Forest Management as a Tool to Increase Climate Resilience in our Forests

Forest management plays a critical role in preparing and maintaining healthy and resilient forests in the face of a changing climate and other stressors such as pests, pathogens, and invasive plants. Past land use—including agricultural clearing of more than 80% of the Vermont landscape in the 19th and 20th century—and previous land use policies in the late 20th century have left many forests lacking the ecosystem characteristics that increase the likelihood of forest resilience in response to current and future stressors. Sustainable forest management can be used to address the lack of complexity in many forests with the intent to increase resilience to climate change and other forest health threats.

Forests through the lens of the past and present

To the lay person, a glance into a typical Vermont forest may seem like a thriving and healthy ecosystem, teeming with plants and animals; however, this may not be the case ecologically. This glance may miss a deeper picture of the forest's overall health and resilience, including the spatial arrangement of open and closed canopies, crown structures of individual trees, diversity of tree species, tree age, understory and leaf litter composition, and the number of dead trees in the canopy and on the ground—all important characteristics of ecosystem function and health. These complexities have not only gone unnoticed by many people but have not always been the primary focus of management efforts until the last few decades (1,2). Since the latter half of the twentieth century, societal shifts supported by an increased scientific understanding of the complex dynamics of forest ecosystems have led to shifts in forestry practices (3). This greater recognition of ecosystem services has spurred a shift in forest management objectives to encompass a broader range of values, such as creating a healthy and resilient forest; and maintaining biodiversity, producing sustainable local wood products, providing wildlife habitat and recreational opportunities, regulating surface water flow, and optimizing carbon sequestration and storage.

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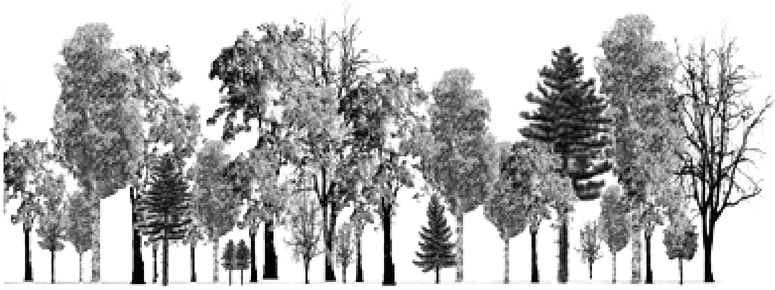
Forests through the lens of the past and present continued...

Further, past land use history has led to homogenized (i.e., similar) forests with simple age structure and lack of species diversity. In Vermont, the extirpation of indigenous knowledge and practices on the landscape, followed by the clearing of 80% of forests and subsequent farm abandonment in the 19th and 20th century led to regrowth of forests across the landscape that fall into this homogenized category (4,5). This landscape-scale disturbance leading to homogeneous conditions across the state increases risk of forest degradation under a changing climate. **Forests with minimal species diversity and similar age and structural composition have increased vulnerability to climate-related disturbances due to reduced recovery pathways (e.g., a forest containing a greater diversity of species have an increased capacity to adapt to warmer conditions or a pest outbreak than a forest containing one species (6,7)), highlighting the importance of a heterogeneous landscape.**

Simple Forest



Diverse Forest

Forests in a changing climate

Our forests are now facing significant threats from climate change, with changes in temperature and precipitation patterns as well as increases in human-introduced insects, pathogens, and plants. Response to these stressors is often thought of in the context of 'resilience'—the recovery and trajectory following a disturbance event (8,9). A resilient forest is one that can recover quickly with minimal change to the forest. Therefore, an important element of any strategy to promote resilience in our forests is to increase heterogeneity—through adding species and age diversity, improving tree vigor, reducing competition, etc.—to increase the likelihood of a forest to recover from climate change and other disturbances and remain as an intact forest into the future (10–12).

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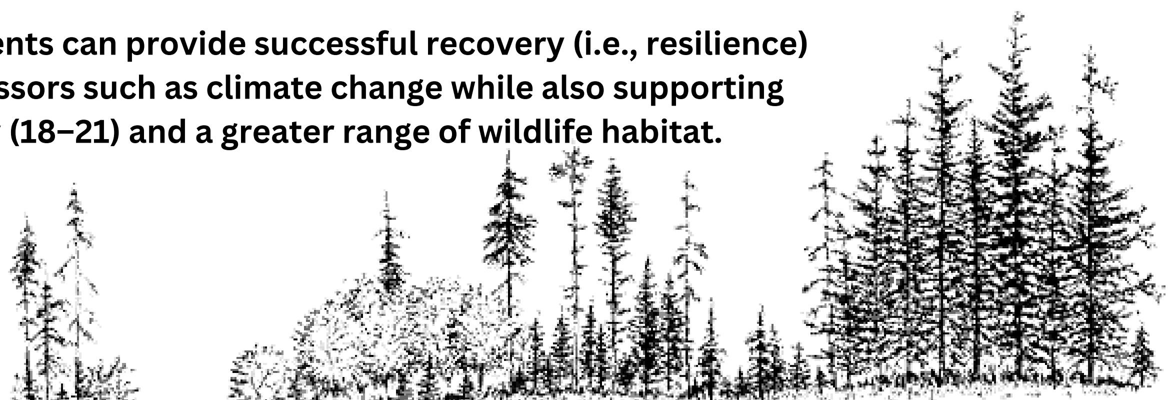
To add **resilient characteristics** to our forests, forests should be managed to improve structural characteristics. Structural complexity at both the stand and landscape scale is important and has been linked to increased resilience (13–15).

At the **landscape scale,** structural complexity includes the presence of young, mature, and old forests which creates a dynamic and resilient landscape that supports a rich array of biodiversity, contributes to climate regulation, and enhances ecological stability.

At the **stand-scale**, “structure” refers to the physical arrangement and organization of various components within the ecosystem including the following:

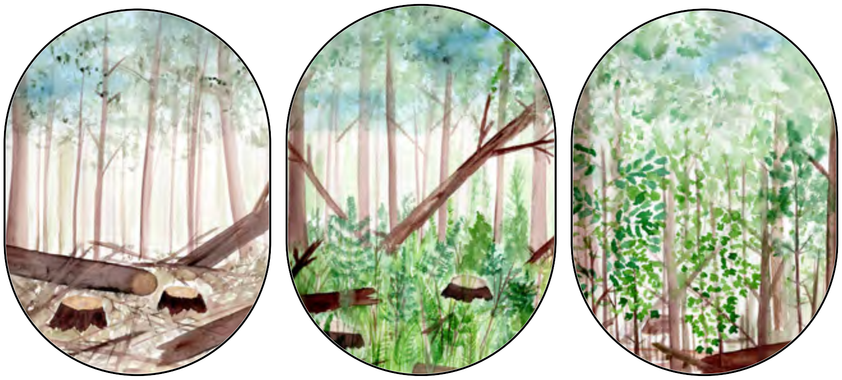
- **Vertical structure** includes the different canopy layers such as the forest floor, understory, midstory, and canopy which represents different age classes. A range of age classes and vertical structure adds resilience to a forest.
- **Horizontal structure** includes the spatial arrangement of trees and plants across the landscape which can be uniform, random, or clumped. Through varying arrangements of forests (e.g., canopy gaps, retention trees in openings, thinned canopies), there are variable combinations of light, moisture, and temperature which in turn support a diversity of regeneration conditions and habitat opportunities (16,17).
- **Diversity of species and age classes** is important given different species have different characteristics and vulnerabilities. For example, having a monoculture of one species can lead to greater vulnerability to drought or a certain pest or pathogen and carries increased risk of reduced tree vigor and, in some cases, widespread mortality.
- **Increased deadwood**, such as snags (standing dead trees) and downed logs, provides habitat for wildlife and arthropods, and contributes to nutrient cycling that supports healthy and diverse soils and plants. Deadwood is an incredibly important structural feature that improves water infiltration in the soil and can act as a ‘nurse log’ for the establishment of future seedlings.

All these structural elements can provide successful recovery (i.e., resilience) in the face of novel stressors such as climate change while also supporting broader biodiversity (18–21) and a greater range of wildlife habitat.



Forest Management as a Tool to Increase Climate Resilience in our Forests

Active Forest Management Can Increase Structural Complexity in a Forest



Although it may seem counterintuitive, active, sustainable forest management can enhance or maintain these structural characteristics in a forest landscape, thereby directly contributing to forest resilience and climate adaptation. One aspect of sustainable forest management is harvesting trees in a manner that promotes both regeneration and a healthier post-harvest forest ecosystem, via silvicultural methods that avoid soil compaction, create site conditions beneficial for the regeneration of species, leave some trees and downed logs for wildlife habitat, and create breaks in the canopy to give regenerating seedlings access to sunlight. It's important to note that when forests are sustainably managed and trees are harvested and then allowed to regenerate, the forested landscape persists and continues to provide ecosystem services, such as water regulation, wildlife habitat, and carbon sequestration. For this reason, sustainable forest management is not the same as fragmentation or deforestation which is defined as the conversion of forest land to non-forest land as defined by the Intergovernmental Panel on Climate Change (IPCC) (27).

By managing forests with active timber harvests, we can add more structural diversity—both horizontal and vertical—as well as species and age diversity. This may be accomplished through varying silvicultural practices such as the following (2,25,26):

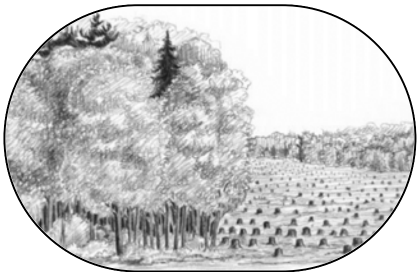
Reserves: reserving healthy individual trees or groups of trees within gaps or patch cuts to serve as seed source for future regeneration, or support continuity of species associated with individual trees or groups of trees like lichen, mycorrhizae, wildflowers and others. Reserves may also apply to stands with high structural diversity as part of a suite of management strategies.

Single-tree selection and group selection: small to moderate gap openings that mimic moderate disturbances like wind throw. Smaller gaps favor shade-tolerant species and larger gaps favor shade intolerant and intermediate intolerant species (27) that have valuable adaptive characteristics (28).

Forest Management as a Tool to Increase Climate Resilience in our Forests

Shelterwood: variable size cuts through which a new generation of trees is established naturally under the shelter of older trees by a series of partial cuttings intended to stimulate seed production and create favorable seedbed conditions.

Patch cuts: larger cuts that are beneficial for wildlife species and young forest habitat. In areas with high concentration of diseased beech and granitic soils, larger patch cuts are recommended for the regeneration of a more diverse forest (29) .



Strip cuts: harvesting long, narrow strips of forest, leaving adjacent areas intact to provide seed sources and protection for regeneration. This technique aims to promote natural regeneration, reduce soil erosion, and maintain biodiversity. Shade-intolerant and intermediate-tolerant species benefit from the increased light and space provided by strip cuts, which mimic natural disturbances such as windthrows and small-scale fires.

These examples are not an exhaustive list but are representative of common silvicultural practices used on state lands. All these strategies—including both active and passive management—require careful consideration of forest regeneration, site conditions, invasive species, and future climatic conditions.

Through active sustainable forest management coupled with passive management strategies, structural complexity increases, creating a more resilient landscape that improves and maintains an array of ecosystem services and addresses social (e.g., wood consumption and production) and ecological (e.g., promoting forest health and resilience, carbon sequestration and storage, biodiversity) needs while also bolstering resilience to climate change impacts and other forest health stressors.

References

1. Bengston, D. Changing Forest Values and Ecosystem Management. Soc. Nat. Resour. - SOC Nat. RESOUR 7, 515–533 (1994).
2. Palik, B. J., D'Amato, A. W., Franklin, J. F. & Johnson, K. N. Ecological Silviculture: Foundations and Applications. (Waveland Press, 2020).
3. Puettmann, K. J., Coates, K. D. & Messier, C. C. A Critique of Silviculture: Managing for Complexity. (Island Press, 2009).
4. Fuller, J. L., Foster, D. R., McLachlan, J. S. & Drake, N. Impact of Human Activity on Regional Forest Composition and Dynamics in Central New England. Ecosystems 1, 76–95 (1998).
5. Shifley, S. R. et al. Five Anthropogenic Factors That Will Radically Alter Forest Conditions and Management Needs in the Northern United States. For. Sci. 60, 914–925 (2014).
6. Oliver, T. H. et al. Biodiversity and Resilience of Ecosystem Functions. Trends Ecol. Evol. 30, 673–684 (2015).
7. Tilman, D., Isbell, F. & Cowles, J. M. Biodiversity and Ecosystem Functioning. Annu. Rev. Ecol. Evol. Syst. 45, 471–493 (2014).
8. Gunderson, L. H. Ecological Resilience—In Theory and Application. Annu. Rev. Ecol. Evol. Syst. 31, 425–439 (2000).
9. Lloret, F., Siscart, D. & Dalmases, C. Canopy recovery after drought dieback in holm-oak Mediterranean forests of Catalonia (NE Spain). Glob. Change Biol. 10, 2092–2099 (2004).
10. Messier, C. et al. The functional complex network approach to foster forest resilience to global changes. For. Ecosyst. 6, 21 (2019).
11. Puettmann, K. J. & Messier, C. Simple Guidelines to Prepare Forests for Global Change: The Dog and the Frisbee. Northwest Sci. 93, 209 (2020).
12. Nagel, L. M. et al. Adaptive Silviculture for Climate Change: A National Experiment in Manager-Scientist Partnerships to Apply an Adaptation Framework. J. For. 115, 167–178 (2017).
13. Liang, L., Hawbaker, T., Zhu, Z., Li, X. & Gong, P. Forest disturbance interactions and successional pathways in the Southern Rocky Mountains. For. Ecol. Manag. 35–45 (2016) doi:10.1016/j.foreco.2016.05.010.
14. Senf, C., Müller, J. & Seidl, R. Post-disturbance recovery of forest cover and tree height differ with management in Central Europe. Landsc. Ecol. 34, 2837–2850 (2019).
15. Wikle, J. L. & D'Amato, A. W. Stand spatial structure outcomes of forest adaptation treatments in northern hardwood forests in North America. Can. J. For. Res. 53, 721–734 (2023).
16. Aussenac, G. Interactions between forest stands and microclimate: Ecophysiological aspects and consequences for silviculture. Ann. For. Sci. 57, 287–301 (2000).
17. Raymond, P., Royo, A. A., Prévost, M. & Dumais, D. Assessing the single-tree and small group selection cutting system as intermediate disturbance to promote regeneration and diversity in temperate mixedwood stands. For. Ecol. Manag. 430, 21–32 (2018).

References

18. Aguilar-Cruz, Y., García-Franco, J. G. & Zotz, G. Microsites and early litter decomposition patterns in the soil and forest canopy at regional scale. Biogeochemistry 151, 15–30 (2020).
19. Mullally, H., Buckley, D., Fordyce, J., Collins, B. & Kwit, C. Bee Communities across Gap, Edge, and Closed-Canopy Microsites in Forest Stands with Group Selection Openings. For. Sci. 65, (2019).
20. Oliver, T., Roy, D. B., Hill, J. K., Brereton, T. & Thomas, C. D. Heterogeneous landscapes promote population stability. Ecol. Lett. 13, 473–484 (2010).
21. King, D., Yamasaki, M., DeGraaf, R. M. & Costello, C. Three decades of avian research on the Bartlett Experimental Forest, New Hampshire, U.S.A. For. Ecol. Manag. 2621 3-11 262, 3–11 (2011).
22. Catanzaro, P. et al. Managing Northeastern Forests Threatened by Emerald Ash Borer.
23. D’Amato, A. W. et al. Towards Tree Species Preservation: Protecting Ash Amidst the Emerald Ash Borer Invasion in the Northeast. J. For. 121, 480–487 (2023).
24. D’Amato, A. W. et al. Species Preservation in the Face of Novel Threats: Cultural, Ecological, and Operational Considerations for Preserving Tree Species in the Context of Non-Indigenous Insects and Pathogens. J. For. 121, 470–479 (2023).
25. Leak, W. B., Yamasaki, M. & Holleran, R. Silvicultural guide for northern hardwoods in the northeast. Gen Tech Rep NRS-132 Newtown Sq. PA US Dep. Agric. For. Serv. North. Res. Stn. 46 P 132, 1–46 (2014).
26. Palik, B. J. & D’Amato, A. W. Ecological Silvicultural Systems: Exemplary Models for Sustainable Forest Management. (John Wiley & Sons, 2023).
27. Russel M. Burns & Honkala, B. H. Silvics of North America: 1. Conifer; 2. Hardwoods. vol. 2 (U.S. Department of Agriculture, Forest Service, Washington, DC, 1990).
28. Peters, M.P., Prasad, A.M., Matthews, S.N., & Iverson, L.R. 2020. Climate change tree atlas, Version 4.
29. Yamasaki, M., Costello, C. A. & Leak, W. B. Effects of clearcutting, patch cutting, and low-density shelterwoods on breeding birds and tree regeneration in New Hampshire northern hardwoods. Res Pap NRS- 26 Newtown Sq. PA US Dep. Agric. For. Serv. North. Res. Stn. 15 P 26, 1–15 (2014).