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Silvicultural Systems Design with Emphasis on the Forest Canopy

Abstract

Silvicultural manipulation of an individual tree canopy, or the live crown, controls the quality and quantity of growth. The growth of trees can be controlled by these manipulations only if clear objectives are defined as measurable parameters. The principles of crown management (e.g., juvenile spacing, commercial thinning, pruning) are well known but have only recently been expanded to include wildlife and other non-timber objectives. Silviculture impacts ecosystem functions of the forest, particularly in the forest canopy. As forest resource management is constantly revised to meet broader range of goals (e.g. habitat maintenance or restoration, watershed functions, carbon sequestration) a systems approach to these operations becomes necessary. A silvicultural system approach is summarized by system design, performance, and tolerance of measurable criteria. Monitoring determines if elements of the system are in predetermined bounds, or control. This active management brings the forest canopy in line with target objectives at numerous temporal and spatial scales. There are many scales (temporal and spatial) and methods of control. Common silvicultural manipulations are used to demonstrate canopy control for wildlife habitat maintenance and restoration at the individual tree level. Landscape level distribution of habitat structure and composition is achieved by retention of various amounts and patterns of forest. Updating and adapting management to either better meet stated goals or modify expectations is a continuous process. Forest management, in this context, becomes a powerful research tool that provides useful results in a timely manner.

Introduction

This paper discusses some of the common uses of canopy manipulation to achieve wood quality, briefly describes historical canopy control in the forest industry and, extends the concepts of silvicultural systems to the control of wildlife habitat functions. The purpose of the paper is to offer a new perspective on the application of silviculture. Silviculture can be quite active and provide very specific objectives but clear, measurable design criteria (e.g., height above ground, density of snags (number per hectare), or size of cavity opening) are required.

Silvicultural manipulation of an individual tree canopy, or the live crown, controls the quality and quantity of wood produced. The principles of crown management, such as juvenile spacing, commercial thinning, and pruning have been applied for timber objectives (Petruncio 1994, Oliver et al. 1986). Only recently have canopy manipulations been viewed from the wildlife or landscape perspective. Many conventional silvicultural measures are characterizations of the canopy, such as live crown ratio (LCR), crown closure, and canopy cover. Commercial thinning typically coincides with crown closure to ensure consistent radial growth of logs. Pruning up to 60 percent of the live crown while the stand is still young maximizes the production of high value clear wood in logs (Smith and Long 1989, Briggs and Fight 1991, Petruncio 1994) but is also keyed to canopy closure and total tree height. Proper timing of silvicultural manipulation delays or prevents stagnation of the forest, which minimizes reductions in growth (and development) and perhaps improves fire resilience of the residual stand (Agee 1993).

Simple height-age charts or estimates of the site index establish the baseline against which actual stand values can be compared. These charts may be improved if they were calibrated by canopy measurements including LCR and percent cover as indicators of forest health and vitality.

Silvicultural decisions are more typically keyed to diameter outside bark at breast height (DBH) because it is fast and easy to measure. A more sensitive measure of growth uses 5-year radial increment: Successive declines in the previous 5-year radial increment indicate, among other things, that crown competition—canopy crowding—is affecting growth and signals an appropriate time for thinning operations. Thinning the canopy density provides two unique benefits: (1) even diameter growth (less variation in annual ring width) for improved wood quality and (2) more efficient use of the live crown by reducing competing trees of inferior quality and lower vigor. But there are numerous other functions harboured in the structure of the crown.

Canopy structure of the forest community holds the key to maintaining populations of a number of plant and animal species. These structures include snags, cavities, thick bark, loose bark, tall stems, branches, leaves and twigs, dense foliage, layered canopy and downed wood (Balda 1975, Mannan et al. 1980, Lundquist and Mariani 1991). Habitat structures of trees could be used in a system of diagnostic criteria regarding their function (Table 1). Birds and mammals use the different structures in the forest for food, nesting, and denning requirements.

Many Pacific Northwest forest ecosystems have been so severely simplified by intensive management that an active approach of restoration may counter declining plant and animal populations. Currently, forest practices in the Pacific Northwest are moving forward with unproved methods. The call for ecosystem management is based on observed declines in habitats and species, and threats to air and water quality. Structural diversity in managed forest canopies will be improved with various levels of retained green trees and snags, as well as varied spatial aggregation of the leave trees. Conventional thinning techniques combined with new innovations in creating canopy structure can be used to improve wildlife habitat.

Silvicultural manipulation produces large dimension trees that can serve as nest trees. In managing for cavity and bark nesting birds, characteristics of foraging habitat should not be overlooked. Canopy structure is often the primary determinant of habitat preferences by wildlife. Snag density is important with regards to wildlife utilization (Bull et al. 1980, Bull et al. 1990). Woodpecker populations can be managed through provision of various snag densities (Balda 1975, Bull and Meslow 1977, Thomas et al. 1979, Nietro et al. 1985).

Design of Silvicultural Systems

Managed stands can be viewed as single replicate experiments or demonstrations if the objectives for stand development are stated as hypotheses. The many harvest units that include retention of live and dead tress in the region are operational experiments but few planners have had the foresight to make reasoned projections about the effects of retention on canopy dynamics, let alone

TABLE 1. Habitat structures of trees and their function

Structure	Function	Source
Broken top snags	Nesting platform for osprey and eagle Expedites snag softening for cavity excavation	Miller and Miller, 1980
Large diameter snags	Forage for woodpeckers Nesting and roosting for woodpeckers and owls	Thomas et al. 1979, Bull 1978
Large diameter live trees with thick bark	Abundant arthropod fauna (forage for brown creeper and nuthatches)	Mariani 1987
Large diameter live trees with thick branches	Nest sites for marbled murrelet and arboreal rodents	Ritchie 1988
Multi-layered understory (space between layers)	Habitat for aerial insectivores such as Vaux's swift	
Loose bark	Bat roosts Brown creeper nests	Christie and West 1993 Mariani 1987
Cavities	Nest sites for secondary cavity nesters	Bull 1978
Mistletoe brooms	Nest sites for arboreal rodents and murrelets	
Heartrot-infected bole of tree	Woodpecker drumming and nest excavation	Bull 1980
Diversity of vegetation heights (also called layers)	Diversity of arthropods and insects	
Flattened, fan-shaped branch arrays	Provides horizontal surface for development of epiphyte communities. The western flycatcher, brown creeper, hermit warbler, and kinglet all use epiphtyes for nest construction.	

measure the key variables. Focus has been on tactical operations and less on long-range strategic implications. Hypothesis generation should begin by recognizing that harvest units are experiments in the control of canopy and ecosystem processes.

Silvicultural systems have several elements; system design, design of performance parameters or design criteria, and design of tolerance levels important to assure the control of the overall goals (Taguchi et al. 1989). System design avoids loss from unexpected deviation from target values. Parameter design develops measurable criteria to answer operational questions. Tolerance bounds are necessary to assess the system.

System design determines the life cycle, or time frame, and processes involved; typically, a timber harvest rotation in forestry. The system may maintain a constant supply of snags of a variety of sizes and species. Other ephemeral structures in the canopy include cavities that disintegrate because of decay but are critically important to wildlife (Bull et al. 1980, Ruggerio et al. 1991). *Parameter design* details levels of controllable measures with which to monitor system performance. Silvicultural variables are, for example, height or diameter growth, canopy cover, and survival of residual trees and seedlings. It is important to include ecological variables such as the number and use of natural and manufactured nests, level of epiphyte production, and habitat use by canopy strata. *Tolerance design* specifies the level of variability for parameters; narrow tolerances assure close adherence to system targets but often at much greater financial cost. The results of monitoring are used in the continuous revision and improvement of the system design (Depta 1984, Dyson 1990). A more advanced notion accepts only increasingly narrow tolerances, if at all, so that systems are continuously improved.

The long range nature of forestry makes some of these decisions difficult. On-line experiments (Taguchi et al. 1989) are done in the course of growing the forest and can be used to assess, in a timely manner, the practicality of ecosystem based forest management. Off-line research, by contrast, stops production while experiments are completed. The contemporary methods being practiced to recover at least some of the complex structure and function the forest canopy involve some fashion of tree retention based on the management hypothesis that much of the function of forest structure is in the canopy. Silviculture needs the application of sound, tested methods. Mixed species and structurally complex stands (Raghavan 1993, Rose 1993, Wampler 1993) are examples where the benefits of on-line canopy experimentation can be applied—while the stand is developing measures can be made to address specific hypotheses. Wood quality and growth are well understood for most tree species in the Northwest; canopy manipulations need to test conjecture about the value and use of manufactured habitat structures (as per Table 1). The next step in silviculture develops a common framework for monitoring, adjusting methods, and communicating results across all of the players involved; agencies, companies, first nations, and citizen groups (Walters 1986).

Scales of control of the forest canopy range from the landscape down to the stand and to the individual tree. We may measure the percent cover of vegetation (e.g., by species, age, land use) and describe basin scale structure in terms of the distribution of the patch type and size; the canopy as sensed from above (Ciesla 1989, Greer et al. 1990). With the larger spatial frame often a longer temporal frame is also needed to see the influences of canopy manipulations (Spies and Cohen 1992, Hudson 1988). Canopy resolution from digital remote imagery is coarse and still requires ground based validation. As the resolution is reduced at the larger scale, measures such as percent canopy cover and sustainable flow of wood are important. The latter requires that harvest settings are designed efficiently and properly placed within the landscape to control landscape level targets of canopy composition and structure.

The ground work of ecosystem management is at the stand level (typically 20-100 ha.) because it is at this level we can control the canopy functions and the growth of trees. There are two distinct spatial patterns of canopy retention (also structural retention, STR, after Berg and Schiess 1994): dispersed trees, widely scattered throughout; and aggregated trees (also called clumps, patches), that may be connected to the uncut forest. Each pattern can be evaluated at different levels measured by residual density (trees per hectare, basal area per hectare), percent canopy cover, or residual percent of stand volume. Functions differ with spatial pattern; dispersed canopy moves toward a multilayer stand over time while the aggregated canopy offers immediate refuge and islands of less disturbed forest conditions. Prescriptions (management direction based on sound, reasoned diagnosis) may be linked at larger spatial scales but the essential building block will be the stand treatments.

Within each individual tree canopy there are also structures that can be measured only at that scale. Because of the thermal and moisture gradient through the length of a canopy, there is a variety of niche spaces. The canopy birds need perches, hiding cover, and cavities that develop from specific microclimatic conditions and vary by the tree species, age, spacing, among other variables. It is important to be clear about the specific location that one expects to see differences resulting from of canopy manipulation.

Methods of Control integrate forest resource management with research methods. Empirical studies of forests are difficult to design and are expensive to implement with often limited application to the broad range of conditions in the region. Working knowledge of how to implement innovations in forestry is accelerated by providing operational examples—on-line experiments (see page 7).

Wampler (1993) and Rose (1993) concur with Isaac (1943) and suggest that STR impairs height growth of Douglas-fir and alters species composition; light is the limiting factor for growth. Issac (1943) states that 50 percent canopy cover (ca 50 trees per hectare, TPH) reduces mean annual height of Douglas-fir growth by 50% compared to the clearcut conditions. Secondary influences (e.g., below ground competition, crown architecture, MAI, % volume growth) are often only discussed (after Long and Roberts 1992, Birch and Johnson 1992) but are poorly understood. Projection of how a retention silvicultural system is expected to perform might use height growth equations and site index curves (e.g., King 1966) to predict the development of the new forest. The response of overstory trees released from competition might be measured by diameter increment. Wood quality of both individual trees and the whole stand might be hypothesized to improve because of the release of growing space in the canopy.

Mortality of the trees retained at harvest can be expected but risk of windthrow might be reduced by leaving trees with low height to diameter ratio, Ht./DBH, usually the dominant and codominant crown classes (Franklin 1963). The live crown ratio (LCR=crown length/total tree height) may be another indication of the wind resistance of a tree and could be used to make decisions about retention. The pattern of leave-trees can follow common rules for placement on the landscape to minimize weather effects.

Monitoring canopy modifications is important in managed forests with elevated levels of structural diversity. But these activities are time consuming and costly (Shaw et al. 1993) emphasizing the importance of describing the exact measurements. Efficient monitoring uses all of the information collected and is an adaptive process that may need refinements over time.

Conclusions

Foresters must constantly revise their methods (Walters 1986); updating and adapting management to either better meet stated goals or modify expectations. Forest management in this context becomes a powerful research tool that provides functional results in a timely manner (Depta 1984, FEMAT 1993). A look to the past indicates that the nature of timber management has changed and the harvest operations are now far more constrained by concern for ecological function. The large dimension, high value old-growth timber is rare and reserves for bird and fish protection are scant. The forward looking forest manager may define a future condition where silviculture and harvesting technology are viewed as critical elements in canopy operations designed for endangered species protection and recovery (Mitsch and Jorgensen 1989).

We can determine the wildlife species that will benefit by planning for structural retention, buffering harvest areas, and canopy modification, however, the use of canopy structures by wildlife is still being described for many animals. If the research can be merged with operations, our collective wisdom about proper harvest and management improve at a rapid rate.

This strategic view is reflected in the contemporary use of large area plans to properly place roads and harvest settings in the landscape. The challenge for the future will be to adapt existing technology and develop new tools that meet increasing constraints of regulations and land ethic.

A critical point is that methods and structures be described in a common language between the roles (managers, loggers, engineers, foresters, ecologists). Honest and open dialog about the success and failures of innovative practices, not litigation, will communicate the goals and perhaps improve our ability to live and work in the forest. As the functions of the forest canopy become more evident this communication will be increasingly important as people from many disciplines work together.

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