Extension Note

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The shelterwood silvicultural system in British Columbia – A practitioner's guide. Part 2: The interplay of stand dynamics, disturbance, and regeneration

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Abstract

Partial cutting, including shelterwood systems, is gaining profile after a long silvicultural history of clearcutting with artificial regeneration in British Columbia. The use of silvicultural systems that employ partial cutting requires good knowledge of the principles of silviculture. In particular, fundamentals about stand dynamics (changes in stand structure over time, including the effects of disturbance) and regeneration ecology are essential knowledge when managing stands for specific objectives, for they give us the ability to manipulate stands in predictable ways. This, the second in a series of three extension notes about the shelterwood silvicultural system, reviews the fundamentals necessary for the application of silvicultural systems involving partial cutting.

KEYWORDS: *management objectives; partial cutting; regeneration ecology; shelterwood silvicultural system; stand dynamics.*

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Introduction

The design and implementation of shelterwood silvicultural systems and other methods of partial cutting requires knowledge about both stand dynamics and ecosystems. The interplay of how trees regenerate, grow, compete with each other, and respond to disturbances and their environment over time is a complex relationship worth forest managers' consideration. The long-term nature of partial cutting systems enables managers to become familiar with changes that stands undergo over several years. Exposure to the concepts of stand dynamics is necessary at the planning stage to be able to evaluate the potential of a given partial cutting system at a given site. Silvicultural fundamentals are addressed in this second of three extension notes regarding implementation of the shelterwood system.

Stand dynamics

A sound understanding of how and why forests change over time is fundamentally important to silviculture and forest management. In British Columbia, silviculturists can find it a challenge to gain personal experience with the changes that occur in stands after manipulation for several reasons.

- Our culture of moving foresters to promote them means that an individual's experience in one location is often short relative to the time scale at which forests grow and change.
- Timber-focussed management over large operating areas coupled with short-term silviculture obligations restrict opportunities for foresters to become intimately familiar with stands.
- The portion of an individual's career in which they do active fieldwork may be quite short, reducing their opportunity to view results of past practices.

Although shelterwood systems have not been widely adopted in industrial forest management in British Columbia, "variable retention"[1] and "clearcut with reserves"[2] are systems that have been reported of late (B.C. Ministry of Forests and Range 2006). These systems retain stand structures that can influence regeneration environments in a similar way to shelterwoods. For example, Kohm and Franklin (editors, 1997) cite others showing that dispersed retention, like a shelterwood overstorey, reduces the height growth of understorey regeneration. Momentum for further implementation of the shelterwood system can be built on this body of research evidence.

The interplay of how trees regenerate, grow, compete with each other, and respond to disturbances and their environment over time is a complex relationship worth forest managers' consideration.

Trees and stands respond to their environment in complex but (generally) predictable ways. Stand dynamics is the study of changes in stand[3] structure[4] over time, including the effects of disturbance (Oliver and Larson 1996). Regeneration, growth, competition, and disturbance are basic building blocks of silviculture, and stand dynamics are the fundamentals that silviculturists manipulate to reach desired objectives. Success depends on knowing how your actions will affect forest stand development on a given site, and how fast the response will happen.

Ecosystems develop in a way that is extremely specific to site conditions (Weetman 1996), so a practitioner must be aware of the linkages between site, stand structure, silvics, and stand dynamics. Experience gained in one location is not readily transferable to other stands unless these linkages are well understood (Weetman 1996).

Plant energy requirements

Using energy from the sun, the process of photosynthesis produces sugar and oxygen from carbon dioxide, water, and nutrients. Respiration is the reaction that converts that sugar and oxygen into the energy that allows a plant to grow.

[1] Variable retention is a variation of partial cutting systems, including shelterwood and selection, with a focus on retention of trees or areas that provide a range of structural and ecological functions.
[2] Clearcutting with reserves retains individual or groups of trees to provide habitat for stand-level biological diversity.
[3] Stand: An aggregation of trees occupying a specific area and sufficiently uniform in composition, age, arrangement, and condition that it is distinguishable from the forest in adjoining areas (Dunster and Dunster 1996).
[4] Stand structure: The distribution of trees and other plants in space and in time (Oliver and Larson 1996).

The minimum amount of energy required to meet a plant's maintenance demands, termed the "compensation point," is the level of photosynthetic activity required to keep a plant alive (Kimmins 1987). Kimmins (1987) tells us that the compensation point is different for different species, and is typically higher for light-demanding species and lower for shade-tolerant species. As a plant grows it requires more energy to survive, because it has more living tissue that must be maintained (Oliver and Larson 1996).

Plants that are more shade-tolerant can photosynthesize at lower light levels than other species (Kimmins 1987). This gives some plants an improved ability to survive in shaded conditions, although the low levels of light will not support much growth (Oliver and Larson 1996).

Tree species have different height growth patterns (Oliver and Larson 1996) that create competitive advantages for different species at different times in a stand's history. For example, lodgepole pine has rapid early height growth that tends to make it dominant at a young age, whereas interior Douglas-fir has relatively slow early height growth but more rapid height growth at mid-age. Site index values (height at age 50) for Douglas-fir are typically slightly lower than those of lodgepole pine for site units within the Alex Fraser Research Forest (B.C. Ministry of Forests and Range 2008), and yet Douglas-fir height at age 100 is substantially taller than that of lodgepole pine (Thrower et al. 1994).

Allocation of energy reserves

Plants have a rank order of priority for allocating their energy (Oliver and Larson 1996, citing others).

1. Respiration of existing living tissue
2. New fine roots and leaves
3. Flowers and seeds
4. Terminal and branch growth, root extension and reaction wood
5. Diameter growth, scar tissue, and resistance to insects and diseases

If a plant has only enough growing space to meet the compensation point, it cannot produce new fine roots and leaves and therefore cannot grow.

Growing space and competition

More than just physical room to stand in, growing space is the area that provides all of the growth factors that give a plant the capacity to grow—sunlight, water, heat, nutrients, oxygen, and carbon dioxide. The total growing space provided by a site is limited by the inherent productivity of that site—the amount of the growth factors that are provided. According to Oliver and Larson (1996), available growing space is reduced as plants grow, both through the plants' use of the growth factors and through changes in the environment created by the growing plants (e.g., accumulation of organic material in cold ecosystems causes soils to cool, resulting in a reduction in growing space).

A plant growing in a fixed or diminishing growing space suffers reduced photosynthesis until it reaches its compensation point. More growing space is needed for any growth to occur, and continued shrinkage of the growing space will result in mortality.

Oliver and Larson (1996) tell us that plants will expand into available growing space until they come into contact with other plants. Trees in a dominant position can meet more of their needs than those in subordinate positions because the subordinate trees receive less light, and therefore proportionally more of their energy is consumed by maintenance respiration. As dominant trees continue to grow and occupy more growing space, the subordinate trees fall below their compensation points and perish.

Competition among neighbours arises from the need for continued growth. Some species combinations provide mutualistic support, such as birch and Douglas-fir mixtures (Simard et al. 1997) and aspen–lodgepole pine mixtures (Newsome et al. 2008). However, since competition is the main type of interaction between species in northern temperate forests (Oliver and Larson 1996), dominant plants regularly cause less vigorous specimens of the same species to die. Competition between different species leads to a hierarchy whereby subordinate species occupy space the dominants cannot use.

Trees are versatile and have many adaptations, the sum of which allows them to occupy and compete in a range of sites or niches. Oliver and Larson (1996) describe the relative competitiveness of species across a range of potential niches. Each species has a niche where it outcompetes other species. This is not necessarily the site where it grows best, only where it grows better than others. For example, ponderosa pine probably grows best in a mesic site in the dry subzones of the Interior Cedar–Hemlock biogeoclimatic zone, but it is the dominant species in the much drier Ponderosa Pine zone.

Some species are sensitive to site conditions, and others are relatively insensitive (Oliver and Larson 1996). For example, relative to lodgepole pine, interior spruce grows poorly on poor sites and grows well on good sites, so spruce is relatively site-sensitive when compared to lodgepole pine. Thus, on a good site, spruce will eventually dominate lodgepole pine, but on a poor site the pine will dominate.

Species also vary in their ability to withstand shaded conditions as advanced regeneration, and the most shade-tolerant can subsist in this suspended growth for very long periods (e.g., up to 100 years or more for subalpine fir). At the Alex Fraser Research Forest, we have found interior Douglas-fir seedlings of about 30 cm height at 25 years of age, and 5 cm height at about 12 years of age (K. Day, pers. obs., 2009).

In light-limited ecosystems, such as mesic sites in the Coastal Western Hemlock zone, trees die once their photosynthetic rate falls below their compensation point. However, moisture-limited ecosystems, such as the dry sites in the Interior Douglas-fir zone, support less leaf area, which allows more light to penetrate into the stand (Kimmins 1987), thus allowing some repressed trees a tenuous hold on life.

Stand density

Stand density is the quantitative measure of number and size of trees on a site; it can be expressed as number, basal area,[5] or total volume standing on a hectare (Dunster and Dunster 1996). Stand density is closely tied to the growing space required by individual trees, which, in turn, depends upon species, size, and vigour.

At stand initiation trees grow vigorously, since they are typically not limited by growing space. At high densities, however, this period of open growth is shortened because the proximity of neighbours means that competition will begin early. As trees become more crowded through their growth, they begin to cast shade on each other, causing the crowns to "lift" as lower branches lose photosynthetic capacity and die. If the crowded conditions do not change and trees lose photosynthetic capacity to the point where they can no longer grow (compensation point), their height growth becomes repressed (Oliver and Larson 1996).

Disturbance

Natural disturbances occur in the form of fire, wind, insects, and disease. Disturbance is characterized by four interacting features—size, intensity, frequency, and type—and interactions of these features influence plant community responses (Bazzaz 1983). Silvicultural manipulations can emulate natural disturbance (Kimmins 2004) by killing some or all of the vegetation in whole or in part and thereby releasing growing space to the survivors and new plants (Oliver and Larson 1996). When planning for harvest intensity, patterns of tree retention, harvesting season, harvest system, duration between harvest entries, and how the managed stand fits into the local landscape, you are defining these features of disturbance.

Stand productivity is dependent upon disturbance because as a stand approaches full site occupancy, disturbance, including competition-induced mortality, redistributes the growing space from the plants that die to those that either survive or regenerate (Waring and Schlesinger 1985). In the absence of disturbance, growth efficiency of individual plants begins to decrease, as does the net production of the stand (Waring and Schlesinger 1985).

Potential fates of advanced regeneration released by a disturbance include death caused by exposure, survival with little growth, or survival with positive growth response as a function of site quality and seedling vigour. When released, the seedlings that do grow rapidly will "act their size, not their age" (Oliver and Larson 1996, p. 137), especially those with lots of leaf area.

Stands can and do grow into a condition where they are predisposed to disturbance, and one disturbance can predispose a stand to a further disturbance (Oliver and Larson 1996). Stands growing at high density develop small crowns and slender form, predisposing them to damage by wind and snow. Accumulation of fuel as a result of wind or snow damage predisposes the stand to fire.

Oliver and Larson (1996) point out that species that compete most effectively at a later age are disadvantaged by frequent disturbance. For example, a disturbance regime dominated by frequent stand-replacing fire will tend to favour pioneer species with fast early growth like lodgepole pine and hinder late-seral species such as interior spruce, which grows faster than pine in their later age.

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5 Basal area is the cross-sectional area of a tree bole (generally) measured at breast height (Dunster and Dunster 1996). The cross-sectional area of all the trees in a stand added together is stand basal area, expressed as square metres per hectare (m^2/ha).

Regeneration ecology and dynamics

After disturbance, newly created growing space is occupied not only by the remaining trees but also by new regeneration. We know that regeneration requires three key conditions, without which it cannot establish or grow. Sometimes described as the "regeneration triangle" (Roe et al. 1970), these three requisites are as follows:

1. a source of seed or other propagules[6]
2. a suitable seedbed for germination and growth
3. a suitable environment for germination, survival, and growth

These three factors are, of course, intimately connected to site and forest community, and they apply equally to both the species we as managers desire and those we view as competitors. The young vegetation that results from treatments during the regeneration period determines most of the future development of the trees and stands (Smith et al. 1997).

Source of seed and other propagules

The term "seed source" generally refers to seed from tree species we are interested in regenerating but should also include the regeneration propagules of competing regeneration. Seeds may be stored on site in trees (e.g., serotinous cones of lodgepole pine), in forest floors (e.g., seeds of the blueberry or cherry families), or be carried into the site from outside (e.g., windblown seed of Douglas-fir or aspen, or spores of ferns). In addition to seed, revegetation of the site can be a result of coppicing: sprouts arising from stumps (e.g., birch, cottonwood, Douglas maple); from roots (e.g., aspen, raspberry); or from rhizomes (e.g., fireweed, beaked hazel, some grasses and ferns). In many situations, a bank of seedlings is already present as advanced regeneration and can grow to occupy released growing space (Oliver and Larson 1996).

Sufficient stocking with natural regeneration is often an expected outcome of partial cutting systems, including the shelterwood, but it is important to realize that the availability of seed sources varies. For example:

- Recent widespread mortality of lodgepole pine caused by mountain pine beetle has resulted in significant declines of seed stored in once-closed serotinous cones (B.C. Ministry of Forests and Range 2007).
- The current outbreak of western spruce budworm affecting Douglas-fir in parts of southern British Columbia has meant that many stands have had a depressed seed production as the budworm consumes most of the flower buds each spring.
- It has been reported that seed predation rates following the seed cut of a uniform shelterwood varied with seasonal population fluctuations of small mammals (i.e., they peaked in late summer and were lowest in late winter but did not increase with increased seedfall rates [Von Trebra et al. 1998]). Predation can therefore likely be mitigated by scheduling harvesting to occur in years preceding high cone crop years. In periods of low seedfall, however, virtually all of the available seed can be consumed by rodents before it germinates. Burton et al. (2000) reported that small mammals consumed 77–99% of the available Douglas-fir seed over a 30-day period. Waterhouse and Newsome (2006) also found that seed viability was generally better in years with high seed production.
- Zhong and van der Kamp (1999) found that a considerable amount of the Engelmann spruce and subalpine fir seeds that fell to undisturbed, high-elevation forest floors were killed by various moulds and seed-attacking fungi both under the snow and after snowmelt.

Artificial regeneration might be used to complement natural regeneration within the shelterwood system, especially if seed source of desired species is lacking. For example, Troup (1928) suggested that underplanting might be used to introduce a new species into a suitable environment or increase the component of a particular species. Underplanting can also introduce genetically improved stock or stock from a desirable provenance (Smith et al. 1997). Underplanting may be necessary in light of climate change, where we aim to assist the migration of provenances or species better suited to the anticipated future climate.

Suitable seedbed

Burton et al. (2000) showed that germination of conifer seeds is highly sensitive to the substrate the seeds land upon. Four conifer species (Douglas-fir, hybrid white spruce, lodgepole pine, and subalpine fir) all showed the same rank order of germination and survival preference. The best germination and survival was on

[6] "Propagules" refers to any part of a plant capable of growing into a new plant, including seeds, cones, fruits, or spores that result in sexual reproduction; or rhizomes, twigs, leaves, or roots that result in asexual reproduction (Dunster and Dunster 1996).

rotting wood, followed by mineral soil, then forest floor, with moss providing the poorest seedbed. Germinant survival followed the same trend as seed germination, although the differences were less pronounced.

Conifer seeds are small, providing the new seedling with little energy to become established. As a result, the conditions of the seedbed are particularly important, especially when considering the competitive advantage of other species that may re-establish vegetatively from root sprouts or rhizomes. The emerging root must encounter moist substrate quickly to allow the cotyledons to grow and emerge from the seed. Hence a substrate such as moss that dries quickly will not provide long-lasting moisture to complete the germination process.

A surprisingly small area of receptive seedbed is required within a shelterwood; a suitable spot for a seed to land and germinate may be only 10 cm^2 (Smith et al. 1997). Day (2007) sought a target 2400 seedlings per hectare after final overstorey removals in partial cuts. There should be sufficient densities of regeneration at that time to allow for damage that will be suffered during the overstorey removal. It is even possible, using the shelterwood system, to have very high densities of germinants that could lead to stagnated thickets.

Suitable growing conditions

The key environmental factors that influence the regeneration process are moisture, heat, and light. As these factors can be moderated by retention of overstorey and soil surface materials using the shelterwood system (Smith et al. 1997), natural regeneration is often a desired outcome.

Moisture

Water is lost from the soil surface and forest floor through evaporation, which is greatly increased by direct solar radiation (Smith et al. 1997). Loose materials of the forest floor lose moisture very rapidly, while surface soil and fine decayed organic materials dry more slowly. However, direct evaporation can penetrate into the soil to a depth of several centimetres through the capillary action of soil pores, and this creates what Smith et al. (1997) term a "capillary fringe."

As water is lost rapidly from the forest floor and soil surface, plant roots must establish where moisture levels are more stable or they will perish. Shade and mulch can greatly reduce the rate of direct evaporation, increasing the window of opportunity for a new plant to penetrate this capillary fringe. In forests with hot, dry summers, it is especially important that tree germinants be protected from desiccation (Burton et al. 2000). Wood in all stages of decay, especially of large diameter, retains moisture much longer than litter and soil and provides refugia to tree roots and mycorrhizal fungi (Stevens 1997; Paul et al. 2006), contributing greatly to the successful regeneration of seedlings.

Heat (and loss of It)

Seedbed warming is necessary for conifer germination (Burton et al. 2000). However, extreme heat transfer from the soil or air to plant tissues can cause heat injury, whereas loss of heat from the plant tissues to the soil or air can cause chilling injuries (summer frost). In much of British Columbia, both extremes can happen in a single summer day.

Shading provided by a canopy is the basic premise of a shelterwood and is the most important physical process that managers can affect silviculturally (Smith et al. 1997). Tall and dense canopies provide the greatest insulation effects against growing-season frost (Steen et al. 1990) and excess heat. A sheltering canopy need not be immediately overhead, though, to modify the thermal exchange of the micro-environment, for the following reasons:

- The sun is never directly overhead in temperate latitudes. For example, at Penticton on July 21 the sun reaches its zenith at 61° (National Research Council 2009), and the zenith is lower as latitude increases northwards.
- Nighttime heat loss from the ground and vegetation is reduced in stands even with dispersed retention. For instance, in a uniform shelterwood in the British Columbia central interior, sites having from 25 to 100% of pre-harvest basal area did not experience any debilitating growing season frost events (< −4°C) over a period of 5 years while an adjacent clearcut did (Waterhouse and Newsome 2006).

Light

Light is necessary for photosynthesis, and since most of the commercial species in British Columbia have very small seeds, new seedlings must begin to photosynthesize very soon after germination to capture energy for respiration. Light regimes are strongly influenced by the proportion of direct versus diffuse light, the quality of the light, and the light's intensity (Smith 1982). Obviously, the amount of canopy above a microsite has a direct influence on the quality of the light and its intensity. Smith et al. (1997) discussed the differences between blue shade (direct light is shaded but diffuse light is received from the sky) and green shade (all light is shaded by a dense overhead canopy). Blue shade is rich in light in the photosynthetically active blue spectrum, whereas green shade is rich only in the green spectrum, which is photosynthetically useless.

Canopy gaps provide new plants with an opportunity to receive diffuse light, while still maintaining the shading from direct radiation that is so important in thermal regulation. Citing others, Smith et al. (1997) reported that photosynthetically active light levels fell from 100% in the open to 76% at the centre of a 200-m^2 gap and to 21% under a fully closed canopy. In uniform shelterwood research trials in the Cariboo-Chilcotin, regeneration experienced the greatest growth rates in stands having the lowest basal area retention levels (Waterhouse and Newsome 2006).

The light environment and adaptation strategies of tree species have strong influences on tree crown architecture, as well as trees' ability to release and grow with a desirable form after a period of shading (Oliver and Larson 1996). Species with a strong ability to maintain a single terminal bud (epinastic control; e.g., subalpine fir, interior spruce, lodgepole pine) maintain a symmetrical crown form and are able to respond to increased light with a single leader. Species with weak epinastic control (e.g., hemlock, cedar) tend to lose their terminal bud and, when released from shade, they respond with lateral branches, causing forks and crooks (Oliver and Larson 1996).

Summary

In British Columbia, silvicultural practice is heavily dominated by clearcutting with artificial regeneration. Certain forest management objectives, however, are better managed with partial cutting systems, and the shelterwood system provides some clear advantages. Greater use of partial cutting systems in general will require that we refresh our knowledge of the principles of silviculture. These principles must be applied to the unique characteristics of each site so we may better understand the manipulations we are employing to achieve our objectives. Understanding stand dynamics and the influence of the forest on the regeneration environment is necessary to achieve sufficient stocking using natural regeneration.

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Test Your Knowledge . . .

The shelterwood silvicultural system in British Columbia – A practitioner's guide.
Part 2: The interplay of stand dynamics, disturbance, and regeneration

How well can you recall some of the main messages in the preceding Extension Note?
Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. Which of the following forest management objectives have been pursued in British Columbia using the shelterwood system?
   A) Even-aged natural regeneration
   B) Timber production
   C) Development of structural heterogeneity
   D) Visual quality
   E) All of the above

2. It is important to have site-specific knowledge of "stand dynamics," or how and why forests change over time, at the planning stage of shelterwood system implementation.
   A) True
   B) False

3. Available growing space in a site
   A) Diminishes as plants grow
   B) Provides all of the growth factors a plant needs
   C) Is used more effectively by dominant trees versus subordinate trees
   D) Is used to the same degree by both dominant and subordinate trees
   E) A, B, and C
   F) A, B, and D

ANSWERS

1. E; 2. A 3. E