has advanced by focusing on structure and process—elements that can be readily measured—rather than on questions of absence of human influence. The difficult reality is that the only places where scientists can learn about the structure and process of old forests is where the absence of human activity has allowed some populations of trees to survive for centuries—so called *virgin* or *near-virgin* forests. At a grand scale these are the scientific *controls*—places against which to compare the changes that result from the unplanned "experiments" of human activities. In fact, the Society of American Foresters recognized this value as far back as 1947 when it began to locate and protect examples of "virgin or old-growth" forests around the United States for forest research purposes (Anonymous, 1959). The need for controls is evident when one considers how intensively managed forests can be treated, not to mention how forests can be converted to residential or commercial uses. It is, however, difficult to find or define a "control" in many landscapes where human activities directly or indirectly influence the development of forests—e.g., forests with a history of fire suppression.

Theoretical Basis of Old-Growth Science

Our scientific thinking about how and why forests changes as they mature has evolved considerably over the past 100 years. In the early 1900s Frederic Clements, an American plant ecologist, proposed a model (Barnes et al., 1998) for vegetation succession in which vegetation changed in response to disturbance, migration, and establishment. Over time, he reasoned, these processes led to a stable climax forest, whose character was controlled entirely by regional climate. This forest allegedly behaved as if it were a superorganism, seeking to maintain equilibrium. Clements's theories have since been discredited and replaced by theories based on the observations that many factors control forest composition, that vegetation change is not so predictable—disturbance and climate change can intervene at any time—and that plant communities are really a loose assemblage of species that may influence their neighbors but are basically behaving individually, not as a group.

Recent Scientific Perspectives

In recent years, our scientific concepts and models of forest structure and dynamics have changed to recognize the complexity of ways forests change and the diversity of old growth. *Forests are like square pegs, and our simple models are like round holes—we have to work hard to make them fit.* In wetter areas of the Pacific Northwest, forest structure changes in a semipredictable way with stand age, as long as a stand can grow for centuries with only minor or moderate disturbances (fig. 3.2). The changes with age are gradual, but there also is much variability as a result of variation in disturbance history and site productivity. Large old live and dead trees can be found in patches in very young forests, and very young forests can be found as patches within older forests. In some areas, young natural forests can be almost as complex as old growth. Furthermore, although the large dead wood did originate in older forests, it is not as distinctive of old-growth forests as was once thought. It can occur in even greater abundance in young forests created following wildfire and windstorm. In drier environments, stand age often does not predict forest structure because trees can be of many ages, making it difficult to say what the age of the "stand" really is. The textbook model of stand development recognizes four stages, while a newer model recognizes eight stages. These might not occur in a linear sequence, and some stages might be skipped (table 3.1).

The opposing forces of patchy disturbances and decay versus biological growth further blur the boundaries of forest types. For example, although many old-growth stands in the western Cascades of Oregon established as young forests following infrequent, high-severity fires, many of these stands experienced low- to moderate-severity fires in the past 200 years that killed some overstory trees and understory vegetation, and created dense patches of young understory hemlock and Douglas-fir trees. In contrast, in

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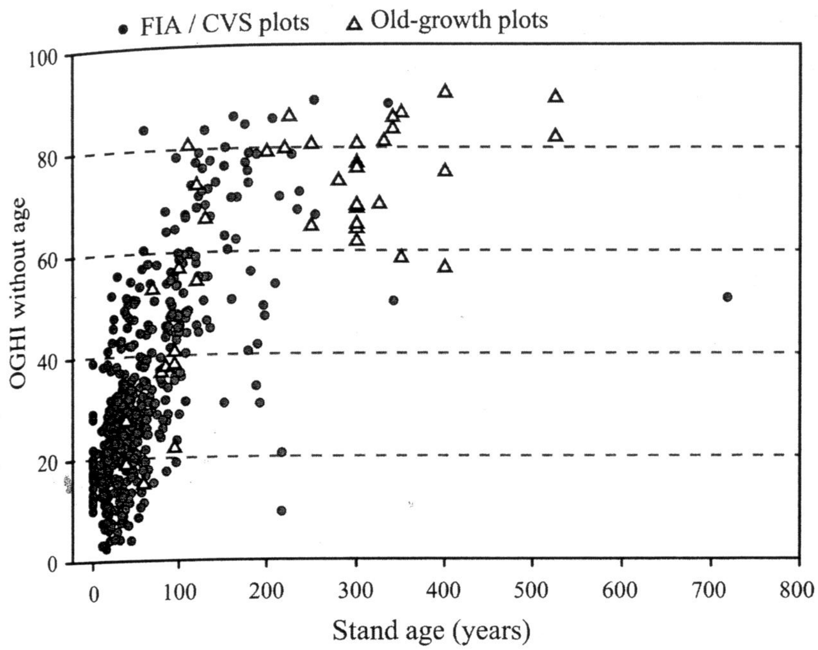

FIGURE 3.2. Old-Growth Habitat Index (OGHI) (structure-based, age not included) plotted against stand age for inventory (FIA/CVS plots) and old-growth research plots in the Oregon Coast Range.

the eastern Cascades in dry old-growth ponderosa pine and mixed conifer types, patchy surface fires burned frequently—every ten to forty years—creating relatively open understories (see chapter 1, fig. 1.2) and scattered patches of regeneration. In these forest types insects and diseases that kill old trees also have added to the structural complexity.

The possibilities of stand development really become apparent at the landscape level (fig. 3.3). The idealized developmental pathway typically presented a stand-level view in which an old-growth forest develops over many centuries with relatively little disturbance and with an orderly progression of stages, but this is only one of many pathways a forest can take, and in many regions it may not be the most common one. For example, the repeated occurrence of low- to moderate-severity fires in old forests can either set back succession, if early successional species regenerate, or advance it, if shade-tolerant species regenerate. Older forests subject to this type of disturbance regime are a complex mosaic of young, mature, old, and very old trees.

TABLE 3.1. Examples of different Douglas-fir stand development stage classifications in relation to stand age.

Typical stage age (years)	*Four-stage model (e.g., Oliver and Larson, 1990)*	*Eight-stage model (Franklin et al., 2002)*
		Disturbance and legacy creation
0		
	Stand initiation	Cohort establishment
20		
		Canopy closure
30	Stem exclusion	
		Biomass accumulation/ competitive exclusion
80	Understory re-initiation	
		Maturation
150	Old-growth	
		Vertical diversification
300		
		Horizontal diversification
800		
		Pioneer cohort loss
1,200		

The danger we face in putting forest development into just a handful of types or boxes is that we will confuse our simple models of reality with reality itself. The focus on old forest also can blind us to the importance of other stages, such as open canopy types with lots of shrubs and snags that are important to many species, including even the northern spotted owl in the southern part of its range (see chapter 4).

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	Canopy closure
n	
	Biomass accumulation/ competitive exclusion
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	Maturation
	Vertical diversification
	Horizontal diversification
	Pioneer cohort loss

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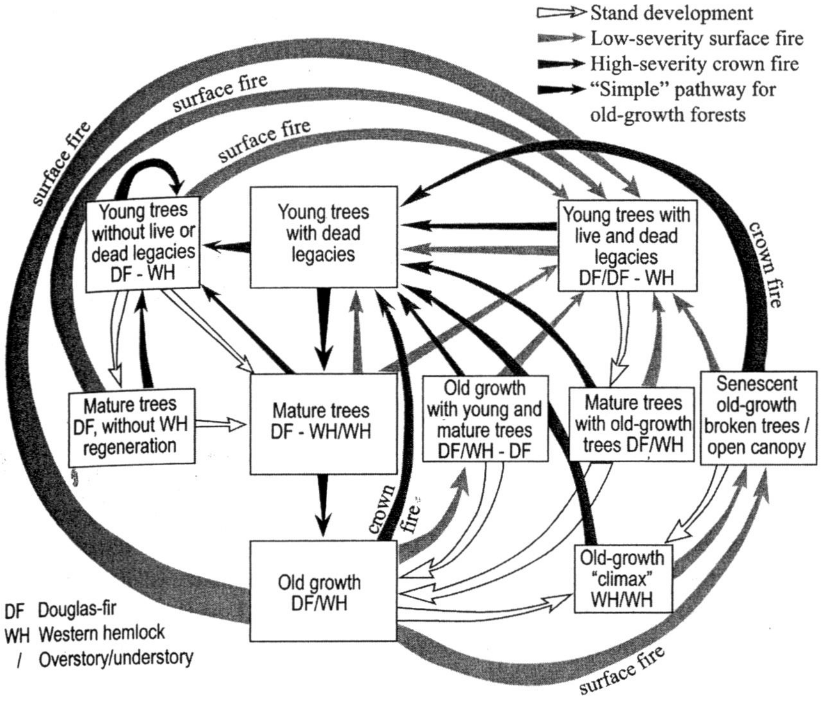

FIGURE 3.3. Conceptual model of multiple pathways of stand development at landscape level for the western Cascade Range in Oregon. (Rapp and Spies, 2003)

If you build it they will come, but they may take their time. The northern spotted owl occurs more commonly in older forests because of the presence of broken tree tops for nesting and multiple canopy layers for roosting and foraging. But not all old forest species are present in older forests because of a particular habitat structure. For example, one canopy lichen, *Lobaria oregana,* a slow-dispersing species, occurs much more frequently in old-growth forests than in young growth, but it is relatively broad in its habitat tolerance. This lichen can be transplanted to much younger forests and survive and grow very well (Sillett and McCune, 1998). Lobaria is more abundant in older forests probably because it disperses slowly from existing sites, and it can take centuries to recolonize and accumulate on a site once its populations have been destroyed by fire or logging. This finding suggests that other "specialists" of old growth may be present simply because of the amount of time that has passed following severe disturbance.

Some Final Thoughts

Humpty Dumpty's Theory of Word Meaning

In *Alice in Wonderland,* when Alice was confused about the meaning of a word that Humpty Dumpty had said, "he replied in a rather scornful tone, 'When I use a word, it means just what I choose it to mean—neither more nor less.'" Ecologists are generally comfortable with rather vague or flexible terminology. For example, "ecosystem" and "community" are scientific concepts and abstractions that often are defined in very situational and arbitrary ways. It is not uncommon for individual scientists to define these terms somewhat differently, creating private scientific models (Shrader-Frechette and McCoy, 1993) that can be barriers to scientific progress. Ecological science also runs the risk of reification—the treatment of abstract concepts as concrete. Definitional consistency is necessary for scientific progress and successful management, but the complexity of forests limits the degree to which these words can have precise and uniform meanings. In the case of old growth, we must always be careful to define our terms and to recognize that the way we define them can have a major influence on how we think about them.

The Goldilocks Problem

The problem of complexity in our scientific models of forests is like Goldilocks's problem of getting the porridge "just right" in the children's story *The Three Bears*. If we make them too complex, few people will understand the models, and managers will not use them. If we make them too simple, we miss important features of the ecology of these forests. The old-growth icon has served scientists and the public as a symbol of forest complexity, but it is a symbol of only one part of it. The unquestioned political success of the icon can also be a trap if researchers and managers do not look at the entire spectrum of forest development.

Old forests are inextricably intertwined in space and time in a continuum of forest development, just as young, mature, and mixed-age forests are. Focusing on only one part of the continuum is like trying to understand light by examining only one color or wavelength, or like trying to understand a river by looking only at the deep, quiet pools and ignoring the rapids. Forest ecology is moving toward becoming a science of complex-

Final Thoughts

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ity, but it is not there yet. Many ecologists have come to realize that it is crucial to avoid ideas that become limiting notions in our quest to better understand our world, even though this approach renders the pursuit of new knowledge a significantly more difficult enterprise. Complexity does not yield easily to simplified thinking.

LITERATURE CITED

Anonymous. 1959. Forest reserve program. *Science* 130(3370):258.

Barnes, B. V., D. R. Zak, S. R. Denton, and S. H. Spurr. 1998. *Forest ecology,* 4th ed. New York: Wiley.

Binkley, D. 2004. A hypothesis about the interaction of tree dominance and stand production through stand development. *Forest Ecology and Management* 190:265–71.

Busby, P. E. 2002. *Preserving “old growth”: Efforts to salvage trees and terminology in the Pacific Northwest.* Cambridge, MA: Harvard University.

Clark, D. B. 1996. Abolishing virginity. *Journal of Tropical Ecology* 12:735–39.

Franklin, J. F., K. J. Cromack, Jr., W. Denison, A. McKee, C. Maser, J. Sedell, F. Swanson, and G. Juday. 1981. *Ecological characteristics of old-growth Douglas-fir forests.* General Technical Report PNW-118. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station.

Franklin, J. F., T. A. Spies, R. Van Pelt, A. B. Carey, D. A. Thornburgh, D. R. Berg, D. B. Lindenmayer, et al. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management* 155(1):399–423.

Munger, T. T. 1930. Ecological aspects of the transition from old forests to new. *Science* 72(1866):327–32.

Oliver, C. D., and B. C. Larson. 1990. *Forest stand dynamics.* New York: McGraw-Hill.

Shrader-Frechette, K. S., and E. D. McCoy. 1993. *Method in ecology: Strategies for conservation.* New York: Cambridge University Press.

Sillett, S. C., and B. McCune. 1998. Survival and growth of cyanolichen transplants in Douglas-fir forest canopies. *The Bryologist* 10(1):20–31.

Thomas, J. W., tech. ed. 1979. *Wildlife habitats in managed forests: The Blue Mountains of Oregon and Washington.* Agriculture Handbook 553. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station.

Wimberly, M. C., T. A. Spies, C. J. Long, and C. Whitlock. 2000. Simulating historical variability in the amount of old forests in the Oregon Coast Range. *Conservation Biology* 14:167–80.

Old Growth in a New World

A PACIFIC NORTHWEST ICON REEXAMINED

EDITED BY

Thomas A. Spies and Sally L. Duncan

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