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The Context of Ecological Silviculture

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1.1 What Is Ecological Silviculture?

In forestry, the tools to carry out on-the-ground management are found in the toolbox of silviculture, that is, the part of forestry that deals with the development and care of forests. This development and care can be all encompassing, including establishment, growth, composition, health, and quality of trees and stands to meet the diverse needs of society. The planned program of all these activities, spanning the entire life of a forest stand, is termed a silvicultural system.

Ostensibly, such a definition for silviculture would seem to recognize most forests, outside of plantations, as natural ecosystems and that the tools to manage these ecosystems would be based on ecological principles. In reality, classical silviculture is largely based on principles of production agriculture, more so than the ecology of natural forests [1]. The outcome of the long-term application of an agricultural model to managed forest is near global-wide simplification of structure and composition [2], as well as a reduced ability to adapt to unexpected and novel threats [3].

This is where ecological silviculture comes in, which we define as an approach for managing forests, including trees, associated organisms, and ecological functions, based on emulation of natural models of development [2]. There are other closely aligned approaches that also are ecological that have similar aims, such as close-to-nature forestry (e.g. [4]). An explicit goal of ecological silviculture and allied approaches is to manage forests in ways that reduce the disparity between natural forests and their managed counterparts in terms of composition, structure, and function. Recognizing that this disparity cannot be eliminated in managed forests, particularly those where timber resources are highly valued, ecological silviculture still rests on the premise that managers can get closer to the natural model than classical silvicultural has allowed. Let us look at why this might be, by contrasting some of the main differences between the two approaches.

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1.2 How Does Ecological Silviculture Differ from Classical Commodity-Focused Silviculture?

The central emphasis of ecological silviculture is on maintaining the full array of structures, functions, and species found in a healthy natural forest ecosystem [2]. To achieve this goal, ecological silviculture builds from an understanding of natural disturbances and forest development to craft silvicultural systems that generate and maintain complexity and heterogeneity in ecosystem attributes. This often includes the application of regeneration harvests patterned after the prevailing natural disturbance regime for an ecosystem, including their scale, severity, and frequency. In addition, the legacies of these disturbances, namely surviving trees, and coarse woody material, are accounted for by placing an equal emphasis on what is left behind relative to what is removed at each silvicultural intervention over the course of the silvicultural system. Although economic objectives are still a priority with ecological silviculture, those associated with ecosystem diversity and resilience are given high priority in the design and implementation of ecological silvicultural systems.

In contrast, commodity-focused silviculture emphasizes the "forest crop" and is correspondingly concerned with silvicultural regimes that generate forest conditions to optimize growth and development of economically desirable species and tree forms. Silviculture treatments under this approach are largely based on agronomic models with a corresponding emphasis on simplifying and homogenizing forest-wide structure (e.g. spacing) and composition (i.e. primarily commercial tree species) to maximize the area occupied by economically desirable trees and to enhance the efficiency of harvest operations. Not surprisingly, the timing, frequency, and severity of silvicultural treatments are largely governed by economic criteria, including maximizing net present value, and avoiding risk of crop-tree loss to damaging agents [5]. Forests managed under this approach can satisfy noneconomic objectives to a degree [6]; however, achievement of economic objectives is the central priority under timber-focused regimes.

1.3 Why Is Ecological Silviculture Needed?

To appreciate the need for ecological silviculture, consider how the forces shaping forest management have changed over the last 70 years. First, globally, it is estimated that there are 4.0 bha of forest, including 0.3 bha of plantations and 3.7 bha of natural-origin forests; moreover, of the latter, 0.65 bha are legally protected reserves [7]. Generally, plantations are managed intensively for wood, such that ecological benefits are marginalized, while reserves usually exclude harvesting. This leaves about 3 bha of natural-origin forests where multiple environmental, economic, and social objectives are pursued [8] and, for the portion of this forest that is managed, ecological silviculture may be the appropriate tool for meeting diverse objectives.

In fact, the drivers of policy and practice across the global forest have changed fundamentally to be more ecological [2]. For example, conservation stewards, such as The Nature Conservancy, have emerged as key players in the forest management world, with their goals being overtly ecological. Also, the objectives of traditional forest stewards, e.g. United States National Forests, have evolved to focus on sustaining whole ecosystems. Additionally, third-party certification, as well as best management practices (BMP's), have led forest stewards to adopt ecological approaches for silviculture. Many largely unprecedented health threats facing forests, including climate change, catastrophic wildfires, and invasive species, require silviculture that restores the structural and functional integrity of forests to better position them to adapt to uncertainty [9]. Finally, the vast increase in our understanding of forests – how they are structured, how they function, and how they are connected across the landscape – argues for a different kind of silviculture, one that focuses on forests as ecosystems, not agricultural ecosystems.

1.4 What Are the Foundational Concepts of Ecological Silviculture?

While the definition of ecological silviculture may vary a bit among stakeholders, all are based on an understanding and modeling of natural disturbance and forest development. For silvicultural application, such a model begins with canopy disturbance and proceeds through stages that reflect structural maturation. The model may include a *preforest* stage, followed by *young*, *mature*, and *old forest* stages (Box 1.1). The model may apply to whole-stands or patches within stands. As you will learn in the chapters that follow, ecological *silvicultural systems* often emulate this developmental model and are catered to the ecological and socioeconomic contexts of the ecosystem being managed.

Box 1.1 Some Concepts and Terms Associated with Ecological Silviculture

Biological legacies: biological legacies are healthy trees, decadent trees, large deadwood, and derivatives of dead trees, e.g. tip-up mounds, and pre-disturbance vegetation (advance regeneration, understory plants) that survive from the previous forest into the new forest after disturbance.

Deadwood: dead trees, including snags and downed wood, and tree components (branches, roots).

Forest developmental stages

Disturbance and legacy creation: a disturbance that kills trees and leaves a legacy of organisms and structures from the pre-disturbance forest.

Preforest: a period when herbs and shrubs dominate growing space and tree abundance is not enough to dominate the site.

Young forest: establishment of new cohort trees of relatively uniform size, along with large legacy trees; density-dependent mortality is a dominant process in this stage.

Mature forest: new cohort trees dominate; mortality shifts to density-independent agents; advance regeneration of shade-tolerant trees are released and species of lesser tolerance may establish in canopy gaps; spatial heterogeneity of structure increases; new deadwood accumulates.

Old forest: a diverse mix of live and dead trees of varying size and condition; high levels of spatial heterogeneity; increasing decline and mortality of trees from exogenous agents; significant inputs of large deadwood.

Recovery period: the time between regeneration harvests of sufficient duration to allow for development of mature forest structures.

Retention tree: a tree retained during a regeneration harvest to live out its natural lifespan so as to provide mature forest structural elements and associated functions.

Structural complexity: abundance, size, conditions, and degree of heterogeneity in living and dead components in a forest.

Variable retention harvesting: retention of living trees and deadwood at harvest in a range of spatial patterns *(dispersed and aggregated) and* abundances; includes retention of species or functional groups, e.g. conifers or hardwoods, and can occur stand-wide or at gap-scales depending on natural developmental model being emulated.

Variable-density thinning: silvicultural strategy that varies the density of removal across a stand, including gaps, standard thinning, and no removal; accelerates the development of complexity and heterogeneity. Although termed a "thinning," this approach includes deliberate consideration for regenerating new cohorts in gaps, so it can also be considered as a regeneration method.

Another commonality of ecological silvicultural systems is that they address several foundational principles derived from a natural model. We have discussed these principles in detail elsewhere [2, 10], which include *continuity*, *complexity/diversity*, *timing*, and *context*. Here we provide a brief review, along with some definitions of terms associated with the principles (Box 1.1).

Continuity is the provisioning of structure, biota, and function from a pre- to post-disturbance forest. The currency of continuity are *biological legacies*, especially *retention trees* and large *deadwood*, and the principle is often addressed using gap-scale or forest-wide *variable retention harvesting* (see Box 1.2) during regeneration harvests.

Box 1.2 Clarifying and Advancing Ecological Silviculture Terminology: Variable Retention Harvests and Variable-Density Thinning

When the important task of inventing the solution has proceeded far enough, the less important task of attaching a name to it can be taken. Standard terminology should be used to the extent of its limited capacity for providing information in terms meaningful to all foresters and then supplemented with additional, detailed information that is usually necessary.

—David Smith [11]/John Wiley & Sons.

The use of a common and standard terminology has been a central aspect of the discipline of silviculture with the core intent of minimizing confusion over intended prescription outcomes and maintaining professionalism and consistency of communication in the field. The silvicultural terms and practices used in North America and many other regions generally owe their origin to European silviculture methods, which were primarily designed to address the predominant socioecological conditions in Europe during the nineteenth and twentieth centuries [1]. These terms and practices were codified into North American professional standards, texts, and curricula in the early twentieth century [12, 13] and have served as the cornerstone of silviculture ever since. It is noteworthy that Indigenous models of forest stewardship actually predated the formalization and organization of the American forestry profession [14], yet these models were largely ignored by early, European-trained forest scientists and foresters and have only recently been recognized by non-tribal institutions as powerful models for informing ecological silviculture (e.g. [15, 16]).

Given the general adherence of North American silviculturists to European terminology and approaches, a long-standing, albeit unfounded, criticism of ecological silviculture has been that it largely reinvented terms for practices that already have names in the traditional silviculture vernacular. This is particularly true for two of the most commonly applied elements of ecological silvicultural systems, *variable retention harvests (VRH) and variable density thinning (VDT)*. For both of these practices, criticism has stemmed from their similarity to existing regeneration methods that include "reserves" or that apply multi-cohort systems that work from and maintain spatial heterogeneity in structure and composition in a forest over time (e.g. group selection and some irregular shelterwood systems). The outcomes of these existing methods may resemble those following VRH or VDT at different stages of implementation; however, there are key differences in the intent of historical silvicultural methods that prevent making them synonymous with certain ecological silviculture terms and approaches.

In an attempt to move terminology forward, particularly given how widespread the use of VRH and VDT has become (as evidenced in the chapters that follow), it is worth defining and clarifying the intent of these ecological silvicultural methods. Our hope is to introduce consistency in communicating the intent and application of these practices and to move beyond forcing the use of traditional terms in cases where they do not make sense nor convey silvicultural intent. Importantly, the use of standard and historical terminology still is a key aspect of any silvicultural application, whether it is ecological or not. Nevertheless, we should strive as a profession to allow for evolution of historical and new terms to allow for operationalization of strategies that match new and emerging objectives in a twenty-first century context.

Variable Retention Harvests

VRH is a two-aged regeneration method that emphasizes the permanent retention of mature canopy trees, as well as other important structural legacies, such as snags and downed logs at the time of regeneration harvest. VRH was first popularized in the Pacific Northwest region of the United States during the 1990s in response to social and ecological concerns surrounding the widespread use of clear-cutting methods [17], with their use expanding globally over the past two decades into many regions where clear-cutting-based methods historically prevailed [18]. In practice, this method encapsulates the ecological silviculture principle of continuity by ensuring structural, functional, and compositional elements from the preharvest forest are carried forward into the new, regenerating stand.

The use of the term "variable" to describe these systems reflects the need to vary the amount and distribution of retained trees depending on management objectives and ecological conditions, with this flexibility contributing to the wide range of global ecosystems and ownerships now applying this approach. In regions where there is a longer history and greater experience with VRH, such as British Columbia, Canada, fairly specific guidelines exist surrounding levels of retention, and spatial patterns of retention when applying VRH as an integrated silvicultural system for achieving ecological objectives [19]. For other regions and forest types, less guidance may exist and the flexibility of VRH should be utilized to determine the retention levels and patterns necessary to achieve ecological goals over time. To this end, although originally termed a "harvest system," VRH is better thought of as a regeneration method, so the seedbed conditions and resource environments required by the desired species on a site are a critical consideration in the design of VRH, with differing patterns of retention often used to accommodate species with varying tolerance [20]. Unfortunately, applications of VRH have led to a common misconception that solely retaining trees at the time of harvest is all that ecological silviculture entails [10]; however, true ecological silvicultural systems often use VRH as the regeneration method occurring at the Disturbance and Legacy Creation stage of a given system. As with other silvicultural systems, subsequent intermediate treatments, such as release treatments and thinning, are applied over time to enhance ecological conditions and future economic outputs and achieve long-term desired future ecological conditions (Figure 1.1).

Existing two-aged regeneration methods, such as clear-cutting, seed-tree, and shelterwood, with reserves certainly have similarities to VRH given these methods include the retention of some mature trees beyond 20% of the rotation age of the new regenerating cohort (the definition of *with reserves* systems). Nevertheless, a key and important distinction between VRH and these older methods is intent. In particular, the historical intent of retaining "reserve trees" largely revolved around allowing canopy trees to grow to larger, more economically valuable sizes before their ultimate harvest [13]. Modern silviculture texts certainly acknowledge that we now also retain "reserves" for many ecological and cultural values [21]; however, future

Figure 1.1 Variable retention harvest in red pine-dominated forests in north-central Minnesota, USA. Left photo represents disturbance/legacy creation stage with right hand photo taken from same site during early portion of the young forest stage. Release treatments were applied to site during young forest stage to enhance development of natural and artificial regeneration established on site.

economic returns from these reserve trees remains an objective linked to this terminology, making it incongruous with the intent of VRH.

Of note, permanent retention of legacy trees is certainly not restricted to VRH, as gap-level retention of legacy trees is a common feature of ecological silviculture systems for ecosystems dominated by gap and mesoscale-disturbance regimes. As with VRH, simply modifying the regeneration methods used for these forests to include "reserves" does not fully convey silvicultural intent given the primary objective for retention is for those trees to live out their natural lifespan. As such, adding modifiers such as "with permanent legacy retention" to regeneration methods, such as group selection or expanding gap irregular shelterwoods, maybe a more effective way to communicate these methods going forward to avoid confusion with traditional strategies developed during a time (i.e. eighteenth and nineteenth century) where permanent retention was not acceptable from a socioeconomic standpoint.

Variable-Density Thinning

VDT is a harvesting method in which the removal of trees is varied spatially across a stand or management unit to increase heterogeneity in horizontal and vertical structure. As with VRH, VDT developed in the Pacific Northwest region of the United States, with the intent of restoring the spatial variability in canopy tree densities and age classes that are a common attribute of natural forests around the globe [22]. This approach reflects the ecological silviculture principle of complexity and is generally applied to forests in the late young forest or mature forest stages of stand development to accelerate heterogeneity in forest conditions. To this end, VDT is a common component of ecological silvicultural systems applied to second-growth forests homogenized by past management practices (e.g., plantations). In its application, VDT includes the creation of a combination of canopy gaps and thinned areas, as well as designation of permanent, unharvested areas as patch reserves (i.e. groups of legacy trees) (Figure 1.2). This pattern of harvesting and retention creates and reinforces structural and compositional conditions found in the old forest stage of development, including canopy gaps, lower density areas

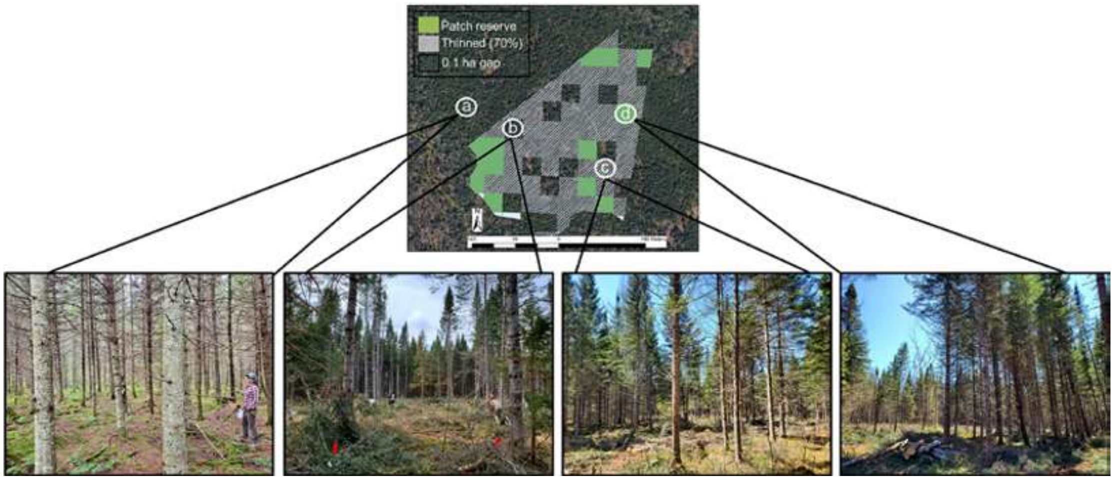

Figure 1.2 Variable density thinning (VDT) within 6-ha harvest unit on the Nulhegan Basin of the Silvio Conte National Wildlife Refuge in Brunswick, VT, USA. Overarching goal of VDT is to meet objectives surrounding increasing ecological complexity in spruce-fir forests simplified by past land use to enhance habitat conditions for priority bird species. (a) Second-growth spruce-fir forest homogenized by historic, intensive management; (b) 0.1 ha gaps for recruiting new age-class and increasing compositional diversity; (c) thinned matrix conditions for accelerating large-tree development; and (d) patch reserves (i.e. skips) to protect unique ecological features and maintain areas of high stem density and canopy cover.

with larger diameter trees, and dense vegetation, all-natural outcomes of a long-term history of gap-phase disturbance and tree maturation.

A primary reason for the widespread appeal of VDT is the relative simplicity with which it operationalizes and achieves desired ecological outcomes (e.g. [23]). In particular, tree marking focuses on identifying logical areas for gap creation (e.g. pockets of advance regeneration) and patch reserves or "skips" (e.g. rare plant communities, areas with high accumulations of deadwood) with thinning applied in matrix areas between these gap and anti-gap elements to accelerate tree growth. Adaptations of this approach have been extended to frequent-fire mixed conifer systems where widely spaced trees, canopy openings, and clumps of trees are created using the Individuals, Clumps, and Openings (ICO) approach [24]. As with VDT, the varying tree densities created by the ICO approach are intended to restore natural patterns of tree density, which in the case of frequent-fire forests are often mosaics of large-diameter individual trees, gaps, and tree clumps of different sizes.

An unfortunate aspect of VDT is its name, as this approach includes provisions for regeneration in the gap elements created. Thinning treatments in a traditional sense are focused on improving the growth and quality of existing trees on a site with no intent to regenerate new cohorts. The use of "thinning" in describing VDT has created confusion over its intent and where it fits with regard to existing silvicultural treatments (i.e. is it an intermediate treatment or regeneration method?). Given the inclusion of regeneration as part of VDT, it is best classified as a regeneration method with aspects similar to hybrid single-tree and group selection and expanding gap and continuous cover irregular shelterwoods. A key difference is that VDT is meant to restore a spatial structure that includes stand areas that will never be harvested (skips). In addition, VDT is best viewed in many applications as a transformative silviculture treatment moving simplified, even-aged stands into more complex, multi-aged conditions [25].

As such, future entries following the application of VDT may take the form of the aforementioned selection and irregular shelterwood methods by either expanding gaps created by VDT or applying single-tree and group removals in thinned matrix areas to further emulate natural developmental models for a given forest. In short, it is an unfortunate name but has been widely demonstrated as a highly valuable tool for conveying and achieving ecological silviculture objectives, so we are sticking with it.

Complexity/diversity addresses the need to create and maintain *structural complexity* and species diversity in managed stands. Often, application of this principle takes the form of restoration, particularly in stands lacking complexity and tree diversity. Some of the tools for addressing complexity/diversity include *variable-density thinning (VDT)* (see Box 1.2), decadence and deadwood creation, and tree enrichment.

Timing is the application of silvicultural interventions at ecologically appropriate intervals, especially the time necessary for *recovery* and development of structure after a major disturbance. It also reflects the need to allow appropriate time intervals between intermediate treatments, such as thinning.

Finally, *context* underscores the importance of implementing silviculture with the landscape perspective in mind. Context recognizes that stand-level actions accumulate to influence the structure and function of landscapes.

1.5 What to Expect from the Chapters that Follow?

The chapters that follow present ecological silvicultural systems for various forest types in North American, as well as examples from Europe, South American, and Australia. These systems have been conceived by innovative researchers and forest stewards who often have been studying their forests for decades. The chapters will vary a bit, depending on the forest type, but all will have some commonalities. Each will present (i) the natural history of the forest, (ii) a summary of the forest's cultural, economic, and ecological importance, (iii) the natural dynamics model for the ecosystem, (iv) a review of the traditional silvicultural system, (v) a presentation of an ecological silvicultural system and a reflection on how the latter reduces the disparity between the natural and management models, and finally, (vi) a consideration of ecological silviculture in the context of climate change.

Another common thread is that all the authors recognize that for their forest, a tweaking of classical, often timber-focused, silviculture is not sufficient to meet the needs of forest management broadly in the twenty-first century. Moreover, the contributors recognize that a simple bifurcation of the forest landscape into production and protected forests [26] is not sufficient to sustain natural forest ecosystems broadly; that is, for much of the global forest ecological silvicultural approaches may better sustain the diverse suite of ecosystem services society expects [27], even under changing climate and disturbance regimes [9]. Providing the tools to meet these expectations in diverse forests is what you can expect from this book.

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