THINNING FOREST STANDS, EAST- AND WESTSIDE

An Inter-Active Self-Study and Reference Pamphlet

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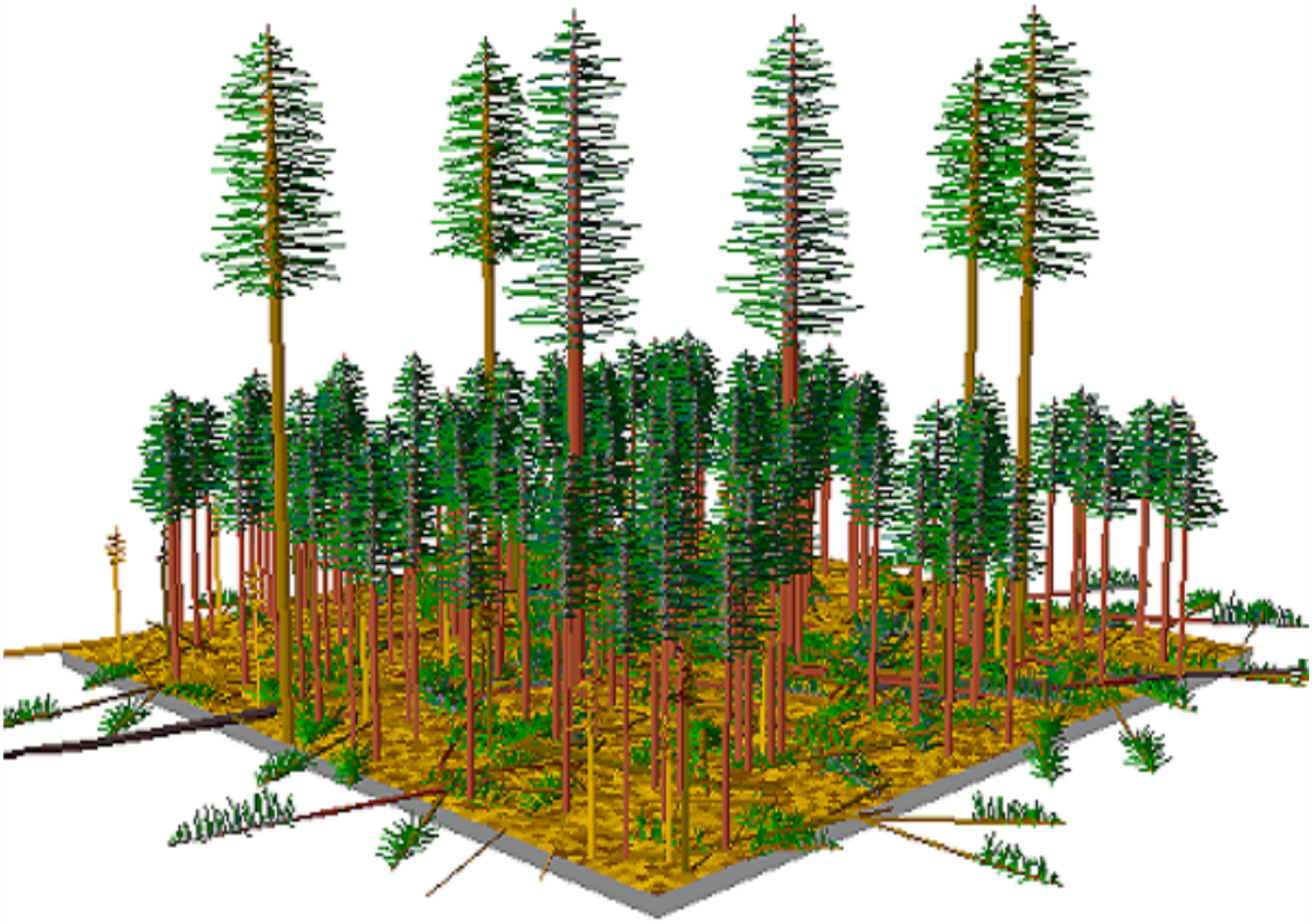

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NOTE: **DRAFT** WESTSIDE SELF-STUDY & REFERENCE MANUAL for THINNING as of 05/17/2007---Summary of current silviculture prescription training with examples, consistent with HCP, Forest Practices and DNR data technology. Expect frequent DRAFT updates, incl. changes, revisions, additions and/or cancellations.

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Notes to the Reader

- Electronic links are in blue underlined text. In Adobe format they will accesses the desired page or publication. Term definition links access the glossary for forested state trust lands.
- This pamphlet is a part of the department's training and education program

Preamble

[This HCP] allows timber harvesting and other management activities to continue while providing for species conservation [through special FMU and landscape objectives] as described in the [federal] Endangered Species Act.

Habitat Conservation Plan for Forested State Trust Lands
Introduction, p. I. 1

The Department will provide professional management of forested state trust lands through . . . [;] use [of] intensive and innovative silviculture to guide the desired progression of stand development to simultaneously produce trust revenue and create structural diversity across the landscape . . . [;] achiev[ing], on a landscape basis, a combination of forest structures that, over time, provide for broad and balanced economic, ecological, and social benefits . . . [; and] identify[ing] suitable structurally complex forest stands to be managed to help meet older forest targets.

Policy for Sustainable Forests
Implementation
Policy on General Silvicultural Strategy

State trust lands are publicly owned and managed, but they are not "public lands" in the sense that we have grown accustomed to thinking about [federal] national parks and forests. ***They are . . . managed as trusts for clearly specified beneficiaries, principally the common schools*** *[emphasis added].*

Souder, Jon A. and Sally K. Fairfax. 1998.
State Trust Lands: History, Management, and Sustainable Use (p.285).
University Press, Lawrence, KS

Thinning is an immensely useful tool to progress forest stands to an array of desired conditions. Thinning, however, cannot replicate all of the sometimes valuable seral and landscape effects of final harvests.

George McFadden, Esq.
Silviculture Scientist, Ph. D.

Intent

This is a self-study and reference pamphlet for field foresters . . .

The intent of this publication is to provide a self-study and reference pamphlet for field foresters. The pamphlet will cover scientific theory as well as techniques and field craft for thinning forested trust lands. In brief, a decision to thin and how to thin a particular stand depends on the stand's biological capability to accelerate progression toward FMU objectives. That is, a decision to thin must demonstrate improved attainment of social, economic, and/or environmental objectives.

Scientific Theory Of Thinning

Thinnings accelerate and enhance natural processes . . .

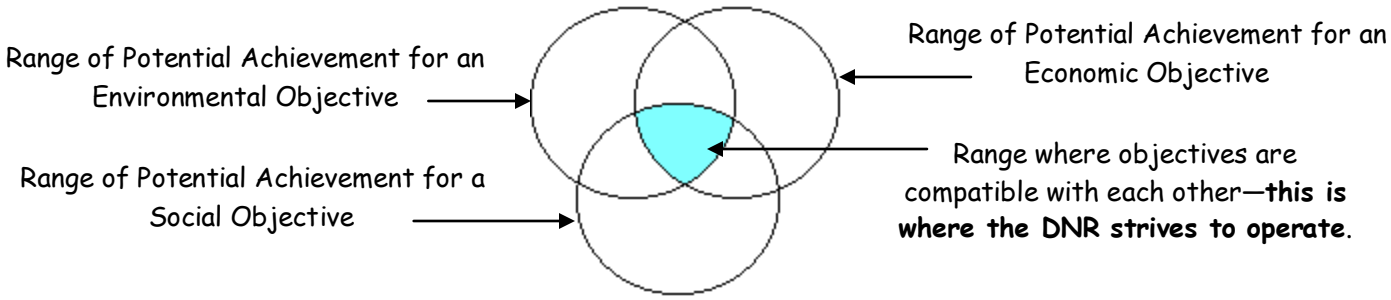
The purpose of thinning is to accelerate and enhance select natural processes. As trees grow, competition gradually increases between individual trees for light, nutrients, and moisture. In time, natural "self-thinnings" will balance the number of stems with the capability of the site to support these needs (see picture on left). How well a site supplies the needed light, nutrients, and moisture i.e., site productivity, is often expressed as height growth over time, or site index.

After several developmental stages, natural selection and stochastic events will generate multiple and diverse cohorts , particularly large snags and large down woody debris (LDWD). The result is a complex multi-aged and -sized mosaic of high commercial, social, and environmental quality (see picture on right). Objective-oriented thinnings accelerate, and sometimes enhance, these otherwise slow natural processes.

Thinning is designed to achieve social, environmental, and economic objectives . . .

Thinning is designed to achieve social, environmental, and economic rotational objectives for forest management units (FMUs) and management areas by accelerating stand development. We do this by reducing the number of trees per acre and by enhancing important structural cohorts. FMU and

landscape objectives derive from higher order plans, such as DNR's Policy for Sustainable Forests (PSF) and Habitat Conservation Plan (HCP) for forested trust lands, as well as from public input, rules, and statutes. In managing trust lands, DNR categorizes objectives as social, economic, and environmental. The DNR manages its forests so that these objective categories will at least overlap, if not complement each other. The following figure illustrates the concept:



The shaded area in the center of the figure is where social, environmental, and economic objectives are in harmony. This is where the DNR manages trust lands. Although DNR has a legal mandate to maximize financial revenues, financial gain has to be consistent with other legitimate objectives. Thus, maximizing financial gain must be consistent with also attaining other objectives.

. . . FMU objectives must be measurable . . .

In order to be achievable and verifiable, FMU objectives must be measurable. Thus, while a FMU objective consists of an action verb and an attribute (and sometimes a modifier), such as "achieve sub-mature habitat," components of the objective's attribute must be *discrete, measurable,* and *achievable* threshold targets, such as trees per acre, height, diameter, etc.

A silvicultural prescription justifies thinning . . .

Thinning a particular stand must be justified by the stand's FMU, i.e., rotational, silvicultural prescription. The silvicultural prescription describes the pathway of treatments that a stand has to undergo in order to best attain FMU objectives. The process involves modeling the stand from its present stage through alternative regimes, or pathways, for the remainder of the rotation and performing financial analysis on each regime. The best alternative will become evident when comparing how each regime, or pathway, satisfies social, environmental, and economic FMU objectives. If, after mitigating for risk, the best regime calls for thinning, then the thinning is justified against FMU objectives; if not, then thinning is not justified. This is true for all thinning, pre-commercial thinning (PCT) as well as commercial thinning (CT), at any stage of stand development, equally for eastern and western Washington. Silvicultural prescriptions are the universal tool to ensure thinnings occur only when they accomplish social, environmental, and economic objectives better than other alternatives (including no action). Thus, overstocking alone is an insufficient criterion to apply a thinning treatment.

. . . The trust mandate has four ethical tenets . . .

The DNR's Trust mandate has four ethical tenets. These are (1) The Prudent Person Doctrine, (2) Undivided Loyalty to the Trust, (3) Intergenerational Equity, and (4) Do Not Foreclose Future Options. These tenets are ethical principles to be applied judiciously.

. . . forest stands go through a series of developmental phases

Between stand initiation and an older forest state, forest stands go through a series of developmental phases. Historically, these developmental phases tend to occur unpredictably when precipitated by natural stochastic events, such as spotty blowdown, spot fires, endemic insects or disease, etc. For westside these phases are: ecosystem initiation, sapling exclusion, pole exclusion, large tree exclusion, understory development, botanically diverse, niche diversification, and fully functional; for eastside they are: stand initiation, stem exclusion, understory re-initiation, young forest, old forest (single-stratum), old forest (multi-strata). Most thinning theory deals with the competitive exclusion phases. However, later phases may also respond to thinning. For example, in eastern Washington, over-stories of ponderosa pine must have the understory thinned periodically to preserve forest health; in western Washington, it is common to see both an overstory response as well understory initiation after older stands are thinned).

Thinning has now evolved beyond simply thinning to produce larger logs and more rotational volume. We now often thin to accelerate creation of later structural phases. We may thin stands in the stem exclusion phases by creating openings, varying density, and reducing density beyond traditional levels. For more on this, see the section on variable density thinning.

In the foreground of the picture above is a plantation in the ecosystem/stand initiation phase. The next plantation beyond has achieved crown closure and there is competitive exclusion for saplings

or poles. The darker stand beyond the second plantation appears to be in the understory development/biomass accumulation stages. The stand to the front right appears (varying tree heights, species, crown cover, snags) to be in the niche diversification or fully functional stage.

Most scientific knowledge and mathematical modeling of stands has traditionally focused on the competitive exclusion stages. In these stages, forest stands consist of a single, usually even-aged canopy. Competition is evidenced by how much of the stem supports live green foliage i.e., crown ratio.

Stochastic events (wind, fire, pathogen mortality) will at some time create openings of varying sizes in the dominant canopy. If the dominant cohort is beyond in-kind replacement, an understory will develop where direct light reaches the ground; this is the understory development stage.

As trees increase in size, live and eventually dead biomass accumulates. This in turn supports a proliferation of plant, animal, fungal, and microbial species. This is the botanically diverse, or biomass accumulation, stage.

Trees eventually become very large, and so do snags. As large trees and snags fall, they create significant openings in the stand. Emerging niche mosaics become increasingly textured and complex. Over time, niches attain sufficient internal diversity, and the stand in turn attains sufficient diversity in niches, to where habitat quality culminates. This is the niche diversification stage which merges into the fully functional stage.

Thinning reduces competition . . .

Thinning is a tool that can be used to accelerate stand development and achievement of FMU objectives. The science of thinning has traditionally focused on even-aged stands in the competitive exclusion stage. Competition between trees decreases to a lower level when a stand is thinned manually as compared to if Nature were to "self thin" the stand. Vigorous trees left after thinning often approach a maximal rate of diameter growth. In contrast, growth in a self-thinned stand is, again, unpredictable. Natural competition can be so severe that it results in not only death of the weakest, but also of weakening of remaining, trees. Growth recovery occurs gradually; surviving trees are often smaller and weaker than leave trees in thinned stands and may not express the growth potential of the site. Therefore, high levels of competition may under some circumstances weaken the entire stand, and mortality can attain epidemic levels if pathogens and/or drought overwhelm already weakened stands. Thus, even dominant trees may be weakened by competition and are then less apt to respond to thinning. The level of competition between trees should therefore always be a primary criterion for whether or not to thin a stand. This is particularly true for stands in the competitive exclusion stage. It is also true, but for more complex reasons, when thinnings occur during later phases of stand development.

. . . both action and inaction have inherent risk . . .

Finally, both action and inaction have inherent risk. Here are some examples:

- On the coast, there is high risk of blowdown when thinning very dense stands of shallow-rooted species, such as western hemlock, in later competitive exclusion stages.

- Most thinnings that remove more than 40 percent of the pre-thinning RD induce additional risk of blow-down, snow-breakage, and/or wind-shear, particularly if leave tree crown ratios are less than 35 percent (root/stem structure of weak trees being inferior).

This is a stand that was thinned in the competitive exclusion stage. What potential thinning-induced risk factors do you see now, and what risks might have been incurred by not thinning?

- Thinnings, particularly on site class III and higher, that are done well prior to nearing the zone of imminent mortality (see below) may cause remaining trees to develop more and thicker branches and lower form class, thereby reducing wood quality and leading to economic loss.

- Elevated risk of annosum root rot (*Heterobasidion annosum*) is induced when western hemlock and/or Pacific silver fir stumps are cut shorter than 12 inches, and when there is bark wounds from logging at or below stump height.

- Thinnings that alter stand composition from mixed to single species induce elevated risk of epidemic insects and disease outbreaks. (Conversely, thinnings that promote mixed stands reduce the risk of pathogen epidemics.)

- Careless operations, lack of contract compliance, improper marking, and poorly designed prescriptions can have a counter-productive effect on the stand.

However, we must also recognize another set of risks incurred by the absence of thinning. Examples are:

Frequent low-intensity fires have historically created a ponderosa pine dominated, healthy seral sub-climax in eastside ponderosa pine, Douglas-fir, and grand fir series. Suppression of these fires is now seriously threatening forest health. What kind of thinning might mimic some of fire's beneficial effects in these forests? (see next page)

- pathogen epidemics brought on by stagnation—this is especially true on the eastside

- foregone critical habitat

- foregone biodiversity
- foregone revenue
- foregone scenic values.

Our globally interacting and modern society increases the number of risk factors to forests. Management that actively seeks to reduce or avoid risk is therefore a must. Consider the following: North America now has ten times the pre-Columbian human population. Expectations for material wealth are unprecedented. Societal changes have lead to global transmission of pathogens, suppression of natural rejuvenating mechanisms such as fire, and unhealthy seral conditions previously uncommon. Given these new and powerful forces acting on our environment, forest development on trust lands cannot be left to mere chance. Risks must be continually identified, suppressed, or deliberately managed for social, economic, and environmental objectives to be realized. Thinning has a vital role in shaping forests to achieve these objectives.

Traditional thinning—Thinning in the competitive exclusion stage

. . . how to measure competition . . . in western [and] . . . eastern Washington

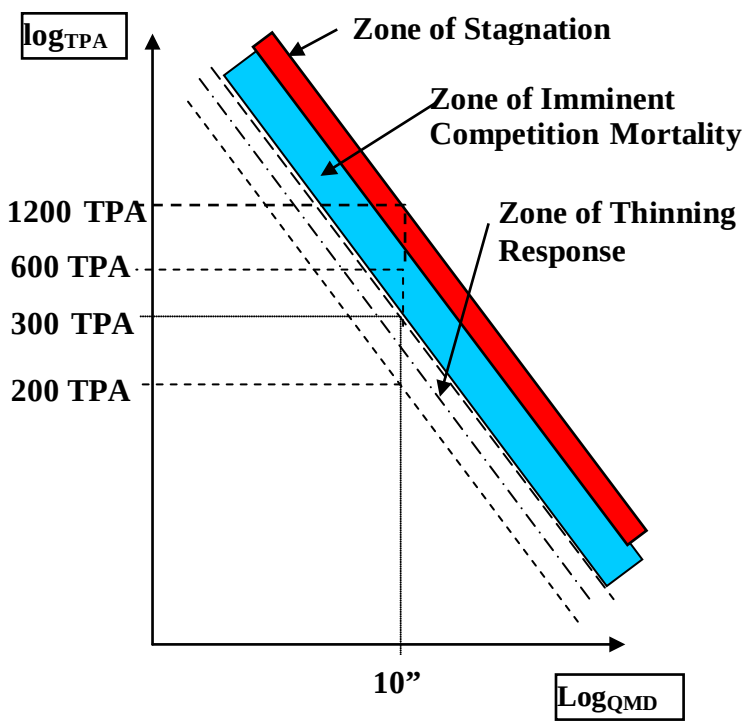
First we will discuss how to measure competition within the competitive exclusion stage. Consider that, as seedlings grow, their individual spaces will eventually, and then increasingly, overlap. Eventually, saplings begin to compete for the three resources trees must have to grow: light, nutrients, and moisture. The least available resource will govern how competition expresses itself.

In western Washington sunlight tends to be the most limited of the three resources. Trees respond by shedding lower branches to maximize top growth and out-compete each other for light.

In eastern Washington, particularly in the ponderosa pine, Douglas-fir, and parts of the grand fir series, moisture is the most limiting resource, and trees compete with root systems for moisture rather than with crowns for light. It is important to recognize that the concept of competitive exclusion applies to multi-cohort (in terms of age, size, or species) stands as well as uniform stands. Healthy culmination in these stands has historically been a fire-induced seral sub-climax maintained by frequent low-intensity fires that killed off thin-barked moisture intercepting invading species, such as grand fir and brush. The result is a single-story park-like stand consisting primarily of thick-barked, fire-resistant species in which pathogens are endemic. Man's suppression of natural fire over the last century has altered the balance to where single-needle species—grand fir and Douglas-fir—proliferate in the understory intercepting moisture previously used by the ponderosa pine overstory. This causes a weakening of vigor and previously endemic pathogens, such as *Armillarea*, become epidemic. Simultaneously, insect pests—spruce budworm in particular—have ample food of grand fir, and populations go from endemic to epidemic. (More volume can sometimes accumulate with grand fir invasions but nearly always results in forest health problems due to moisture deprivation, insect infestation, parasite—mistletoe—epidemics, root rot, or a combination.)

Therefore, for both eastern and western Washington there is a common principle regarding stand density dynamics: as trees that make up stands in the competitive exclusion phase grow and occupy more space, the number of trees per acre must eventually decrease. The graph below illustrates how several levels of competition—the diagonal lines—remain constant if trees per acre die as they grow in size, as measured by diameter at breast height (DBH). The graph below shows an example for an even-aged fictional stand in which, for an index DBH of 10 inches, a stocking of 200 trees per acre enters the zone of thinning response. At the same mean DBH of 10 inches and 300 trees per acre the stand verges on the zone of imminent competition-induced mortality. At over 600 trees per acre with the same average DBH, the stand enters a stagnation phase.

Note that the axes have logarithmic scales. Thus, lines that would be curved with arithmetic scales become straight. The concept of expressing competition through an index DBH and trees per acre was described by Reineke as stand density index (SDI). In the graph below the diagonal lines represent stocking levels for the index DBH and are referred to as SDI 200, 300, and 600, respectively. Although data collection for SDI requires fixed plots and generally a crew of two, the SDI concept illustrates competition in terms that are easy to grasp. Refer to McKenna's (2006) notes on use of Reineke SDI for more information on SDI and contributing stand parameters.



Curtis' relative density, or RD

A similar and more practical concept for expressing competition within a stand is Curtis' Relative Density (RD) (click to see the paper by Curtis, 1982). Curtis' RD, or simply RD, is the Department standard. Data gathering and statistical manipulation are quick and easy. RD is also useable for mixed and uneven-aged stands if stands are first stratified. RD can then be used for the whole stand or selected cohorts. In the formula

$$RD = SBA \div \sqrt{QMD}$$

SBA (stand basal area) is the sum of the square footage of the cross-sections of all trees at breast height for an average acre. SBA is a measure of stocking. Quadratic mean diameter (QMD or D_g) is the diameter at breast height, in inches, of the tree of average basal area. An advantage of RD is that a single person can do all sampling from the centers of variable radius plots, while SDI requires time consuming measurement of individual tree DBHs, usually with a crew of two. Click on the link to McKenna above to see how to measure and calculate these parameters.

Regressions are universal; response zones . . . are species-specific . . .

RD graphs are essentially identical to SDI graphs; the slope of SDI and RD regression lines will be the same, about –3/2. This is called "the rule of negative three halves." For RD, as for SDI, there are zones of thinning response, imminent mortality, and stagnation. Slopes of RD regressions are practically universal, regardless of species. However, competition levels associated with the zones of thinning response, imminent mortality, and stagnation are species-specific. Think of this as a representation of shade tolerance; if zones are far to the right, the species is shade tolerant.

Traditional thinning should occur as a stand verges on the zone of imminent mortality . . .

Traditional thinning should occur as a stand verges on the zone of imminent mortality. This allows natural pruning but precludes competition mortality; it imitates nature without the delay caused by waiting for natural thinning through mortality. In the thinning zone, crown ratios are generally between 30 and 40 percent. In the zone of stagnation, crown ratios are less than 30 percent. Thus:

--Westside species—traditional thinning guidelines

	Douglas-fir or Sitka spruce predominance	**Western hemlock, western redcedar, or true fir predominance**	**Mixtures**
Best thinning range:	55 ≤ RD ≤ 60	65 ≤ RD ≤ 70	Add 5 RD points to the RD of the most shade tolerant species
After thinning, there should be:	Crown Ratio ≥ 35% Height/diameter ratio < 95 SBA reduced by approximately 30 percent (no more than a 40% reduction of pre-thinning RD except when managing specific cohorts and risk has been documented as acceptable)		

--Eastside species—traditional thinning guidelines

	Ponderosa pine stands in the ponderosa pine series	**Other stands historically dominated by ponderosa pine (Douglas-fir, and some grand fir series)**	**Douglas-fir, western larch, lodgepole pine dominated stands and also wetter, more productive grand fir dominated stands**	**Western hemlock, western redcedar[1], Engelmann spruce, and sub-alpine fir dominated stands**	**Mixtures**
Estimated best thinning range:	30 ≤ RD ≤ 35	35 ≤ RD ≤ 45	50 ≤ RD ≤ 60	60 ≤ RD ≤ 70	Use RD of species favored to dominate
After thinning, there should be:	--Small openings to favor natural regeneration --Thinned patches of saplings as one of three age cohorts	--Crown Ratio ≥ 35% --SBA reduced by approx 30 percent --Opening size regulated to limit brush species			

[1] For thinning eastside western redcedar, see Appendix B—Thoughts on Thinning Eastside Western Redcedar

. . . thinning budgets . . . several options for thinning . . .

Let us now discuss thinning budgets. From a budgeting stand-point, there are several options for thinning: pre-commercial thinning (PCT), PCT with recovery rights (PCT-R)[2], and commercial thinning (CT) in young stands done with either conventional trust accounts or through the experimental thinning revolving fund (a.k.a., forest improvement thinning—FIT—fund). PCT is an unmitigated budget outlay since cut trees generate no revenue and, by being left on the ground, constitute an additional fire hazard (possibly leading to additional budget outlays). When cut trees are removed and sold to off-set cost (PCT with recovery rights), budgetary cost and fire hazard are minimized. If cut tree value exceeds logging and transportation costs—i.e., a CT—we incur both lay-out and compliance costs, but we also earn a modest income. The income earned goes either primarily to the trusts or, in the case of the experimental forest improvement thinning revolving fund, primarily to fund the thinning operation. In view of the many thinning options available, it may be best, if biologically feasible, to defer PCTs until CT or schedule final harvest without intermediate thinning.

In . . . "ecosystem based forestry" . . . we thin . . . older stands

Specifically older stands are usually thinned to create a certain habitat as well as to accelerate growth and capture volume. In so-called "ecosystem based forestry," we frequently thin older stands. So, let's first get a basic overview how older stands develop into functional habitat.

Sites with ample soil moisture: Competition and response are somewhat different in stands that are beyond competitive/stem exclusion from what we have so far discussed. Recall that trees in competitive exclusion stands compete for light and subsequently for space. In later stand development phases, however, there tends to be ample room between tree tops in the dominant and co-dominant canopy, even though lower branches may touch. As openings occur (naturally or through thinning) and sufficient light reaches the forest floor to stimulate regeneration, a second canopy will develop if the openings are sufficiently large. Carey found that changes in natural stands with structure to support fertile pairs of nesting owls generally exhibit such variations on a spatial scale of ½ to five acres. As large trees die, primary cavity nesters (e.g., wood peckers) colonize them and are in time followed by secondary cavity nesters (e.g., spotted owls, flying squirrels). Eventually snags end up on the ground as large down woody debris (LDWD) and then become foraging and hiding habitat for the prey food base (e.g., flying squirrels, voles) or denning structure for predators (lynx, bear). As niches increase in complexity, there is a corresponding proliferation in floral, faunal, fungal, and microbial diversity. These later phases of stand development are the culminate in functionality as nesting, roosting, and foraging (NRF) habitat for northern spotted owls in some areas and as denning habitat for Canada lynx in other areas.

Dry sites, primarily in eastern Washington: Competition and response are somewhat different in eastside stands that are beyond stem exclusion. Recall that trees in stem exclusion stands in

[2] The role of PCT-R is likely to dissipate if the 2007 Legislature enacts authority for DNR to maintain a thinning revolving fund (a.k.a., "forest health thinning" or "stand improvement thinning") to permit DNR to use proceeds from marginally merchantable thinnings to primarily fund such operations. This approach has been successfully tried on an experimental basis in the two eastside regions for the last two years as a special provision under the contract logging authority.

Ponderosa pine seral sub-climaxes compete for soil moisture and subsequently for below-ground space. If deprived of frequent low-intensity fires, understories of Douglas-fir and/or grand fir become established and move the stand towards ecological climax. Understory thinning or removal will serve to maintain forest health by reducing competition for soil moisture.

Absent management of any kind, stochastic events will cause stand development "pathways" through time that increase in biodiversity. Such pathways to biodiversity may take the better part of a millennium or less than a century—it all depends on frequency, severity, and nature of the events. Specifically designed thinning prescriptions could be used to simulate stochastic events. A series of such thinnings could be used to simulate the shortest possible pathway towards biodiversity by gradually fostering cohorts characteristic of the fully functional stage. Thus, biodiversity thinnings enhance more than growth of crop trees.

. . . "ecosystem based forestry" . . . thin to accelerate . . . biodiversity pathways

In traditional forestry, we were often taught that thinning had but one objective: to increase merchantable wood volume and, thereby, profits. The scope, and perhaps understanding, was limited to stands in the competitive exclusion stage. "Ecosystem based forestry" thinning objectives are social and environmental as well as economic. Of particular focus is to thin to accelerate development of biodiversity pathways in order to create habitat for critical species such as the northern spotted owl, the marbled murrelet, and riparian obligates. "Critical species" refers to species that are health indicators for their particular ecosystem. Focusing on critical species implies securing sufficient habitat not only for a particular species but for all other species, known and unknown, that depend on the ecosystem's—as we superficially observe and define it—known and unknown nuances. The Department's Habitat Conservation Plan (HCP) for forested state trust lands is intended to ensure that sufficient critical habitat for all known native species is developed and perpetuated. Since the plan is relatively recent, it stands to reason that critical habitat may be temporarily insufficient on a landscape basis. Thinning has a vital role in accelerating stand development to achieve habitat conditions as efficiently and effectively as possible. Furthermore, thinning for habitat, and accelerating development of older forest characteristics, implies thinning to mimic conditions beyond the competitive exclusion stage. In developing habitats for the northern spotted owl or lynx denning, we must hasten habitat functionality as well as tree growth.

. . . "ecosystem based forestry" . . . variable stand density to emulate natural diversity

In traditional forestry, we thin to uniform spacing, often in even-aged monocultures, to maximize wood volume and profits. Ecosystem based forestry recognizes synergistic benefits of mixing high-value shade-intolerant and tolerant species (such as red alder and western redcedar or Douglas-fir and western redcedar) and stresses variable stand density that emulates natural diversity and resilience. Thus, even though we may model and prescribe for a single average density, on the ground density should vary by 5 to 7 RD points either side of the average. (This, by the way, is not unlike what we more-often-than-not ended up with when we tried to thin to even spacing.)

As described in the HCP, A and B types of habitat for the northern spotted owl include openings, thickets, a lower canopy (shade-tolerant conifers plus hardwoods such as bigleaf or vine maple),

snags or snag candidates, large down woody debris, and variable ground vegetation with frequent openings. What this describes is a forest on the verge of the "fully functional" stage.

Habitat objectives imply that variability be introduced as early as possible . . .

Habitat objectives imply that variability be introduced as early as possible and amplified as the stand ages. For example, older cohorts are left from the previous rotation, and shade tolerant and intolerant species are mixed when planting. Early thinnings increase diversity through leave tree selection. They should also create small openings, leave small thickets, and enhance growth of dominants. Later thinnings should replenish snag and LDWD cohorts and then nurture a second canopy and niche diversification.

Niche-related features that older stand thinnings strive to secure are (1) nesting opportunities for the prey—squirrels and voles—as well as for spotted owls (cavities in snags, trees, and LDWD); (2) food for the prey (truffles growing on LDWD and seed from conifers and maples); (3) "predator traps" i.e., openings in the ground vegetation where owls can successfully observe and pounce on their prey; (4) roosts and perches (lower canopy branches, particularly of suppressed trees and hardwoods) where owls rest/sleep and observe "predator traps", respectively; and (5) hiding and thermal cover provided by the dominant canopy and thickets. For west of the Cascades, a baseline scale to consider over which variability may be imposed is on the order of $\frac{1}{2}$ ($\frac{1}{4}$ to 1) acre. Roughly 85 percent should be in two thinning densities (a spread of around 15 RD points) with the remaining 15 percent in skips and gaps. (Existence of other natural regional patterns should supersede this pattern.) This is called variable density thinning (VDT).

. . . VDT will target and manage multiple stand cohorts . . .

Unlike traditional forestry, VDT will target and manage multiple stand cohorts. Of course, in VDT we still nurture the crop, or commercial, cohort(s) (were it not for crop cohorts, funds to manage other cohorts would disappear and DNR would have disregarded its trust mandate). However, VDT also provides for the roost (under-story), legacy, snag, LDWD, predator trap, thicket, and thicket recruitment (openings) cohort niches, and replacements may be recruited out of the crop cohort. The cartoon on the next page shows various cohorts after a VDT: (1) the dominant, mainly the crop, canopy in three densities—thicket (center), lower RD (right), higher RD (left); (2) snag (center); (3) LDWD (either side of the snag in center); (4) under-/mid-story hardwoods and conifers (left and right); (5) openings (landing with temporary log deck); (6) ground vegetation with cover and "predator trap" openings (hemlock natural seedling patches and openings on forest floor); and (7) a harvested commercial cohort, here indicated by stumps and a log deck.

. . . at some point . . . the stand enters its habitat objective window . . .

As stand development progresses, present cohorts gradually transform, often developing into other cohorts. The dominant canopy mostly becomes the future commercial cohort but may also contribute to replenishing the snag cohort; the snag cohort becomes the LDWD cohort, openings become thickets, and so forth. At some point, habitat threshold targets are all achieved. When this occurs, the habitat objective—such as *dispersal*, *sub-mature*, or *high quality nesting habitat*—is

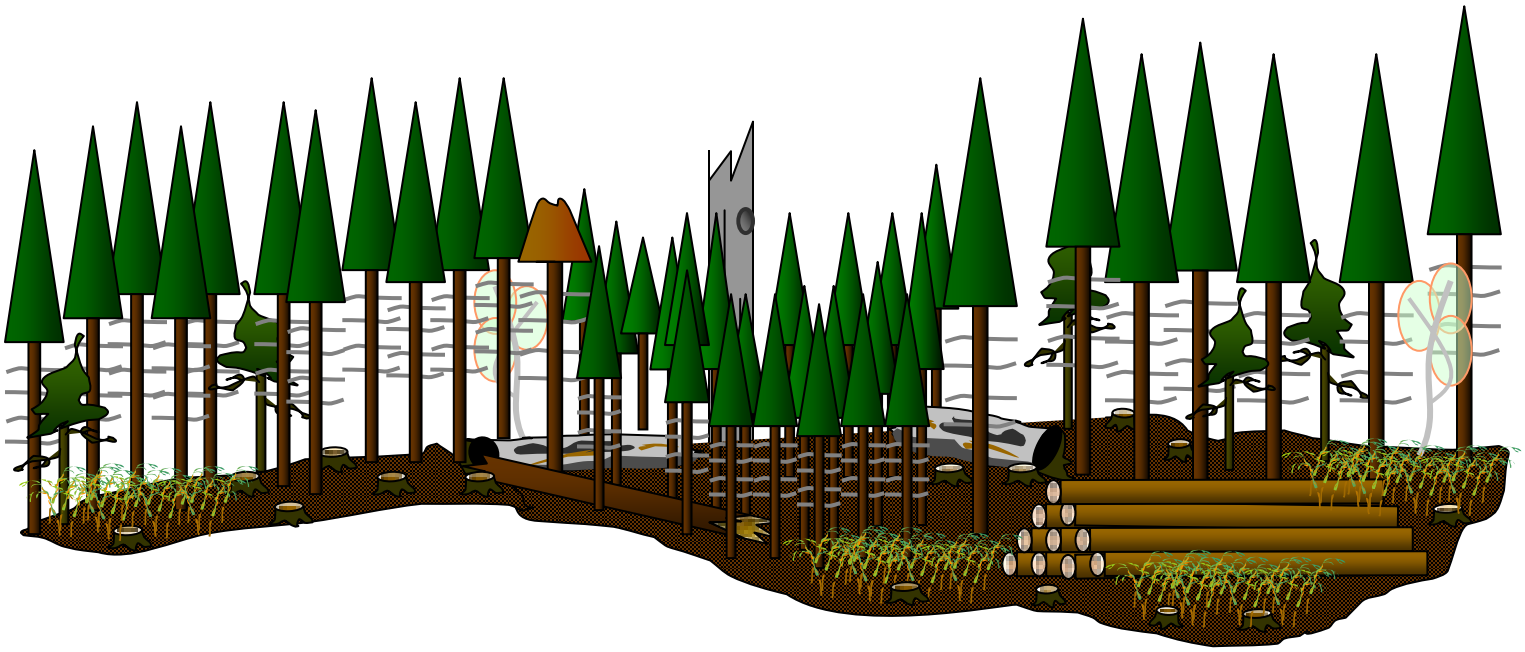
attained, and the stand enters a habitat FMU objective window. This is a pivotal occurrence in landscape management. A stand entering its habitat FMU objective window now contributes to the habitat landscape objectives and thereby frees up a corresponding acreage for harvest. Hence, forecasting this event in P & T makes availability of other stands for final harvest clearly visible to future foresters. This is how today's foresters communicate to future generations.

Techniques And Field Craft Of Thinning Decisions And Prescriptions

In discussing thinning techniques and field craft, we'll partly rely on cartoon illustrations and decision trees. We'll separate the discussion into three segments: (1) comparison of traditional thinning and VDT, (2) prioritization of candidate stands, and (3) translating silvicultural (rotational) prescriptions into activity prescriptions and activity prescriptions into marking/selection rules.

Comparison of traditional with variable density thinning (westside)

VDT has hidden economic opportunities. While variable density thinning (VDT) may seem overly complex at first, the opposite may in fact be true. Let's look at the stand in the cartoon below. You'll notice that, first of all, the "skip" around the old snag is required for safety reasons, and the opening around the landing would also be there in any kind of CT operation. You'll also notice understory trees are left; they are not felled, yarded, and piled for burning as was often the case in traditional thinnings. Furthermore, the stand to the left in the cartoon is denser than the stand to the right. Since the trees on the left are slightly smaller than the trees on the right, there is



probably a constant basal area. However, since DBHs on the left are smaller, RD is higher than on the right. Such variability could serve to minimize risk of blowdown and would most likely have occurred whether the thinning was traditional or variable density. In sum, variable density generally results even where we strive for uniformity; we simply need to adopt the scale at which

variability should exist, promote under-story development, replenish snags and LDWD, and create a few thickets and openings.

There are savings in not disposing of un-merchantable under-stories. There are also economic advantages to occasional openings—landings, decking and sorting areas, and converging skid roads—that are now essential (even though logging spurs and yarding corridors should still be at minimum width). Leaving the hard-to-reach areas and areas next to standing snags as un-thinned thickets is now mandatory according to safety regulations. However, it is crucial not to mistake a thinning that accomplishes variability only for a satisfactory VDT. Simple high grading accomplishes variability, but satisfactory VDT accomplishes variability while it also serves the trust mandate.

Arid forestry and other low site thinning (eastside)

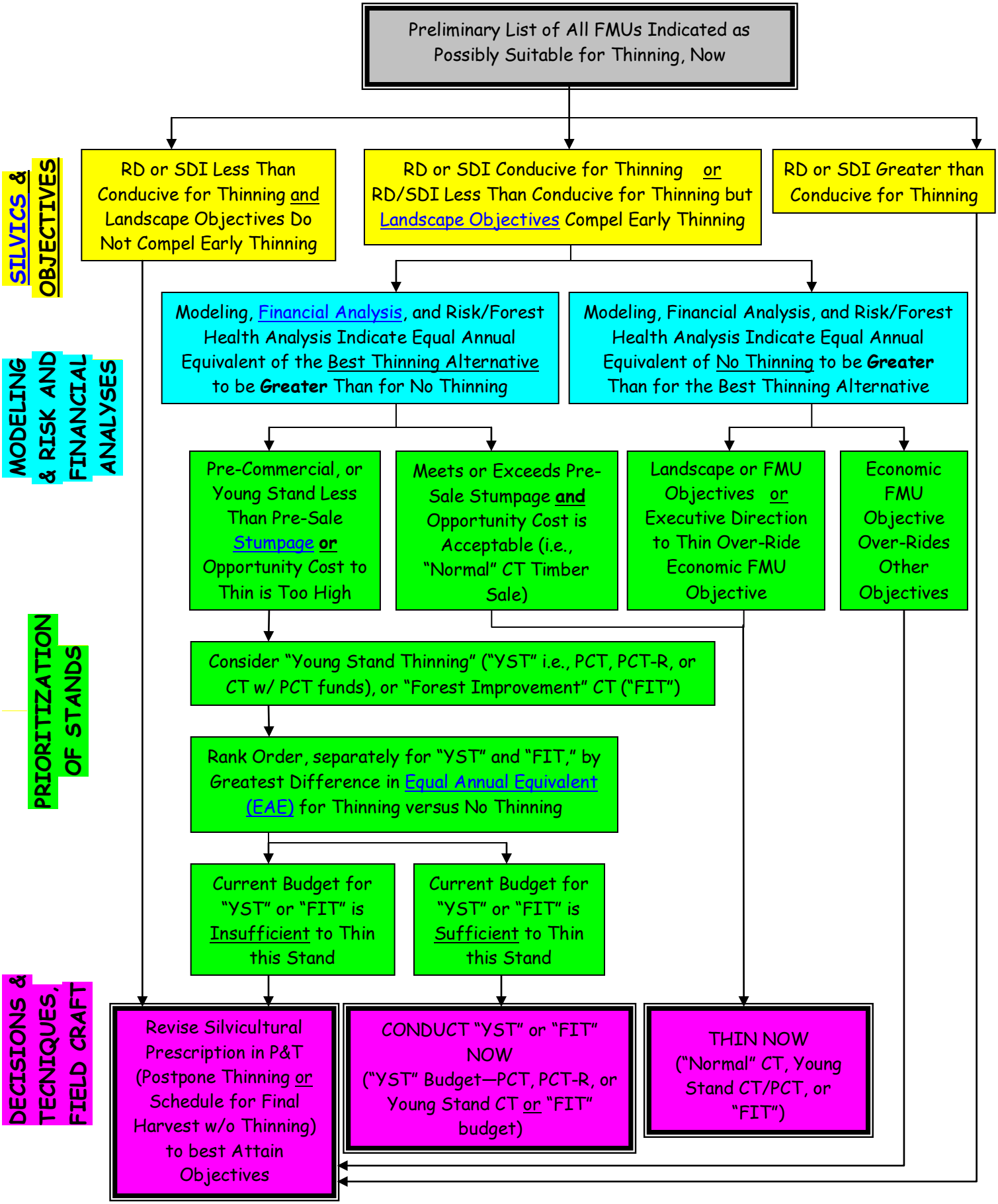
In arid forestry—where moisture availability, as well as heat and frost, are critical factors—thinning can be a concept that is more sensitive yet also a common practice. In some cases, economics and site productivity are so marginal that thinning is the only harvest activity that the site can tolerate without extensive seral regression. Notably, in the ponderosa pine series (except for better sites around Glenwood and Trout Lake), we manage for a three-aged stand. We do this by carefully thinning so that at each entry—30 or more years apart—we increase the amount of direct sunlight that reaches the ground so that after planting or natural seeding there is limited invasion of brush or other competing species and also reduced potential for frost or sun/heat damage to young seedlings. At each thinning entry, we also attempt to fell and yard in such a way that we accomplish a constructive reduction in stocking of younger trees. A driving factor is that extremely low economic returns are possible only if investment costs are practically zero.

Other types of low site thinning, such as in the subalpine fir series (the lodgepole pine sere as well the series' climax sere), perpetual thinning (as in the ponderosa pine series), runs contrary to the silvics of short-lived, shade intolerant species (lodgepole pine) and ecologically unnecessary for other conifer species that inhabit the series. On the other hand, intermediate thinning entries (when and if permissible) would considerably accelerate attainment of lynx denning habitat by promoting establishment of shade-tolerant under-stories while also sacrificing some volume for log-ricks that lynx use for denning. As in the ponderosa pine series, it is economically desirable to postpone the first thinning entry until a commercial entry is possible.

On better sites, such as in the Douglas-fir and grand fir series, it is imperative to periodically thin out shade-tolerant under-stories and favor an overstory dominated by ponderosa pine. A general guideline is that "single-needle species" should contribute no more than 35 percent of the total stand stem count (saplings and larger). Such a condition will generally ensure forest pathogens are kept at an endemic level.

Prioritization of candidate thinning stands (east- and westside)

It is important to prioritize candidate thinning stands. The decision tree, below, provides a method to do so. Prior to entering the decision tree, you should have a preliminary listing of candidate thinning stands.



NOTE: **DRAFT** WESTSIDE SELF-STUDY & REFERENCE MANUAL for THINNING as of 05/17/2007---Summary of current silviculture prescription training with examples, consistent with HCP, Forest Practices and DNR data technology. Expect frequent DRAFT updates, incl. changes, revisions, additions and/or cancellations.

Translating silvicultural prescriptions into thinning activity prescriptions and selection rules

Translating silvicultural and thinning activity prescriptions into logger selection, or marking, rules is a vital action. This action must accurately reflect the overall rotational intent to attain FMU objectives along an optimal pathway.

Thus, the first step is to review FMU, or rotational, objectives for candidate stands. Universal FMU objectives are (1) maximize financial benefit consistent with other FMU objectives; (2) comply with laws, rules, policy (as reflected in higher order plans), and agency directives; and (3) a habitat objective that is either a specific habitat for a specific species or General Ecological Management (GEM).

The first objective consists of two threshold targets. The first of these is to maximize time value of money for the rotation henceforth, expressed as Equal Annual Equivalent (EAE) for intermediate entries. The second threshold target is to maximize positive current cash flow, expressed in current dollars, and derived from stand modeling.

The second objective has one or more threshold targets for each law, rule, policy or directive to be implemented. For GEM lands, this objective is drawn from the Washington Administrative Code and covers habitat requirements.

The third – habitat – objective has threshold targets that are measurable and discrete. This objective is covered by laws, rules and regulations for gem Lands, but is separate for lands with specifically designated habitat, such as for the spotted owl.

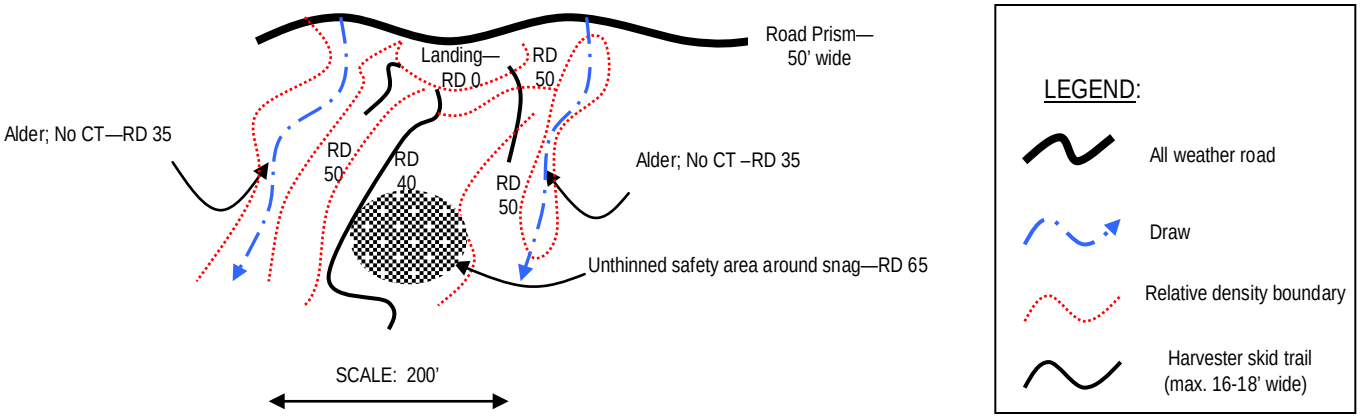
After completing this first step you are now at the first – gray – box in the decision tree on the previous page.

The next step is to determine feasibility for thinning. This often entails field visits to observe and verify stand conditions as well to take plots for modeling and financial analysis. The outcome of this analysis should be one of the following: (1) the stand has a relative density suitable for thinning, (2) the stand has yet to reach a RD suitable for thinning, or (3) the stand has degenerated past a condition suitable for thinning. This brings you through the yellow tier of the decision tree.

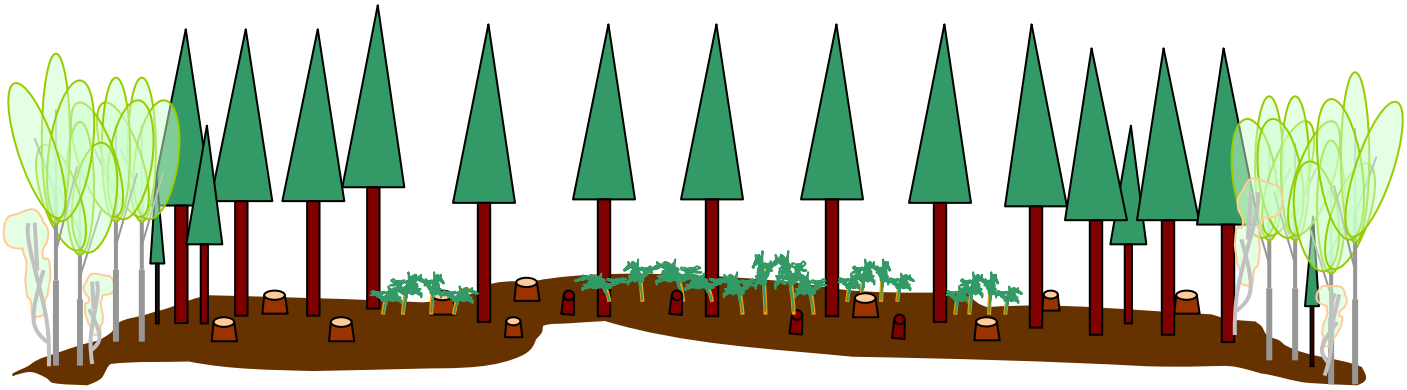
Following the decision tree through the blue (modeling and analysis) and green (prioritization) tiers, some stands will eventually receive a high priority for thinning – the two rightmost red boxes.

If you landed in the middle red box, young stand thinning only, you have a stand that is in the competitive exclusion stage. Here you are thinning to accelerate growth of the dominant canopy. In other words, you retain the largest and best trees, but you may also begin to introduce variability (species selection and RD variability, for example). To guard against risk (wind, snow) you leave an RD that is around 20 RD points less than the pre-thinning RD and generally remove no more than 40 percent of the pre-thinning RD. If you have an owl habitat objective, you should consider identifying and leaving end-of-rotation legacy trees in addition to other leave trees (included in RD calculations). You should also begin to introduce variability into the stand. In introducing RD

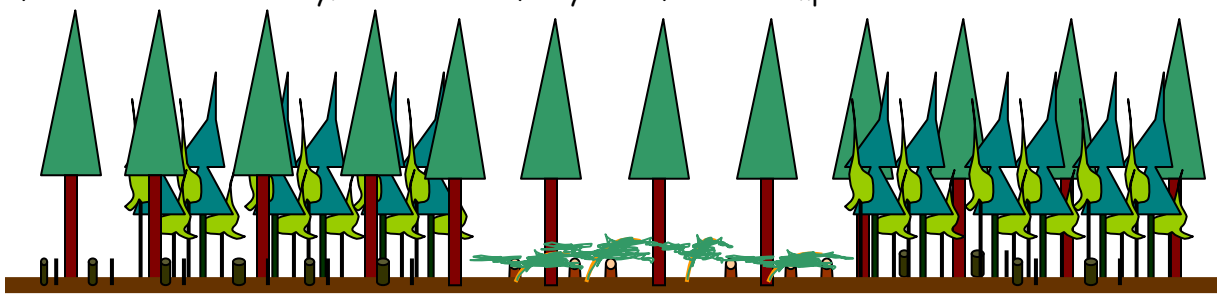
variability, follow land forms rather than an artificial pattern. Here is an example in a map view where RD variability follows side-ridges:



Taking this example as seen looking down the side-ridge it would appear as in the drawing below. A lower RD in the center of the side-ridge promotes development of a shade-tolerant understory while retaining existing species variability in the draws. After hemlock naturals—future roosts—seeded in, the stand would look like this:

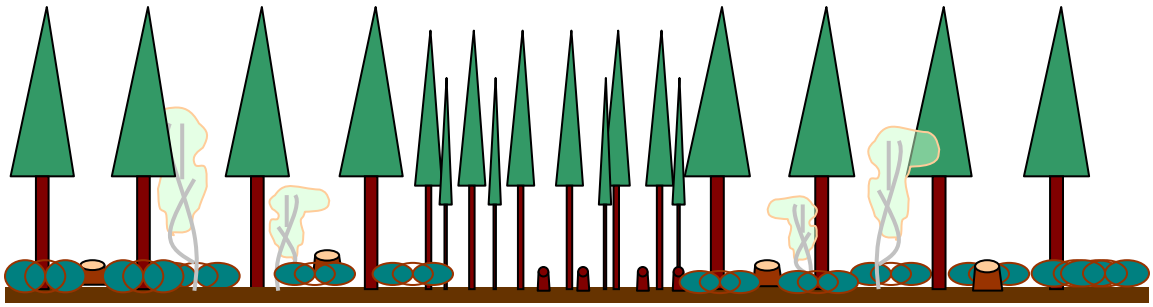


Another example, below, shows a stand with an existing shade tolerant or deciduous understory and a relatively open overstory. Here, thinning focuses on variable understory retention and minor modification to the overstory. A side-view a few years after CT completion would be:



In a third example, a stand with an inherent clumpy mix of intolerant and tolerant species, minimal understory and heavy salal ground vegetation, might best reach threshold targets by enhancing the variability already present. A technique is to mark for a single BA for the stand. However, if pre-

CT variability were short of targeted conditions, the emphasis should be shifted to prescribing a higher RD for tolerant than intolerant tree concentrations. Also, be cautious of heavy thinning; too much day-lighting may release the salal and not the leave trees. A post-CT side-view would be:



A collective message of these three examples[3] is that marking prescriptions are means to achieve activity objectives, and activity objectives are means to best achieve FMU rotational objectives. How a thinning is performed should therefore represent the best actual stand modification to put the stand on the fastest possible path towards FMU (rotational) objectives. The effect is to mimic biodiversity mechanisms in older forests.

Specific techniques and field craft for thinning northern spotted owl habitat

In habitat for the northern spotted owl, HCP requirements supersede Forest Practice Rules. Achieving maximum trust benefit must be in conjunction with attaining habitat threshold targets for stands and landscapes. The role of thinning, where allowed by the HCP, is to minimize the time it takes for stands to enter the habitat FMU objective window. Thus rotation lengths may become shorter than they might otherwise be, and this also synchronizes the highest possible timber volume and trust benefit over time with habitat imperatives. Older stand thinnings are used to further accelerate habitat quality improvement. Some techniques and field craft are:

- Apply variable density to ensure earliest possible attainment of habitat threshold targets (exclude unthinned and group selection areas from RD averages).
- Define the future commercial cohort(s), and use thinnings to maximize development towards high value product standards in this cohort.
- Define and identify which cohorts are necessary for the spotted owl. Use thinning entries to replenish them so they are sufficiently sustained until the next projected entry and can in the next rotation further hasten entering the dispersal habitat condition window.

[3] To avoid clutter, cohorts such as LDWD and snags/recruits, although vital for some habitat, are not shown in these drawings.

- Sustain or create foraging habitat, particularly LDWD and "predator traps" (small openings in the ground vegetation where roosting owls may observe and strike their prey).

- Retain snags and provide for recruitment from the largest tree class for nesting habitat (break out tops and excavate cavities as needed and practical).

- Unmanaged western hemlock and Pacific silver fir stands often fail to increase volume after CT because of blow-down and other events whose risk of occurrence was elevated by thinning. Therefore, these stands should be thinned only when risks are identified and sufficiently mitigated.

- *Thin from the middle* i.e., retain selected dominants / co-dominants (owl hiding and thermal cover), a component of mid / understory trees (roosting habitat), present and future snags (nesting habitat), and large down woody debris (LDWD) / recruits (prey base feeding habitat and "predator traps). The mid / understory will consist of deciduous tree species (two to three single stemmed bigleaf maple per acre, vine maple or alder) and / or shade tolerant suppressed or intermediate conifers.

- Spacing between leave tree crowns determines whether or not winds will get in between leave trees and cause blow-down or just sweep over the tops of them. The outer perimeter, or "dripline," of adjacent crowns should be used to estimate spacing. With some on-site experimentation, one can relate a desired dripline spacing to a targeted post-thinning stand basal area. Once you know the targeted post-thinning SBA, you can easily check you crew's or a logger's marking with a few variable radius plots.

- In the absence of forest land planning derived rotation lengths, it is feasible to use rotation lengths suggested in prescription pamphlets in performing financial analysis of regimes as candidate silvicultural prescriptions.

Specific techniques and field craft for thinning General Ecological Management (GEM) lands

Many westside GEM lands may forego thinning, specific habitat not being an objective. Beyond forest practices habitat rules, primary considerations on GEM lands are to benefit the trusts i.e., merchantable volume and value. The most common role for thinning on these GEM lands is to adjust early stocking, maintain forest health and, if needed, to delay final harvest for selected stands for landscape management and even flow reasons. Thinning activity prescriptions and marking rules must therefore maximize value of merchantable volume by ensuring site occupancy with high-value trees at rotation's end. Some techniques and field craft are:

- Thinnings are treatments from which modest intermediate income is possible that are intended to maximize value of merchantable volume at rotation's end, and thinnings must not be over-done to increase current versus future benefit.

- Avoid opening the canopy to an extent that releases or generates unwanted understory or ground vegetation or, if this is not possible, deal with the brush problem in the silvicultural prescription.

- Avoid opening the canopy in a way that is likely to cause heavy blow- or snow-down over the vulnerable post-thinning period—usually around a decade.

- Use trees designated to be harvested as "bumper trees" along skid/skyline roads to minimize damage to leave trees. Fell and yard bumper trees last for each road. Residual damage to more than 5 percent of crop trees per acre is unacceptable.

- Consider the economic benefits of not felling and yarding sub-merchantable understory trees as well as the forest health benefits from the resulting stand diversity. Note that this is not true for the eastern Washington grand fir series in which forest health considerations mandate ensuring a minimal grand fir component.

- Lower site quality stands should not be routinely CTed unless there is a demonstrable economic advantage and risk of prescription failure is duly mitigated. Extended response times of low sites increase the risk of prescription failure through extended blowdown susceptibility, longer duration of post-treatment shock, and less stand vigor to combat pathogen introduction.

- If the stand is generally pure western hemlock or true fir, notably overstocked, and low crown ratios (often older than 40 yrs), do not thin. Generally, such stands have poorly anchored root systems and are highly prone to blowdown.

- When CTing western hemlock or true fir dominated stands, keep dripline spacing ≤ 3'.

- Yard uphill as a rule. Skyline yarding with drop line carriage or yarding by shovel—or other long-reach (35 feet), low impact ground-based equipment—is preferred over highlead or tractor systems. Pre-yard to designated skyline corridors /yarding roads to limit leave tree and soil damage. Except when deliberately creating openings, corridors/roads should be less than 18 feet wide and around 70 feet or more apart and preferably parallel (no "wagon wheels") to minimize soil compaction and confine it within less than average leave tree spacing. Hard-to-reach areas between skid trails should favor high densities, and vice versa.

- Consider avoiding operations in the spring when the sap is flowing and tree bark is loose—significant risk of enduring damage to leave trees.

- Evaluate whether thinning will enhance or stifle root rot of various kinds—*Armillaria* can accelerate after thinning; *Heterobasidium* (annosum root rot) can be stifled if using non-susceptible species for leave trees and stumps for susceptible species are one foot or higher; *Phellinus* can be stifled if using non-susceptible species as leave trees.

APPENDIX A—Integrated Pest Management

Integrated pest management (IPM) is managing forest stands to prevent or combat epidemic insect and disease outbreaks by using the situationally best manual, chemical, or biological means. This section will list insects and diseases common to commercial tree species in Washington and measures that have proven useful to combat each. The Pacific Northwest's most authoritative website for forest insect and disease pests is the USDA-Forest Service, Region 6, Forest Insect and Disease office at http://www.fs.fed.us/r6/nr/fid/wid.shtml. Alternatively, the Canadian Forest Service website, for diseases only, is http://www.pfc.cfs.nrcan.gc.ca/diseases/CTD/index_e.html. Additional, or more direct, links are listed after each section.

Needlecasts in Douglas-fir. Douglas-fir is susceptible to **Swiss needlecast** as well as other needlecasts such as ***Rhabdocline***. Needlecasts cause pre-mature shedding of all but the current year's foliage and gives the tree a distinctly thin-crowned, grayish, and often chlorotic appearance. Although not a direct killing agent, needlecasts often reduce annual growth by as much as 35 percent and also increase susceptibility to other pathogens such as root rots. Susceptibility and risk are mitigated by inclusion of western hemlock, western redcedar, various true firs, and/or red alder. For further information, see: http://www.cof.orst.edu/cof/pub/home/rc/RC30.pdf, http://www.fs.fed.us/r6/nr/fid/mgmtnote/swissnc.pdf, and http://www.fs.fed.us/r6/nr/fid/mgmtnote/rhabdo.pdf.

Root Rots in Douglas-fir. Douglas-fir is highly vulnerable to *Phellinus (Poria) weirii*, **laminated root rot**. It lingers in a viable, infectious form in old root systems for more than 80 years following clearcutting. Phellinus may be recognized as having stand infection centers with fallen Douglas-fir without root wads; as one moves outward from the infection center, symptoms gradually subside. *Phellinus* is financially infeasible to eradicate and is best treated by clearcutting at least one tree length beyond outermost visible trace symptoms (chlorosis or thinning crowns) and reforesting with red alder (immune) or western redcedar (highly resistant) for west of the Cascades and with ponderosa pine, lodgepole pine, western white pine, Engelmann spruce, and/or western redcedar for east of the Cascades. For further information, see: http://www.fs.fed.us/r6/nr/fid/fidls/fidl159.htm.

Other Rots in Conifers. Douglas-fir, western and mountain hemlock, pines, and true firs are susceptible to **red ring rot** (aka **honeycomb rot, white pocket rot, or white pitted rot),** caused by the fungus *Phellinus (Fomes) pini*. It is the most common stem decay of conifers in the Pacific Northwest. The perennial conks are distinctly "hoof-shaped" to bracket-like, often emerging from knots or branch stubs. The upper surfaces of conks are rough, dull gray to brownish black with concentric furrows paralleling the lighter colored margin. The lower surface is a rich brown color with small circular pores. This disease spreads by wind-carried spores that germinate on wounds and branch stubs. Prevention includes establishment of stands that include intermingled significant components of western redcedar and red alder and not scarring leave trees in harvest. Anecdotal references to leaving branch stubs long enough to compartmentalize the pathogen in the stub and managing for tree vigor also exist. Reactive management involves salvaging infected trees before excessive merchantability is lost (increasing amounts of decay within the tree is indicated by more

and larger conks). For further information see:
http://www.pfc.forestry.ca/diseases/CTD/Group/Heart/heart13_e.html,
http://www.fs.fed.us/r6/nr/fid/mgmtnote/redring.pdf, and
http://www.fs.fed.us/r6/rogue/swofidsc/stemdecay/redringrot.html.

Bear Damage. Douglas-fir and western redcedar are susceptible to **bear damage**, particularly in the free-to-grow to sub-merchantable age bracket. Damage usually occurs in the spring when Douglas-fir sap is an attractive food source. The best prevention is species diversity; bears often develop a taste for Douglas-fir sap when plentiful and easy to get. In cases where FMU objectives dictate Douglas-fir as a final crop but shade tolerant species are ecologically adapted, consider that full stocking at age 60 is only 100 to 150 trees per acre for Douglas-fir. An initial site-adapted species mixture of 150 Douglas-fir and 250 western hemlock per acre allows targeted stocking with Douglas-fir at final harvest and the preponderance of western hemlock will make the FMU less apt to attract bears than a FMU with pure Douglas-fir or western redcedar. In addition, the Washington department of Fish and Wildlife has as standard operating procedure to cooperate with land owners to reduce bear damage. To that end, local agents may cooperate with department foresters in allowing specific bears to be taken under so-called depredation permits.

Tip Weevil. Sitka spruce is susceptible to the **white pine weevil** (previously known as the **Sitka spruce weevil**). The insect lays its eggs on the terminal shoot. Larvae mine the phloem and girdle the leader, causing it to die and curl. Damaged trees are often overtopped and suppressed by other species. Surviving spruce may be crooked, bushy or low value. These weevils require relatively high temperatures to thrive. Areas immediately adjacent to the coast are lower hazard due to cool, misty climate. However, even in areas of lower risk for weevils one can expect a phase in which trees are attacked but later recover. On warmer sites, attacks commonly begin five years after planting, when leaders become large enough to attract weevils. Often, damaged trees develop multiple tops, which may be re-attacked annually. Weevil populations and attack rates stabilize when average plantation heights are between 6 and 30 feet and then begin to decline when tree height exceeds 30 feet. Severe infestations have an average of 30 percent or more attacked leaders per year. The spruce weevil is not a problem in older stands.

FMUs spaced at low densities at an early age are at increased risk from weevil attack, because more vigorously growing trees produce longer, thicker leaders, which in turn provide better nutrition for the weevil. While high levels of weevil attack are also observed in high density FMUs, the resulting defect is generally less severe due to the reduced branching in tightly spaced trees. For further information, see:
http://www.fs.fed.us/r6/nr/fid/widweb/wid-twig.shtml#twig-4,
http://www.pfc.cfs.nrcan.gc.ca/diseases/hforest/Pests/spweevil_e.html, and
http://www.forestry.ubc.ca/fetch21/FRST308/lab4/pissodes_strobi/sitka.html.

Spruce Aphid. Sitka spruce is periodically defoliated by the **spruce aphid**, *Elatobium abietina*, believed to have been introduced from Europe. The spruce aphid causes premature loss of older foliage. Repeated years of defoliation can cause growth loss, branch die-back, and tree death. Usually buds are unaffected, so new growth flushes normally. Although aphids are present year round, mild winter temperatures can allow dramatic population increases in February and March. In

May and June, damaged needles turn completely brown and drop off the tree. Insecticides are used to control spruce aphids on ornamental trees and Christmas trees, but not forest trees. Avoid fertilizing spruce, since the increased nitrogen content in foliage may result in greater aphid fecundity. For further information, see:
http://www.for.gov.bc.ca/hfp/forsite/pest_field_guide/Green_spruce_aphid.htm,
http://www.forestry.ubc.ca/fetch21/FRST308/lab5/elatobium_abietinum/aphid.html, and
http://www.fs.fed.us/r6/nr/fid/widweb/wid-suck.shtml#suck-5.

Balsam Wooly Adelgid. True fir (*Abies*) species are affected by the exotic aphid-like insect **balsam woolly adelgid** (BWA), *Adelges piceae*. Sub-alpine fir, Pacific silver fir, and grand fir are frequently attacked throughout their natural ranges. BWA infestations can develop in off-site plantings of noble fir, but little damage has been observed in its native range. Infected grand fir have suffered few direct effects from BWA, but greater than expected damage from the combined effects of BWA and drought, in the Puget Sound region, and western spruce budworm, east of the Cascades. Although it has been present in Washington for several decades, and initially caused mortality on thousands of acres, BWA has not yet fully colonized all susceptible sites nor fully exhausted the resistance of partially susceptible trees. More damage is expected. Harvest true fir infested with BWA and plant non-host trees appropriate for the site. Discriminate against infested fir when thinning mixed stands. True fir cone collections should be restricted to trees with no symptoms of BWA infestation. For further information, see:
http://www.pfc.cfs.nrcan.gc.ca/diseases/hforest/Pests/bwaphid_e.html,
http://www.forestry.ubc.ca/fetch21/FRST308/lab4/adelges_piceae/balsam.html , and
http://www.fs.fed.us/r6/nr/fid/widweb/wid-suck.shtml#suck-5.

Annosus Root Rot. Western hemlock, and to lesser extents, other conifer white-woods, are susceptible to *Heterobasidion (Fomes) annosum*, also known as **annosus root rot**. Annosus root rot produces a dark brown conk and brown-heart rot. It spreads through both spores and root grafts. Spore propagation prefers live bare wood i.e., fresh stump surfaces or logging damage to stem bark, to germinate. Serious, stand-level damage from annosus root rot occurs when the rot has migrated from the stem or stump of original infection through the roots to where they graft with roots of live trees. However, Annosus is slow growing, and shorter rotations (limited to culmination of periodic or mean annual increment) and subsequent stands dominated by red alder, Douglas-fir, or western redcedar would serve to diminish future infections. For further information, see:
http://www.pfc.cfs.nrcan.gc.ca/diseases/CTD/Group/Root/root3_e.html,
http://www.pfc.cfs.nrcan.gc.ca/pathology/rootd/annosus_e.html, and
http://www.fs.fed.us/r6/nr/fid/widweb/wid-rd.shtml#rd-1.

Dwarf Mistletoe. Western hemlock, Rocky Mountain Douglas-fir, ponderosa pine, lodgepole pine, and western larch are all susceptible to species-specific strains of **dwarf mistletoe**, a parasitic plant (*Arceuthobium spp.*) that adheres to branches and stems. Mistletoe seeds are sticky and are forcibly discharged as far as 60 feet in the fall. Spread is most rapid in multi-storied stands; spread in single storied stands is slower. Severe infestations cause growth loss, reductions in wood quality, mortality and, in western hemlock, exceptional nesting platforms for the marbled murrelet. For further information, see: http://www.fs.fed.us/r6/nr/fid/widweb/wid-mt.shtml#mist-1.

Hemlock Looper. Western hemlock is susceptible to epidemics of the **hemlock looper,** *Lambdina fiscellaria lugubrosa*, a defoliating caterpillar. Recent outbreaks have occurred only in Northwest region, but could conceivably occur in any westside locale. Hemlock looper outbreaks historically have occurred in overmature hemlock stands, but recently have occurred in 60 year old second growth. Outbreaks generally last three years, and can kill vast acres of stands dominated by western hemlock. Strong epidemics of hemlock looper and the associated insect phantom hemlock looper *Nepytia phantasmaria* (whose main hosts include Douglas-fir and western hemlock) often kill other incidental conifers as well. Recent anecdotal observations indicate that stands whose vigor has been enhanced by thinning are relatively resistant to surrounding epidemics. Diversity and high tree vigor at both FMU and landscape levels are useful in moderating outbreaks to within acceptable levels. For further information, see: http://www.fs.fed.us/r6/nr/fid/widweb/wid-def.shtml#def-16, http://www.pfc.cfs.nrcan.gc.ca/diseases/hforest/Pests/whlooper_e.html, and http://www.forestry.ubc.ca/fetch21/FRST308/lab5/lambdina_fiscellaria_lugubrosa/looper.html for the hemlock looper and http://www.pfc.forestry.ca/entomology/defoliators/loopers/phantom_e.html for the phantom hemlock looper.

White Pine Blister Rust. Western white pine is susceptible to a **blister rust** caused by the fungus *Cronartium ribicola.* This is the most serious pest of 5-needle pines in the Pacific Northwest. Alternate hosts include members of the genus *Ribes*. Diseased trees are identified by yellow/red needle spots; spindle shaped swellings on branches; dead patches along stem with greenish-yellow to orange margins; flagging of branches and tree tops. Reforest with resistant 5-needle planting stock; retain uninfected or lightly infected trees for seed sources. Bundle pruning contracts with bough sales to expeditiously eliminate the most susceptible lower branches. For further information, see: http://www.fs.fed.us/r6/nr/fid/widweb/wid-rust.shtml#rust-8, http://www.fs.fed.us/r6/nr/fid/mgmtnote/wpbr.pdf, http://www.na.fs.fed.us/spfo/pubs/howtos/ht_wpblister/toc.htm, and http://www.pfc.cfs.nrcan.gc.ca/diseases/CTD/Group/Rust/rust7_e.html

APPENDIX B—Thoughts on Thinning Eastside Western Redcedar

By Hollis W. (Bill) Barber
Eastside Silviculture Scientist

The following notes are synthesized from various published studies dealing with release and management of western redcedar.

Authors agree that western redcedar should be released slowly, e.g. three light thinnings over a period of 15-20 years. Trees thinned all at once to final harvest density commonly seem to respond well for about five years, only to succumb to root disease; *Armillaria ostoye* is often the cause.

In one study, release and survival seemed best on *Thpl/Clun* and *Thpl/Arnu* plant associations (and possibly other western redcedar associations). Western hemlock plant associations are not good candidates for releasing western redcedar advance reproduction — western hemlock often reinvades and outgrows western redcedar.

Pure stands. More or less pure stands of western redcedar should be PCTed between ages 10 and 30 years. Only dominant and codominant trees should be retained. Bigger trees release better, i.e. bigger crowns, better vigor. Suppressed and intermediate trees often have lost their apical dominance and tend toward multiple tops, even if they survive release. Spacing to 10 feet by 10 feet is appropriate for such young stands. This is fairly tight, but should minimize retention of lower branches, which may be related to butt swell and fluting. Height growth of residual western redcedar is likely to be slow. In one study, western redcedar released best on north aspects.

Mixed stands. Slow height- and volume-growth are often the result of growing western redcedar in mixed stands, where other trees suppress it. If suppression is avoided by growing in pure, even-aged stands, its growth is more acceptable. Relatively tight spacing helps ensure that lower branches die off, thus minimizing the growth of the bole below them and reducing butt swell. This should also help minimize fluting since " . . . each limb 'feeds' the cambium immediately beneath it" (a function of the straight grain of western redcedar). Finally, stand conditions that encourage death of lower branches minimize knot size, and promote growth of clear wood.

Many observers have noted that even-aged management of western redcedar *sawtimber* can be difficult in mixed stands. Even-aged management tends either to harvest a stand too early for good western redcedar sawtimber, or to harvest too late for optimum production of the other conifers. However, western redcedar poles can be satisfactorily grown and harvested with mixed conifers, and this may be the best bet. The point is that thinning decisions must be made with full awareness of the impact of thinning on the final product.

APPENDIX C – Relative Density and Quadratic Mean Diameter

Relationship of Basal Area & Trees/acre or Spacing to Relative Density

Tree/acre & Spacing

Basal Area	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450
	42x42	30x30	24x24	21x21	19x19	17x17	16x16	15x15	14x14	13x13	13x13	12x12	12x12	11x11	11x11	10x10	10x10	10x10
40	10	11	13	14	14	15	16	16	17	17	18	18	18	19	19	19	20	20
60	13	16	17	19	20	21	21	22	23	23	24	24	25	25	26	26	27	27
80	16	19	21	23	24	25	26	27	28	29	30	30	31	31	32	33	33	33
100	19	23	25	27	29	30	31	32	33	34	35	36	36	37	38	38	39	40
120	22	26	29	31	33	34	36	37	38	39	40	41	42	43	43	44	45	45
140	25	29	33	35	37	39	40	42	43	44	45	46	47	48	49	49	50	51
160	27	33	36	39	41	43	44	46	47	49	50	51	52	53	54	55	56	56
180	30	36	39	42	45	47	49	50	52	53	54	56	57	58	59	60	61	62
200	32	38	43	46	48	51	53	54	56	57	59	60	61	63	64	65	66	67
220	35	41	46	49	52	54	56	58	60	62	63	64	66	67	68	69	70	71
240	37	44	49	52	55	58	60	62	64	66	67	69	70	72	73	74	75	76
260	39	47	52	56	59	62	64	66	68	70	72	73	75	76	77	79	80	81
280	42	49	55	59	62	65	68	70	72	74	76	77	79	80	82	83	84	86
300	44	52	58	62	66	69	71	74	76	78	80	82	83	85	86	88	89	90
320	46	55	61	65	69	72	75	77	80	82	84	86	87	89	90	92	93	95
340	48	57	63	68	72	75	78	81	83	86	88	90	91	93	95	96	98	99
360	50	60	66	71	75	79	82	84	87	89	91	93	95	97	99	100	102	103
380	52	62	69	74	78	82	85	88	91	93	95	97	99	101	103	105	106	108
400	54	65	72	77	81	85	88	91	94	97	99	101	103	105	107	109	110	112

Relationship of Basal Area & Trees/acre or Spacing to Quadratic Mean Diameter (Dq)

Tree/acre & Spacing

Basal Area	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450
	42x42	30x30	24x24	21x21	19x19	17x17	16x16	15x15	14x14	13x13	13x13	12x12	12x12	11x11	11x11	10x10	10x10	10x10
40	17.1	12.1	9.9	8.6	7.7	7.0	6.5	6.1	5.7	5.4	5.2	4.9	4.8	4.6	4.4	4.3	4.2	4.0
60	21.0	14.8	12.1	10.5	9.4	8.6	7.9	7.4	7.0	6.6	6.3	6.1	5.8	5.6	5.4	5.2	5.1	4.9
80	24.2	17.1	14.0	12.1	10.8	9.9	9.2	8.6	8.1	7.7	7.3	7.0	6.7	6.5	6.3	6.1	5.9	5.7
100	27.1	19.1	15.6	13.5	12.1	11.1	10.2	9.6	9.0	8.6	8.2	7.8	7.5	7.2	7.0	6.8	6.6	6.4
120	29.7	21.0	17.1	14.8	13.3	12.1	11.2	10.5	9.9	9.4	8.9	8.6	8.2	7.9	7.7	7.4	7.2	7.0
140	32.0	22.7	18.5	16.0	14.3	13.1	12.1	11.3	10.7	10.1	9.7	9.3	8.9	8.6	8.3	8.0	7.8	7.6
160	34.3	24.2	19.8	17.1	15.3	14.0	12.9	12.1	11.4	10.8	10.3	9.9	9.5	9.2	8.8	8.6	8.3	8.1
180	36.3	25.7	21.0	18.2	16.2	14.8	13.7	12.8	12.1	11.5	11.0	10.5	10.1	9.7	9.4	9.1	8.8	8.6
200	38.3	27.1	22.1	19.1	17.1	15.6	14.5	13.5	12.8	12.1	11.5	11.1	10.6	10.2	9.9	9.6	9.3	9.0
220	40.2	28.4	23.2	20.1	18.0	16.4	15.2	14.2	13.4	12.7	12.1	11.6	11.1	10.7	10.4	10.0	9.7	9.5
240	42.0	29.7	24.2	21.0	18.8	17.1	15.9	14.8	14.0	13.3	12.6	12.1	11.6	11.2	10.8	10.5	10.2	9.9
260	43.7	30.9	25.2	21.8	19.5	17.8	16.5	15.4	14.6	13.8	13.2	12.6	12.1	11.7	11.3	10.9	10.6	10.3
280	45.3	32.0	26.2	22.7	20.3	18.5	17.1	16.0	15.1	14.3	13.7	13.1	12.6	12.1	11.7	11.3	11.0	10.7
300	46.9	33.2	27.1	23.5	21.0	19.1	17.7	16.6	15.6	14.8	14.1	13.5	13.0	12.5	12.1	11.7	11.4	11.1
320	48.4	34.3	28.0	24.2	21.7	19.8	18.3	17.1	16.1	15.3	14.6	14.0	13.4	12.9	12.5	12.1	11.7	11.4
340	49.9	35.3	28.8	25.0	22.3	20.4	18.9	17.7	16.6	15.8	15.1	14.4	13.8	13.3	12.9	12.5	12.1	11.8
360	51.4	36.3	29.7	25.7	23.0	21.0	19.4	18.2	17.1	16.2	15.5	14.8	14.3	13.7	13.3	12.8	12.5	12.1
380	52.8	37.3	30.5	26.4	23.6	21.6	20.0	18.7	17.6	16.7	15.9	15.2	14.6	14.1	13.6	13.2	12.8	12.4
400	54.2	38.3	31.3	27.1	24.2	22.1	20.5	19.1	18.1	17.1	16.3	15.6	15.0	14.5	14.0	13.5	13.1	12.8

APPENDIX D – Site Index Tables--Westside

DOUGLAS FIR
50-YEAR SITE INDEX TABLE

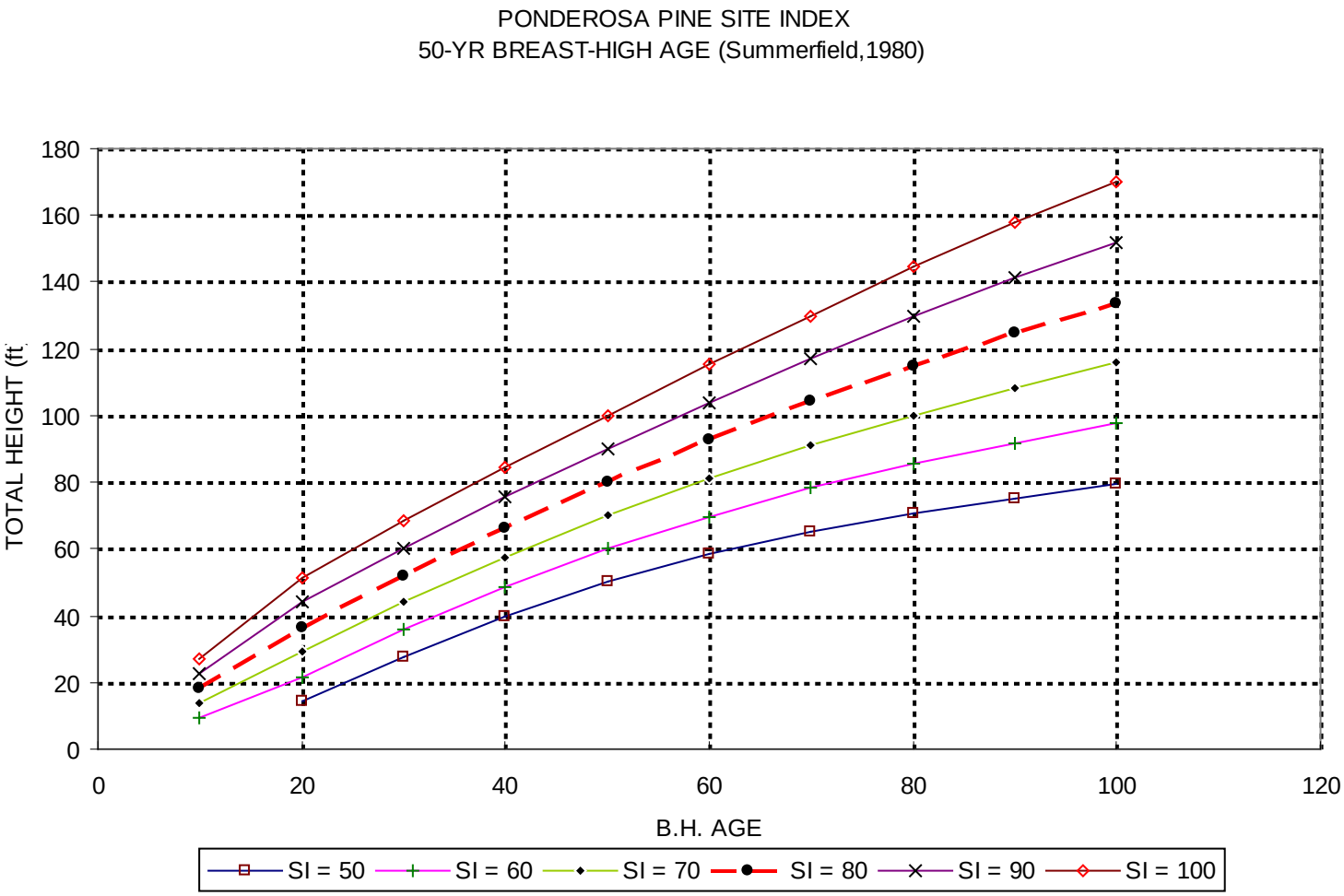
State of Washington — Department of Natural Resources

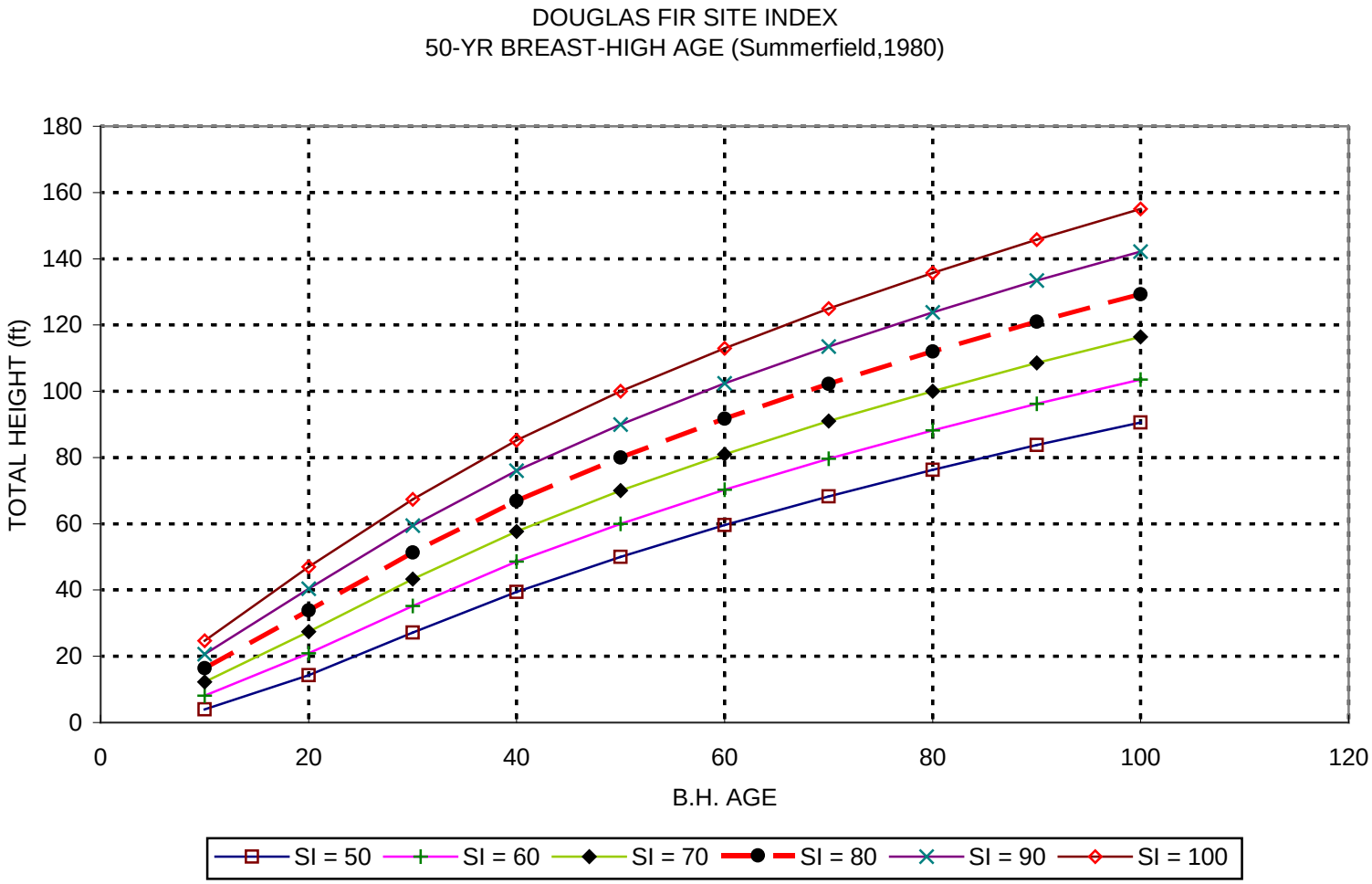
Application: Western Washington

Source: James King

Breast Height Age	Site Index (top)/Site Class (bottom)									
	60	70	80	90	100	110	120	130	140	150
	V		IV		III		II		I	
6	10.7	11.8	12.9	14.1	15.2	16.5	17.8	19.1	20.5	21.9
8	13.1	14.7	16.3	18.0	19.7	21.5	23.3	25.2	27.2	29.1
10	15.7	17.8	20.0	22.3	24.5	26.8	29.2	31.6	34.1	36.6
12	18.7	21.4	24.1	26.9	29.7	32.5	35.4	38.3	41.3	44.3
14	21.7	24.9	28.2	31.5	34.7	38.1	41.5	44.9	48.3	51.8
16	24.7	28.4	32.1	35.9	39.7	43.5	47.4	51.3	55.2	59.2
18	27.5	31.7	36.0	40.3	44.5	48.8	53.1	57.4	61.8	66.2
20	30.3	35.0	39.7	44.4	49.1	53.9	58.6	63.4	68.2	73.0
22	32.9	38.1	43.3	48.4	53.6	58.8	64.0	69.2	74.4	79.7
24	35.5	41.0	46.7	52.3	57.8	63.5	69.1	74.7	80.3	86.0
26	37.9	43.9	49.9	55.9	61.9	68.0	74.0	80.0	86.0	92.1
28	40.2	46.6	53.1	59.5	65.9	72.3	78.7	85.1	91.5	97.9
30	42.4	49.3	56.1	62.9	69.7	76.4	83.2	90.0	96.8	103.5
32	44.5	51.8	58.9	66.1	73.3	80.4	87.5	94.7	101.8	109.0
34	46.6	54.1	61.7	69.2	76.8	84.2	91.7	99.3	106.7	114.3
36	48.5	56.4	64.3	72.2	80.1	87.9	95.8	103.6	111.4	119.3
38	50.4	58.6	66.8	75.0	83.2	91.4	99.6	107.8	116.0	124.1
40	52.2	60.7	69.3	77.8	86.3	94.8	103.3	111.9	120.4	128.8
42	53.9	62.7	71.6	80.4	89.3	98.1	106.9	115.7	124.6	133.4
44	55.5	64.6	73.8	83.0	92.1	101.3	110.4	119.5	128.6	137.7
46	57.0	66.5	76.0	85.4	94.8	104.3	113.7	123.1	132.5	142.0
48	58.5	68.3	78.0	87.7	97.4	107.2	116.9	126.6	136.3	146.0
50	60.0	70.0	80.0	90.0	100.0	110.0	120.0	130.0	140.0	150.0
52	61.4	71.6	81.9	92.1	102.4	112.7	122.9	133.2	143.5	153.8
54	62.7	73.2	83.7	94.3	104.7	115.3	125.8	136.4	147.0	157.5
56	64.0	74.7	85.5	96.2	107.0	117.8	128.6	139.4	150.2	161.1
58	65.2	76.2	87.2	98.2	109.2	120.2	131.3	142.4	153.4	164.5
60	66.4	77.6	88.8	100.1	111.3	122.6	133.9	145.2	156.5	167.9
62	67.5	79.0	90.4	101.9	113.4	124.9	136.4	148.0	159.6	171.1
64	68.6	80.3	91.9	103.6	115.3	127.1	138.8	150.6	162.5	174.3
66	69.7	81.5	93.4	105.3	117.2	129.2	141.2	153.2	165.3	177.4
68	70.7	82.8	94.8	106.9	119.1	131.3	143.4	155.7	168.0	180.4
70	71.7	83.9	96.2	108.5	120.9	133.2	145.7	158.2	170.7	183.3
72	72.6	85.1	97.6	110.0	122.6	135.2	147.8	160.6	173.3	186.1
74	73.6	86.2	98.8	111.5	124.3	137.1	149.9	162.8	175.8	188.8
76	74.5	87.2	100.1	113.0	125.9	138.9	151.9	165.0	178.2	191.4
78	75.3	88.3	101.3	114.4	127.5	140.6	153.9	167.2	180.6	194.0
80	76.2	89.3	102.5	115.7	129.0	142.4	155.8	169.3	182.9	196.5
82	77.0	90.3	103.6	117.0	130.5	144.0	157.6	171.3	185.2	199.0
84	77.8	91.2	104.7	118.3	131.9	145.6	159.4	173.3	187.3	201.4
86	78.5	92.1	105.8	119.5	133.3	147.2	161.2	175.3	189.4	203.7
88	79.2	93.0	106.8	120.7	134.7	148.8	162.9	177.2	191.5	206.0
90	80.0	93.9	107.8	121.9	136.0	150.2	164.5	179.0	193.5	208.2
92	80.7	94.7	108.8	123.0	137.3	151.7	166.2	180.8	195.5	210.3
94	81.3	95.5	109.8	124.1	138.6	153.1	167.7	182.5	197.4	212.4
96	82.0	96.3	110.7	125.2	139.8	154.5	169.3	184.3	199.3	214.5
98	82.6	97.1	111.6	126.2	141.0	155.8	170.8	185.9	201.1	216.5
100	83.2	97.8	112.5	127.2	142.1	157.1	172.2	187.5	202.9	218.4

APPENDIX E – Site Indices — Eastside




DOUGLAS FIR SITE INDEX
50-YR BREAST-HIGH AGE (Summerfield,1980)
TOTAL HEIGHT (ft)
0
20
40
60
80
100
120
140
160
180
B.H. AGE
0
20
40
60
80
100
120
SI = 50
SI = 60
SI = 70
SI = 80
SI = 90
SI = 100