



Disturbances during old-growth development: lessons for silviculture and restoration

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Many forests in the temperate rainforests of the Pacific Northwest of North America are dominated by conifer species, including Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), Pacific silver fir (*Abies grandis*), and most prominently Douglas-fir (*Pseudotsuga menziesii*) (Franklin & Dyrness, 1973). The Mediterranean climate with moderate temperatures and most precipitation falling in winter generates seasonally dry, high productivity forests. Historically, the major disturbances in the region leading to stand replacement were high-severity fires occurring at multi-century intervals. Long periods without high-severity fire allowed for development of iconic old-growth forests. In addition, the Indigenous community actively stewarded the landscape, with diverse cultural burning techniques adapted for a variety of purposes and environments (Long et al., 2021). Douglas-fir is a keystone species historically found throughout the region in a wide variety of stand structures. It can be long-lived, reach large sizes, and maintain substantial fire resis-

tance at older ages facilitated by its thick bark. Consequently, Douglas-fir was a prominent component in most old-growth forests (Figure 1; Burns & Honkala, 1990).

Many of the older forests in the region were harvested starting in the early 20th century. Beginning in mid-century the clearcut stands were mostly artificially regenerated, resulting in dense even-aged monoculture Douglas-fir stands. As these practices became more widespread and scientific understanding of the resulting impacts increased, the public became concerned about the impacts of these management practices. These environmental concerns led to major shifts in land management on most public lands starting in the early 1990s (U.S. Department of Agriculture and U.S. Department of Interior, 1994). On federal land, this resulted in a shift away from regeneration harvests. Instead, management foci expanded beyond timber production when entering the dense plantations with thinning operations to sometimes include gaps and skips. One of the typical goals of these entries was to counter past efforts to homogenize the forests and



Figure 1 - Douglas-fir dominated old-growth forests in western Oregon. Photo credit: Weiskittel et. al 2012 (a) and M. Betts (b).

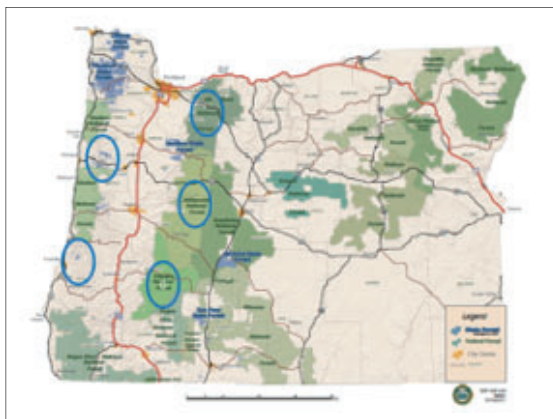


Figure 2 - Map of Oregon highlighting state and federal forests. Blue ovals indicate approximate locations of studies that highlighted the prominence of non-stand replacing disturbances impacting stand development after stand replacement. Modified from <https://geo.maps.arcgis.com/sharing/rest/content/items/ec-704651d1914ccca4c748614548bbc5/data>.

increase the spatial diversity so stands develop more efficiently towards conditions that reflect the historically dominant old-growth forests (Anderson & Ronnenberg, 2013).

The restoration efforts were based on early work that indicated that old-growth forests in the region initiated after stand replacing fires and then developed almost undisturbed for multiple centuries (Franklin et al., 2002). Because of a lack of disturbances after stand establishment in areas with Douglas-fir seed availability, stands developed through a mostly mono-specific (Douglas-fir) stem exclusion phase (Franklin et al., 2002). In areas with

limited Douglas-fir seed availability, it could take several decades until stands were fully stocked following a more precocious stand development pathway (Donato et al., 2012), where forests often underwent a mixed-species stem exclusion phase. In either setting, the models suggested that mortality patterns after the stem exclusion phase resulted in an increase in spatial variability, which eventually would lead to the iconic stand structures of old-growth forests.

The predominance and extent of infrequent, high-severity fire regimes and the resulting successional models briefly described above have been prominently reflected in planning and policy decisions during the last decades. Among others, this is reflected in the LANDFIRE program (<http://landfire.gov>) and in the science synthesis of the Northwest Forest Plan Review (Spies et al., 2018). Many conservation plans designed at recovering threatened and endangered species were based on these models and thus relied heavily on set-aside, no intervention strategies (e.g., US Fish and Wildlife Service, 2011).

However, recent work challenged the assumption of the prominence of these stand development models in the region. This assumption was based on early research which did not collect evidence of small scale, low severity fires, labeled non-stand replacing (NSR) fires. Recent studies that also included such disturbances showed their prevalence in various areas in the region, including the western side of the Oregon Cascades (Johnston et al., 2026; Merschel et al., 2024; Tepley et al., 2014), the Oregon Coast Range (Merschel, 2023; Drake, 2025), and sites across the Mt. Hood, Siuslaw, and Willamette National Forests (A. Merschel, unpublished data; Figure 2).

The variability in fire regimes and forest development histories and especially the widespread and prominent evidence of NSR fires

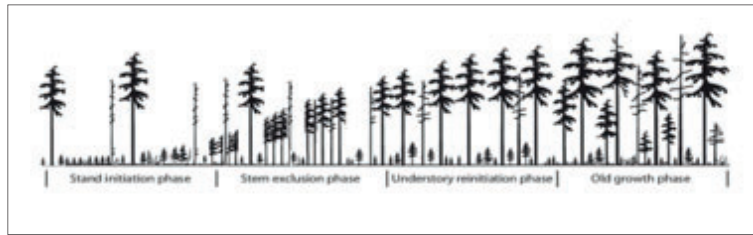


Figure 3 - Drawing of stand development patterns that includes effects of repeated small-scale non-stand replacing fires. Modified from Oliver and Larson (1996).

occurring repeatedly after stand establishment highlighted that multiple stand development models played out in the region (Merschel et al., 2024; Johnston et al., 2026; Puettmann et al., 2026). Intermittent NSR disturbances led to small-scale mortality and gaps that regenerated to shade tolerant and intolerant species, depending on gap size and understory vegetation (Merschel et al., 2024), as well as influenced tree growth (Dodson et al., 2012) and crown development of trees adjacent to gaps (Seidel et al., 2016, Figure 3).

In addition, these fires locally impacted the forest floor environment and understory vegetation, including tree regeneration (Puettmann et al., 2026). These NSR disturbances also created and emphasized legacy and habitat structures important for selected late successional wildlife species. For example, the avoidance of a stem exclusion phase due to NSR fires may lead to maintenance and earlier development

of stand structural components associated with old-growth forests, such as larger crowns with branches at lower stems (Ishii & McDowell, 2002; Seidel et al., 2016; Figure 4).

The variability of NSR disturbances in terms of spatial patterns and frequencies (Figure 5) suggests that there is no single, quantifiable pattern that can be used to represent an NSR-driven development pathway. Instead, it is suggested that a wide variety of stand development patterns played out in the past as a function of spatial variability in topography and vegetation, climate, Indigenous fire stewardship, and interactions among disturbances over time. However, while forests in some places developed following the traditional models, the frequencies of NSR fires found in various parts of the region (see citations above) suggested that development models that were influenced by multiple and usually several NSR and/or Indigenous fires with various extent and severity patterns, were likely the most common patterns.

Thus, we propose to account for the diversity of fire regimes and expand the recognized development pathways beyond the traditional and precocity model to be inclusive of NSR and Indigenous disturbance driven patterns (Puettmann et al., 2026; Figure 3). We suggest that adding the NSR and Indigenous disturbance findings to the knowledge base used in implementing conservation, restoration, and management efforts will facilitate more efficient and historically accurate development of old-growth structures in western, moist forests in the region. Appreciating the role of NSR



Figure 4 - Large sizes of branches on the lower stems (a) indicate that trees grew up without direct competition from neighboring trees, suggesting establishment of a low density stand or local mortality due to NSR disturbances. Similarly, epicormic branches indicate sudden opening of adjacent canopy layers (b).

creased frequency and severity of drought may lead to lower water availability and higher fire frequencies (Dale et al., 2001). Accordingly, management practices can account for this by encouraging lower tree stocking than historically present in the region. At the same time, climate smart silviculture includes encouraging a species composition that is shifted to more drought tolerant species, as well as species that are resistant to low- to moderate-severity fires or adapted to resprout after fires (Puettmann et al., 2026).

Integrating the variety of stand development models as well as the historical role of Indigenous populations and climate smart practices into silvicultural prescriptions is quite challenging. It requires prescriptions that have enough flexibility to accommodate small-scale ecological differences but also allow for multiple values and ways of knowing to be accommodated, including incorporating Indigenous Knowledge (IK). Eisenberg et al. (2024) highlight general ideas about integrating IK and Supplement 2 in Puettmann et al. (2026) provides a detailed decision tree as an example of how IK and other aspects reflecting the diversity of stand development models can be operationalized in practical applications.

REFERENCES

- Anderson, P. D., & Ronnenberg, K. L. (2013). *Density management in the 21st century: West side story* (General Technical Report PNW-GTR-880). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. <https://doi.org/10.2737/PNW-GTR-880>
- Burns, R. M., & Honkala, B. H. (1990). *Silvics of North America* (Agriculture Handbook 654). U.S. Department of Agriculture, Forest Service.
- Dale, V. H., Joyce, L. A., McNulty, S., Neilson, R. P., Ayres, M. P., Flannigan, M. D., Hanson, P. J., Irland, L. C., Lugo, A. E., & Peterson, C. J. (2001). Climate change and forest disturbances. *BioScience*, 51(9), 723–734. [https://doi.org/10.1641/0006-3568\(2001\)051\[0723:CCAFD\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2001)051[0723:CCAFD]2.0.CO;2)
- Dodson, E. K., Ares, A., & Puettmann, K. J. (2012). Early responses to thinning treatments designed to accelerate late successional forest structure in young coniferous stands of western Oregon, USA. *Canadian Journal of Forest Research*, 42(2), 345–355. <https://doi.org/10.1139/x11-187>
- Donato, D. C., Campbell, J. L., & Franklin, J. F. (2012). Multiple successional pathways and precocity in forest development: Can some forests be born complex? *Journal of Vegetation Science*, 23(3), 576–584. <https://doi.org/10.1111/j.1654-1103.2011.01362.x>
- Drake, C. (2025). *Historical frequent fire in the culturally modified landscape of the McDonald-Dunn Forest* [Master's thesis, Oregon State University]. ScholarArchive@OSU. oregonstate.edu
- Eisenberg, C., Prichard, S., Nelson, M. P., & Hessburg, P. F. (2024). *Braiding Indigenous and western knowledge for climate-adapted forests: An ecocultural state of science report*. University of Washington. washington.edu
- Franklin, J. F., & Dyrness, C. T. (1973). *The natural vegetation of Washington and Oregon* (General Technical Report PNW-GTR-8). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.
- Franklin, J. F., Spies, T. A., Pelt, R. V., Carey, A. B., Thornburgh, D. A., Berg, D. R., Lindenmayer, D. B., Harmon, M. E., Keeton, W. S., Shaw, D. C., Bible, K., & Chen, J. (2002). Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management*, 155(1-3), 399–423. [https://doi.org/10.1016/S0378-1127\(01\)00575-8](https://doi.org/10.1016/S0378-1127(01)00575-8)
- Ishii, H., & McDowell, N. (2002). Age-related development of crown structure in coastal Douglas-fir trees. *Forest Ecology and Management*, 169(3), 257–270. [https://doi.org/10.1016/S0378-1127\(01\)00751-4](https://doi.org/10.1016/S0378-1127(01)00751-4)
- Johnston, J. D., Merschel, A. G., Schmidt, M. R., & Reilly, M. J. (2026). Diverse historical fire disturbance and successional dynamics in Douglas-fir forests of the western Oregon Cascades, USA. *Ecosphere*, 17, e70474. <https://doi.org/10.1002/ecs2.70474>
- Johnston, J. D., Schmidt, M. R., Merschel, A. G., Downing, W. M., Coughlan, M. R., & Lewis, D. G. (2023). Exceptional variability in historical fire regimes across a western Cascades landscape, Ore-

- gon, USA. *Ecosphere*, 14(12), e4735. <https://doi.org/10.1002/ecs2.4735>
- LANDFIRE. (2026). *20+ years of critical data for Wild-land Fire & Natural Resource Management*. <http://landfire.gov>
- Long, J. W., Lake, F. K., & Goode, R. W. (2021). The importance of Indigenous cultural burning in forested regions of the Pacific West, USA. *Forest Ecology and Management*, 500, 119597. <https://doi.org/10.1016/j.foreco.2021.119597>
- Merschel, A. G. (2021). *Historical forest succession and disturbance dynamics in Coastal Douglas-fir forests in the southern western Cascades of Oregon* [Doctoral dissertation, Oregon State University]. ScholarsArchive@OSU.
- Merschel, A. G. (2023). *A dendrochronological history of fire and tree establishment on the Elliott State Research Forest*. Oregon State University. oregonstate.edu
- Merschel, A. G., Krawchuk, M. A., Johnston, J. D., & Spies, T. A. (2024). Historical pyrodiversity in Douglas-fir forests of the southern Cascades of Oregon, USA. *Forest Ecology and Management*, 572, 122306. <https://doi.org/10.1016/j.foreco.2024.122306>
- Oliver, C. D., & Larson, B. C. (1996). *Forest stand dynamics*. John Wiley and Sons.
- Puettmann, K. J., Merschel, A. G., & Swanson, E. (2026). Integrating multiple dimensions of disturbances into the silviculture of moist temperate forests of the Pacific Northwest. *Journal of Forestry*. <https://doi.org/10.1007/s44392-026-00086-9>
- Seidel, D., Ruzicka, K. J., & Puettmann, K. (2016). Canopy gaps affect the shape of Douglas-fir crowns in the western Cascades, Oregon. *Forest Ecology and Management*, 363, 31–38. <https://doi.org/10.1016/j.foreco.2015.12.024>
- Spies, T. A., Stine, P. A., Gravenmier, R., Long, J. W., & Reilly, M. J. (Tech. Coords.). (2018). *Synthesis of science to inform land management within the Northwest Forest Plan area* (General Technical Report PNW-GTR-966). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. <https://doi.org/10.2737/PNW-GTR-966>
- Tepley, A. J., Swanson, F. J., & Spies, T. A. (2014). Post-fire tree establishment and early cohort development in conifer forests of the western Cascades of Oregon, USA. *Ecosphere*, 5(7), art80. <https://doi.org/10.1890/ES14-00112.1>
- U.S. Department of Agriculture, & U.S. Department of the Interior. (1994). *Record of decision for amendment to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl (Northwest Forest Plan)*. U.S. Department of Agriculture; U.S. Department of the Interior.
- USDI Fish and Wildlife Service. (2011). *Revised recovery plan for the northern spotted owl (Strix occidentalis caurina)*. USDI Fish and Wildlife Service.
- Weiskittel, A. R., Crookston, N. L., & Rehfeldt, G. E. (2012). Projected future suitable habitat and productivity of Douglas-fir in western North America. *Schweizerische Zeitschrift für Forstwesen*, 163(3), 70–78. <https://doi.org/10.3188/szf.2012.0070>