THE ROLE OF SILVICULTURE IN ECOSYSTEM MANAGEMENT: A PRACTICE IN TRANSITION

Russell T. Graham, Jonalea R. Tonn, Theresa B. Jain, and David L. Adams

ABSTRACT

The cedar (*Thuja plicata*) -hemlock (*Tsuga heterophylla*) -white pine (*Pinus monticola*) forests are some of the most productive in North America. Silvicultural practices used in these forests originated in Europe and usually concentrated on producing high-value commercial products.

Beginning in the 1960s society's interest in the management of natural resources, especially forests, increased, and a component of society no longer desired forests managed exclusively for timber production. But a significant portion of the public still expect a high level of wood products. As society changed in the 1960s the practice of silviculture became more scientifically based. Habitat types, forest genetics, forest growth models, fire models, and forest soils were integrated into silvicultural planning.

Because of the concern for ecosystem sustainability and biodiversity, new methods of analyzing and planning forest treatments are being developed. Forest ecosystems are being analyzed for function and sustainability in a hierarchical framework both temporally and spatially. These analyses will help evaluate the impact of forest uses on forest ecosystems and indicate if, when, and where forest treatments may be needed to sustain the forest.

Even though this approach is new, the practice of silviculture will still need to provide plans and methods for manipulating forest vegetation. All of the traditional silvicultural practices used to produce timber crops can be used to manage sustainable forest ecosystems.

Keywords: Western white pine, Northern Rocky Mountains, landscapes, western redcedar, western hemlock

INTRODUCTION

Now, more than ever before, society is actively interested in how natural resources are managed. Many visitors to publicly and privately owned forests do not approve of forests managed primarily for timber production. Such individuals, plus those interested in noncommodity values (wildlife, scenery, etc.) are criticizing management practices and demanding that forest management change. Moreover, the sustainability of forest ecosystems is becoming a major issue throughout the United States. Still, a large portion of society views forests as a source of commodities and jobs. These diverse views of how forests should be managed have led to major confrontations at all levels, from the small community and individual forest to the Congress and Administration of the United States (Anon., 1993). Because of their high productivity and diverse values, the interior cedar (*Thuja plicata*)-hemlock (*Tsuga heterophylla*)-white pine (*Pinus monticola*) forests are becoming a focal point for controversy in the Northern Rocky Mountains.

The challenge facing silviculturists is developing silvicultural systems that maintain a wide variety of objectives, such as wildlife habitat, water quality, and scenic quality, that provide timber and livestock and still ensure the long-term sustainability of forest ecosystems. The cedar-hemlock-white pine forests provide challenges and opportunities for silviculturists and forest managers.

THE PRACTICE OF SILVICULTURE

Timber production has been the management objective for most of the forests in the United States (Kennedy and Quigley, 1993). Most silvicultural practices were directed at meeting this objective (Graham et al. 1983). Consequently, silviculture is often equated with timber management by many resource managers and society in general. However, timber management is the application of business (economics, marketing, accounting, etc.), social (political science, public involvement, etc.) and technological (silviculture, engineering, logging, mensuration, etc.) principles to the management of forest property (Davis 1966). Thus, silviculture is only one of the many components of timber management.

Silviculture, was synonymous with timber management during its beginnings in North America in the early 1900s. Fernow (1916) defined silviculture as the production of wood crops (farming), the basis of forestry. Using this philosophy, silviculturists in North America adapted European concepts and practices (Schlich 1906) to develop methods for the establishment, development, and reproduction of forest stands for sustained production of wood crops (Toumey 1928; Baker 1934).

Even though silviculture in the early 1900s concentrated on management of forest stands, some silviculturists recognized that silviculture could be applied at the forest level (Hawley 1937). Smith (1962), building on Hawley's writings, defined silviculture as the art of producing and tending a forest, creating and maintaining a forest that fulfills the objectives of the owner. Daniel et al. (1979) defined silviculture as: controlling the establishment, growth, composition, and quality of forest vegetation to meet clearly defined management objectives for a variety

Reprinted from 1994 symposium proceedings of *Interior Cedar-Hemlock-White Pine Forests: Ecology and Management,* held March 2 - 4, 1993 at Spokane, Washington; Department of Natural Resource Sciences, Washington State University, Pullman, WA 99164-6410.

of wildlands, including forests, brush-lands, ranges, fresh-water and other riparian areas, and wilderness areas. Therefore, by the 1960s silviculture had evolved from developing and using practices for the management of forest stands for producing timber products to the manipulation of forest vegetation to meet a variety of land management objectives. But, more often than not, timber production dominated forest management as it did in many of the cedar-hemlock-white pine forests.

DESCRIPTION OF CEDAR-HEMLOCK-WHITE PINE FORESTS

The climate of cedar-hemlock-white pine forests is influenced by the Pacific Ocean 400 km (248 mi) to the west. Precipitation ranges from 72-150 cm (28-60 in) with the majority occurring in the fall and winter. The elevation of the forests ranges between 500 m and 1,600 m (1,640-5,910 ft). The extent of the forest type is limited at the lower elevations by insufficient moisture and at the upper elevations by cold temperatures. The landscape has both V-shaped and round-bottomed valleys with a variety of slopes and aspects. Soils are diverse with depths ranging from 25 cm (10 in) to over 230 cm (90 in) that developed from a variety of parent materials, including granite, shale, basalt, glacial, and lacustrine deposits. The surface soil horizons of the forests are usually composed of ash or loess deposits and can have a wide range of fertility (Graham 1990).

These forest support diverse vegetation. Ten or more coniferous species, ranging from western white pine to subalpine fir (*Abies lasiocarpa*), can occur in these forests, along with several deciduous trees. These species have a wide range of growth characteristics and tolerance to shade, fire, insect, and disease, making multi-story, multi-age, and multi-species stands very common (Foiles et al. 1990; Graham 1990).

Shrubs growing in cedar-hemlock-white pine forests range from low shrubs such as pachistima (*Pachistima myrsinites*), to tall shrubs such as mountain maple (*Acer glabrum*). The understory usually contains a luxuriant layer of herbs and grasses. Species such as the bittercress (*Cardamine constanci*), which is an indicator of a coastal climate, and the endangered Idaho phlox (*Phlox idahoensis*), can grow in these forests (Crawford 1980). Another prevalent species is Pacific yew (*Taxus brevifolia*), which was often considered a forest weed and is now in demand for cancer treatment.

These forests contain a rich assortment of wildlife from the grizzly bear (*Ursus horribilis*) to the pine marten (*Martes americana*), some of which some are threatened or endangered. Others, such as the elk (*Cervus canadensis*), are of high commercial value. Also, portions of these forests are the headwaters of the Snake River, which is home to the threatened spring-run chinook salmon (*Oncorhynchus tshawytscha*).

Cedar-hemlock-white pine forests are fire-dependent ecosystems (Habeck and Mutch 1973). In the moister portions of these forests one to three surface fires can occur before stand-replacing fires, which occur at intervals of 275-400 years. On the drier habitat types fires occur at 25- to 50-year intervals (Arno 1980). The stand-replacing fires have created even-aged stands of western white pine, western larch (*Larix occidentalis*), and Douglas-fir (*Pseudotsuga menziesii*), while the surface fires opened or thinned many stands. In recent years fire control has reduced the frequency of fires, but large stand-replacing fires can still occur. Fire control has contributed to the development of many multi-story stands containing a wide variety of tree species.

Insects and diseases also affect cedar-hemlock-white pine forests. Mature lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), and western white pine are often heavily damaged by the mountain pine beetle (*Dendroctonus pseudotsugae*). Grand fir (*Abies grandis*) and Douglas-fir are subject to damage by the Douglas-fir tussock moth (*Orgyia pseudotsugata*) and western spruce budworm (*Choristoneura occidentalis*). Early in the 1900s western white pine dominated the cedar-hemlock-white pine forests, but since then blister rust (*Cronartium ribicola*) has infected many stands, decreasing the abundance of western white pine (Haig et al. 1941; Ferguson et al. 1986). Western white pine comprised approximately 35% of the forest composition before the introduction of blister rust, but now represents only 3% in northern Idaho (Zack 1993). The root diseases *Armillaria* spp., *Phellinus weirii*, and *Heterobasidium annosum* attack all tree species and are most damaging to Douglas-fir and grand fir on drier sites (Graham 1990).

The interaction of fires, diseases, insects, and timber harvest has led to the development of a wide variety of forests and landscapes. Because these forests contain high-value trees, have rich soils, a favorable climate, and are highly productive, the emphasis on timber production was easy to justify. Therefore, silvicultural practices were designed to produce crops, even though these forests contain many attributes that may be just as important, if not more important, than forest crops.

SILVICULTURE IN CEDAR-HEMLOCK-WHITE PINE FORESTS

In the late 1800s and early 1900s forest management in the cedar-hemlock-white pine forests focused on fire prevention and limited commodity extraction. The large trees in these forests, primarily western white pine, produced valuable lumber, toothpicks, and match sticks (Anderson 1935). These raw materials fueled the economies of many towns within the Northern Rocky Mountains.

In 1926 the Forest Service was directed to:

> "Wherever it is practicable to reserve enough small, thrifty timber to provide a second cut in 25 to 60 years this will be done. In stands of deteriorating timber or mature timber of uniform age, clean cutting is usually necessary, but seed trees, usually 5 to 10 percent of the present volume and of the better species in mixed stands, will be retained. Restocking or planting will not be planned for except under conditions so unusual that natural reproduction can not be expected, and only with approval from the Chief of the Forest Service. Inferior species of low value will not be pushed on the market in advance of recognition of their real worth and usability by consumers." (USDA, 1926)

This management directive made partial cutting of forest stands the common type of harvest for much of the early 1900s. Western white pine was the preferred species, but western redcedar (*Thuja plicata*), Douglas-fir and western larch also had commercial value. Western hemlock, grand fir, subalpine fir, and lodgepole pine were of minimal value. Often these species were destroyed to reduce the fire hazard and to clear sites for commercial trees (Hutchison and Winters 1942; Foiles 1950).

SILVICULTURE FOR TIMBER PRODUCTION

As timber production became more important in western forests, partial cutting often resulted in undesirable forest conditions (forests contained high proportions of insect- and disease-susceptible species). The European model of forest management began to be applied. It contained silvicultural practices designed for managing stands for intensive timber production (Schlich 1906). Concepts such as maximizing mean annual increment, stand rotation, economic rotations, and the application of economic theory to forest growth were developed for managing the cedar-hemlock-white pine forests (Davis 1942).

Clearcut, seed-tree, and shelterwood systems were effectively used to regenerate and manage most sites (Haig et al. 1941). Clearcutting was very effective on north-facing slopes but sometimes failed to produce adequate regeneration on south aspects because of high temperatures, weed competition, and animal damage (Graham et al. 1983).

Large areas (>100 acres) were often harvested, and logging debris was either broadcast burned or tractor piled for site preparation and to reduce fuels. Such treatments removed most of the organic material and exposed large amounts of mineral soil. Both natural and planted regeneration usually survived well. This success was attributed the treatments that reduced competing vegetation, exposed mineral soil for planting sites and seed beds, and good nursery practices.

Because of the abundant regeneration, dense stands (>10,000 trees per acre, 24,700 trees per ha) can become established (Haig et al. 1941; Graham 1988). For trees in these dense stands to develop into large, mature trees, the stands need to be thinned by fire, weather, or disease, or by mechanical means.

Until the stands are 30 years old stand composition and tree growth are relatively plastic. Trees can respond readily to treatments during this time. Afterward, western white pine does not readily increase growth unless stand density is severely reduced (Deitschman 1966; Foiles 1972; Graham et al., these proceedings). Likewise, younger grand fir and western redcedar have a greater growth response to cultural treatments (Ferguson and Adams 1980; Graham 1982). In addition, cleanings and weedings early in a stand's life do not create large amounts of fine fuels, making early cultural treatments desirable. Therefore, for molding stand composition, for regulating stand growth, and for minimizing the fire hazard, cultural treatments are preferred early in the life of a stand.

Even though early treatments are desirable, they encourage regeneration of shade-tolerant western redcedar, grand fir, and western hemlock (Graham 1988). If treatments are delayed until apical dominance is expressed and minimal amounts of growing space are available, new regeneration will have a limited impact on stand development. Also, the later a stand containing western white pine is thinned, the more time western white pine blister rust has to kill susceptible trees, or to visibly infect them so they can be identified and removed. Accordingly, the timing of cultural treatments is a balancing act involving tree growth, stand composition, regeneration, fire hazard, and blister rust.

CHANGES IN SOCIETY

During the mid-1960s in places like the Bitterroot National Forest of western Montana and the Monongahela National Forest of West Virginia, local residents expressed concerns about forest management. The congress responded by passing the National Forest Management Act (NFMA), National Environmental Policy Act (NEPA), and Forest and Rangeland Renewable Resource Planning Act (RPA), but concerned publics continued applying pressure to decrease timber harvest and increase the value placed on noncommodity forest amenities. Moreover, concern about maintaining the supply of clean water was increasing throughout the West. Even with this pressure to feature other values, economics and commodities maintained a high profile and continued to steer most forest plans and alternatives.

By the 1990s many segments of society recognized there was more to forests than trees. Soil, animals, lower vegetation (shrubs and forbs), and the flora and fauna in the soil were all identified as important parts of functioning forest ecosystems. Forests of the Northern Rocky Mountains were recognized to contain important linkages and corridors for wildlife on regional and continental scales. Also, the issue of maintaining biodiversity both temporally and spatially increasingly became a forest management concern. Therefore, the maintenance and management of forest ecosystems are becoming more relevant. The European model of high-yield forestry is being replaced with the concept of sustaining ecological systems. What is left in a forest is as important as what is removed.

The needs and desires of society have often out-paced managers abilities to grasp and implement changes. The shift in society's emphasis from extracting commodities to sustaining ecosystems has not always been recognized. Moreover, a large component of society does not want changes in forest management, and desiring a continual high output of commodities. Consequently, the conflict among different user groups on forests management continues to provide challenges for forest managers.

CHANGING SILVICULTURE

As society's needs and desires have changed since the 1960s, the science and art of silviculture also has changed. The importance of lower vegetation as forest component was recognized when the concept of habitat types became widely used (Daubenmire and Daubenmire 1968; Pfister et al. 1977; Cooper et al. 1991). The use of habitat types for classifying forest sites became commonplace when making silvicultural and other forest management decisions. The habitat type concept was an integral part of estimating growth and yield of forest stands using the prognosis model (Stage 1973; Wykoff et al. 1982). The prognosis model enabled silviculturists to evaluate stand treatment alternatives using both yield and economic criteria.

In the 1960s the genetics of forest trees started playing an ever increasing role in the silvicultural practices used in the cedar-hemlock-white pine ecosystems. Foremost was the development of blister rust-resistant western white pine (Hoff and McDonald 1980; Bingham 1983). Resistant planting stock was produced, making western white pine once again a viable component of these forests. Genetics also played an important role in the selection of seed sources for planting stock for other species. For instance, Douglas-fir and lodgepole pine are genetic specialists with narrow seed transfer zones compared to ponderosa pine, western white pine, and western larch, which are generalists with wide seed transfer zones (Rehfeldt 1979; Rehfeldt, these proceedings).

The importance of soil and organic materials (mineral soil organic matter, forest floor, down logs, buried material, snags) in the function of forest ecosystems also became apparent (Harvey et al. 1976; 1987). Coarse woody debris was recognized as a major forest component providing organic matter for the forest floor and forest soil, sites for nitrogen fixation, habitat for small animals, and as an important factor in stream ecology (Harmon et al. 1986; Jurgensen et al. 1987; Reynolds et al. 1993). Ten to 25 tons per acre of coarse woody debris (22-56 Mg per ha) should be left in cedar-hemlock-white pine forests after timber harvesting to maintain forest productivity (Graham et al., in press). Lesser debris is recommended for the drier portions of these forests and more is recommended for the moister portions. More material may be prescribed for sites where organic materials have been depleted or where other resources such as fisheries or wildlife may have a greater need.

Both broadcast burning and tractor piling can be detrimental in these forests if not properly applied. By removing or compacting organic materials they can eliminate a large portion of the forest's nutrients and damage its soil structure, decreasing productivity. Grapple piling equipment is an alternative to tractors for fuel reduction and site preparation. This equipment usually does not compact the forest floor and maintains the desired amount of coarse woody debris more effectively than tractors. Likewise, prescriptions such as burning when the lower forest floor moisture is equal to or greater than 100% can protect much of the organic material on a site when logging debris is burned to prepare sites for regeneration and reduce fire hazard.

As site preparation practices improved, so did the production and handling of planting stock. Nursery practices for producing both bare-root and container stock have greatly improved the success of forest plantations. The use of container stocks has extended the planting season into the fall and, in some locations, into the summer. For example, early fall plantings have improved the development of out-planted tree seedlings compared to spring or late fall plantings (Catlin et al., these proceedings).

Even though most of the changes in silvicultural practices and knowledge has been directed at timber production, much of the information developed provided a good understanding of forest ecosystem structure, processes, and function. With this new knowledge and the fundamentals used since the early 1900s, the practice of silviculture is well poised to address the analysis and management of forest ecosystems.

SILVICULTURE'S ROLE IN ECOSYSTEM MANAGEMENT

Silviculture is the art of producing and tending a forest; the application of the knowledge of silvics in the treatment of a forest; and the theory and practice of controlling forest establishment, composition, and growth (Smith 1962). If the word "forest" in Smith's definition is replaced with the word "ecosystem," the practice of silviculture becomes key to managing forest ecosystems. Thus, if society wants forest ecosystems managed for function and sustainability, silviculture's role is to provide the tools and plans to do so.

The traditional tools for timber production can be used to sustain forested ecosystems. All variations of regeneration methods, site preparation, cleanings, weedings, and thinnings used to produce of forest crops can be used to produce stands with a variety of compositions, structures, and functions.

In managing for ecosystem sustainability the stand will continue to be the basic unit for silvicultural activities. The exception is that all treatments applied at the stand level need to be in concert with the surrounding ecosystems. This can be accomplished by analyzing ecosystem structure and function using a hierarchy of both temporal (historical to future) and spatial scales (continent to stand) (Bourgeron and Jensen 1993).

Ecosystems can be described at points along temporal and spatial scales. These descriptions can be used as reference points to which present conditions can be compared. The present condition of ecosystem elements (water, soil, tree species, habitat type, etc.) at the stand level is usually available. In contrast, the same elements at the watershed level 500 years prior are more difficult to determine. Ideally, these conditions could be estimated by examining undisturbed ecosystems, but most ecosystems have been modified by humans. Therefore, information on historical ecosystems needs to be collected from a variety of sources, including historical records, fire histories, succession models, and process models, and by examining ecosystems that are minimally disturbed by humans. Sources of information for estimating the condition of future ecosystems include succession, prognosis, and climate change models.

Using all of these techniques, reference conditions can be assembled that best describe how ecosystems might have naturally functioned at various temporal and spatial scales. Present forest conditions can be compared with reference conditions to determine if, where, and when forest treatments may be necessary to maintain forest ecosystems. Also, reference conditions can be used to compare forest use alternatives such as recreation developments or high-yield forestry to display the compatibility of these uses with the maintenance of naturally functioning ecosystems.

For example, portions of the cedar-hemlock-white pine forests could easily be managed for high yields of forest products. The location, size, and applicability of such practices could be evaluated by comparing the alternative to a set of reference conditions. This comparison could be used to show the impact of the alternative on ecosystem function. Also, these evaluations could be used to show where forest treatments would be necessary to sustain the composition, structure and function of cedar-hemlock-white pine forests. This is especially true because forests are mortal—they regenerate, grow, are attacked by insects, diseases, and weather, are burned by fires, and die.

CONCLUSIONS

Ecosystem elements and processes related to vegetation (types, patterns, succession, development, etc.) are easily changed when forest vegetation is burned, harvested, or destroyed by weather. The vegetation changes affect other elements of the ecosystem (soil, wildlife, water, etc.). Many of the vegetation changes caused by past timber harvesting were easily within the historical range of forest disturbance, both temporally and spatially, but others were likely outside this range. As we progress in the analyzing and understanding forest ecosystems and their function, we will be able to better understand the consequences of forest management practices.

There is a tremendous amount of knowledge on the establishment and development of cedar-hemlock-white pine forests. This knowledge can be applied not only at the stand level but also at larger scales (watershed to regional levels) to help analyze forest ecosystem processes, structure, and function. These analyses can be used to decide if, where, and when vegetation modifications would be necessary to sustain the forest ecosystem and to evaluate alternative forest uses to see if they are compatible with sustainable ecosystems.

Silviculture has often been equated with the production of forest crops (timber management). Now it should now be equated with ecosystem management. All of the tools used to produce of forest crops can be used to modify forest ecosystems for sustainability. There is more than enough information, expertise, and money to start managing cedar-hemlock-white pine ecosystems for sustainability.

LITERATURE CITED

Anderson, I. V. 1935. Match plank and commercial lumber from western white pine logs. App. For. Note 72. Missoula, MT: USDA Forest Service, Northern Rocky Mountain Forest and Range Exp. Sta. 3 pp.

Anon. 1993. Voices from the forest conference. J. For. 91: 9-13.

Arno, S. F. 1980. Forest fire history in the northern Rockies. J. For. 78: 460-465.

Baker, F. S. 1934. The principles of silviculture. New York: McGraw-Hill. 502 pp.

Bingham, R. T. 1983. Blister rust resistant western white pine for the Inland Empire: the story of the first 25 years of the research and development program. Gen. Tech. Rep. INT-146. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Exp. Sta. 45 pp.

Bourgeron, P. S. and M. E. Jensen. 1993. An overview of ecological principles for ecosystem management. *In:* Jensen, M. E. and P. S. Bourgeron eds. Eastside forest ecosystem health assessment. Missoula, MT: USDA Forest Service: 49-60.

Cooper, S. V., K. E. Neiman, and D. W. Roberts. 1991. Rev. 1991. Forest habitat types of northern Idaho: A second approximation. Gen.Tech. Rep. INT-236. Ogden, UT: USDA Forest Service, Intermountain Research Sta. 143 pp.

Crawford, R. C. 1980. Ecological investigations and management implications of six northern Idaho endemic plants on the proposed endangered and threatened lists. M.S. Thesis. Moscow: Univ. of Idaho.

Daniel, T. W., J. A. Helms, and F. S. Baker. 1979. Principles of silviculture. New York: McGraw-Hill. 500 pp.

Daubenmire, R. and J. B. Daubenmire. 1968. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Pullman: Washington Agric. Exp. Sta. 104 pp.

Davis, K. P. 1942. Economic management of western white pine forests. Tech. Bull. 830. Washington, DC: USDA. 77 pp.

Davis, K. P. 1966. Forest management: regulation and valuation. New York: McGraw-Hill. 519 pp.

Deitschman, G. H. 1966. Diameter growth of western white pine following precommercial thinning. Res. Note INT-47. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Exp. Sta. 4 pp.

Ferguson, D. E. and D. L. Adams. 1980. Response of advance grand fir regeneration to overstory removal in northern Idaho. For. Sci. 26: 537-545.

Ferguson, D. E., A. R. Stage, and R. J. Boyd. 1986. Predicting regeneration in the grand fir-cedar-hemlock ecosystem of the northern Rocky Mountains. For. Sci. Mono. 26. Society of American Foresters. 41 pp.

Fernow, B. E. 1916. Suggestions as to possibilities of silviculture in America. Society of American Foresters Proceedings. 11: 171-176.

Foiles, M. W. 1950. Recommendations for poisoning western hemlock. Res. Note 77. Missoula, MT: USDA Forest Service, Northern Rocky Mountain Forest and Range Exp. Sta. 1 pp.

Foiles, M. W. 1972. Responses in a western white pine stand to commercial thinning methods. Res. Note INT-159. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Exp. Sta. 8 pp.

Foiles, M. W., R. T. Graham, and D. F. Olson, Jr. 1990. Silvics of grand fir. *In:* Burns, R. M., ed. Silvics of forest trees of the United States. Agric. Hdbk. 271. Washington, D.C.: USDA: 52-59.

Graham, R. T. 1982. Influence of tree and site factors on western redcedar's response to release: a modeling analysis. Res. Pap. INT-296. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Exp. Sta. 19 pp.

Graham, R. T. 1988. Influence of stand density on western white pine, western redcedar, western hemlock, and grand fir tree and stand development in the Mountain West. *In:* Schmidt, W., ed. Future forests of the mountain West: a stand culture symposium. Gen. Tech. Rep. INT-243. Ogden, UT: USDA Forest Service, Intermountain Research Sta.: 75-84.

Graham, R. T. 1990. Silvics of western white pine. *In*: Burns, R. M., ed. Silvics of forest trees of the United States. Agric. Hdbk. 271. Washington, D.C.: U.S.D.A.: 385-394.

Graham, R. T., C. A. Wellner, and R. Ward. 1983. Mixed conifers, western white pine, and western redcedar. *In*: Burns, R. M., ed. Silvicultural systems for the major forest types of the United States. Agric. Hdbk. 445. Washington, D.C.: USDA Forest Service: 67-69.

Graham, R. T., A. E. Harvey, M. F. Jurgensen, T. B. Jain, J. R. Tonn, and D. S. Page-Dumroese. 1994. Recommendations for managing coarse woody debris in northern Rocky Mountain forests. Res. Paper, in press. Ogden, UT: USDA Forest Service, Intermountain Research Sta.

Habeck, J. A. and R. W. Mutch. 1973. Fire dependent forests in the Northern Rocky Mountains. Quaternary Res. 3: 408-424.

Haig, I. T., K. P. Davis, and R. H. Weidman. 1941. Natural regeneration in the western white pine type. Tech. Bull. 767. Washington, D.C.: USDA. 99 pp.

Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. R. Sedell, G. W. Lienkaemper, K. Cromack, Jr., and K. W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Adv. Ecol. Res. 15: 133-302.

Harvey, A. E., M. J. Larsen, and M. F. Jurgensen. 1976. Distribution of ectomycorrhizae in a mature Douglas-fir/larch forest soil in western Montana. For. Sci. 22: 393-398.

Harvey, A. E., M. F. Jurgensen, M. J. Larsen, and R. T. Graham. 1987. Decaying organic materials and soil quality in the Inland Northwest: a management opportunity. Gen. Tech. Rep. INT-225. Ogden, UT: USDA Forest Service, Intermountain Research Sta. 15 pp.

Hawley, R. C. 1937. The practice of silviculture. New York: John Wiley & Sons. 252 pp.

Hoff, R. J. and G. E. McDonald. 1980. Improving rust-resistant strains of inland western white pine. Res. Paper INT-245. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Exp. Sta. 13 pp.

Hutchison, S. B. and R. K. Winters. 1942. Northern Idaho forest resources and industries. Misc. Pub. 508. Washington, D.C.: U.S.D.A. 75 pp.

Jurgensen, M. F., M. J. Larsen, R. T. Graham, and A. E. Harvey. 1987. Nitrogen fixation in woody residue of northern Rocky Mountain conifer forests. Can. J. For. Res. 17: 1283-1288.

Kennedy, J. J. and T. M. Quigley. 1993. Evolution of Forest Service organizational culture and adaptation issues in embracing ecosystem management. *In:* Jensen, M. E. and P. S. Bourgeron, eds. Eastside forest ecosystem health assessment. Missoula, MT: USDA Forest Service: 17-28.

Pfister, R. D., B. L. Kovalchik, S. F. Arno, and R. C. Presby. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Exp. Sta. 174 pp.

Rehfeldt, G. E. 1979. Ecological adaptations in Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) populations I. North Idaho and Northeast Washington. Heredity. 3: 383-397.

Reynolds, R. T., R. T. Graham, M. H. Reiser, R. L. Bassett, P. L. Kennedy, D. A. Boyce, Jr., G. Goodwin, R. Smith, and E. L. Fisher. 1992. Management recommendations for the northern goshawk in the southwestern United States. Gen. Tech. Rep. RM-217. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Exp. Sta. 90 pp.

Schlich, W. 1906. Manual of forestry, Volume II. Silviculture. London: Bradbury, Agnew & Co. 393 pp.

Smith, D. M. 1962. The practice of silviculture. New York: John Wiley. 578 pp.

Stage, A. R. 1973. Prognosis model for stand development. Res. Paper INT-137. USDA Forest Service, Intermountain Forest and Range Exp. Sta. 32 pp.

Toumey, J. W. 1928. Foundations of silviculture upon an ecological basis. New York: John Wiley & Sons. 438 pp.

U.S. Department of Agriculture. 1926. The national forest manual: regulations and instructions. Washington, D.C.: USDA Forest Service. 9 sections.

Wykoff, W. R., N. L. Crookston, and A. R. Stage. 1982. User's guide to the stand prognosis model. Gen. Tech. Rep. INT-133. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Exp. Sta. 112 pp.

Zack, A. 1993. Personal communication. USDA Forest Service, Idaho Panhandle National Forests, Coeur d' Alene, ID.

Authors

Russell T. Graham
Research Forester
USDA Forest Service
Intermountain Research Station
1221 South Main
Moscow, ID 83843

Jonalea R. Tonn
Forester
USDA Forest Service
Intermountain Research Station
1221 South Main
Moscow, ID 83843

Theresa B. Jain
Forester
USDA Forest Service
Intermountain Research Station
1221 South Main
Moscow, ID 83843

David L. Adams
Professor
Department of Forest Resources
College of Forestry, Range and Wildlife Sciences
University of Idaho
Moscow, ID 83843