RESTORATION OF YOUNG FORESTS WITH AN EMPHASIS ON PRE-COMMERCIAL THINNING

Notes from the First Meeting of the Pacific Northwest Forest Restoration Cooperative

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INTRODUCTION: THE PACIFIC NORTHWEST FOREST RESTORATION COOPERATIVE

Over the last century, low elevation temperate coniferous forests along the Pacific Northwest Coast, from Southeastern Alaska to Northern California, have largely been managed for commercial timber production. Extensive removal of forested areas began in the early 1900s. Intensive timber management regimes typically began in the 1970s and include regeneration harvests (clearcutting), extensive road building, dense monoculture replanting of commercially valued conifer species, and physical or chemical control of competing vegetation. Such practices have left a legacy of altered habitat on public and private lands throughout the region.

To abate ongoing threats to freshwater, estuarine, and terrestrial habitats, forest and watershed restoration efforts aimed at increasing complexity in forest structure and composition are being implemented across an array of ownerships, landscapes, and forest types throughout the Pacific Northwest. Some current large-scale projects include: Headwaters Forest Reserve (U.S. Bureau of Land Management (BLM), CA, 7,400 acres; http://www.blm.gov/ca/st/en/fo/arcata/headwaters.html), Mill Creek (National Park Service, CA State Parks, Save the Redwoods League, CA, 25,500 acres; see Appendix A), Cedar River Watershed (City of Seattle, WA, 91,500 acres; see Appendix A), and South Willapa Bay (The Nature Conservancy, Willapa National Wildlife Refuge, WA, 15,000 acres; see Appendix A). Additional restoration projects have begun or have been targeted on thousands of acres of land designated as Late-Successional Reserves by the U.S. Forest Service as well as non-reserve federal lands (e.g., "Matrix" and "Adaptive Management Areas") and on significant areas of other public (e.g., state) and private lands. On these projects, land managers are trying innovative restoration approaches and scientists are conducting research to better understand and inform future restoration practices.

While the growing interest in forest landscape restoration is exciting, sharing information among a diverse group of stakeholders can be challenging. The Pacific Northwest Forest Restoration Cooperative (hereafter, the Co-op) was founded to facilitate communication between managers and scientists and catalyze growth in practical restoration knowledge. The Co-op includes members from restoration projects within young, managed forest landscapes on private and public lands throughout the Southeastern Alaska and British Columbia Coastal Forests and Mountains, North Cascades and Pacific Ranges, Pacific Northwest Coast, West Cascades, and California North Coast ecoregions (an ecoregion is an area ecologically and geographically defined and utilized for conservation planning; The Nature Conservancy 2006; based on Olson and Dinerstein 2002, Bailey 1995, and Wiken 1986).

Specific goals of the Co-op are to:

1. Promote in depth discussion and debate concerning specific management practices relevant to restoration within young-managed forest landscapes
2. Bring restoration practitioners and academic scientists together to enhance each others understanding of the state of scientific knowledge and key management questions relevant to restoration within young, managed forest landscapes

3. Develop and promote the distribution of state-of-the-art knowledge concerning best management practices relevant to restoration within young, managed forest landscapes
4. Develop personal relationships between land managers to enhance ongoing communication and collaboration

The Co-op plans to meet annually to discuss topics pertinent to forest restoration, such as road decommissioning and upgrading, commercial thinning, ecological monitoring, and ecosystem services. The first meeting of the Co-op was held July 9-10, 2007, at the City of Seattle Cedar River Watershed Education Center and included natural resource practitioners and scientists from The Nature Conservancy, City of Seattle, U.S. Forest Service (PNW Research Lab, Mt. Hood and Tongass National Forests), Washington Department of Natural Resources, Save-the-Redwoods League, University of Washington, and Oregon State University. The meeting focused on pre-commercial thinning (PCT) of young forests, with an emphasis on practical development and implementation of PCT prescriptions and ecological impacts. Appendix A provides a summary of the presentations given at the meeting. This paper synthesizes the common themes identified during the meeting and addresses reasons why PCT may be a useful tool for forest restoration as well as important considerations for developing, implementing, and contracting PCT prescriptions, and key uncertainties that remain.

Terminology Notes

To improve clarity, several terms that are used throughout the paper will be defined here. These definitions are for the purposes of this paper and are not necessarily inclusive of other forestry-related discussions.

Managed forest - a forest where forest management (e.g., silviculture, fire suppression, insect control) activities have been or will be performed.

Young forest - generally, even-aged forests less than 80 years old; most of this paper focuses on forests less than 25 years old ("very young")

Stand – forest patch that is homogenous in age, composition, and structural characteristics such that it can readily be distinguished from adjoining areas; often delineated by past management activities, but can also be delineated by soil type, topography, and land ownership

Ecological restoration – the process of assisting in the recovery of an ecosystem (e.g., forest, watershed) that has been damaged, degraded, or destroyed (Society of Ecological Restoration). In this paper, 'ecological restoration' often refers to a desire to increase complexity of forest structure and composition

Commercial thinning – generally, thinning conducted in stands where thinned trees are large enough to be of commercial value (depending on local markets, this is likely to be when tree size is at least 8"-11"). Thinned trees are sold.

Juvenile spacing – see Pre-commercial thinning

Mature drop and leave (MDL)—generally, thinning conducted in stands where trees are large enough to be of commercial value. Thinned trees are not sold, but are left on the site.

Pre-commercial thinning – (PCT) generally, thinning conducted where thinning costs exceed revenue (if any). This usually occurs in stands where thinned trees are too small in diameter to be of commercial value. While PCT is often conducted in stands less than 25 years old ("very young stands"), some stands may be older under certain growing conditions. In uneven aged or multi-cohort stands, PCT can also be used to remove small diameter understory trees in stands with larger diameter overstory trees. Thinned trees usually are left on site during PCT. PCT is also called "juvenile spacing" and "young drop and leave", especially when future revenue is not envisioned or a goal. <u>In this paper, these terms are used interchangeably, regardless of economic intent</u>.

Restoration thinning – thinning that is conducted for the primary purpose of ecological restoration (see definition above). Commercial thinning, mature drop and leave, and/or pre-commercial thinning done to achieve objectives of ecological restoration is often, but not always, referred to as "restoration thinning."

Gaps – canopy openings in a stand that are artificially created during management or are naturally introduced by pathogens, wind, fire, or other natural disturbance

Skips - areas in a stand that are purposefully left unthinned

Young drop and leave – see Pre-commercial thinning

FOREST THINNING BACKGROUND

Throughout the Pacific Northwest, hundreds of thousands of acres of forest are considered to be "young, managed forests." This term generally includes forests under the age of 80 that developed from planting and/or natural regeneration following anthropogenic removal of the previous forest, often by clear-cutting. These forests are quite different from the old-growth forests that they replaced. Young, managed forests often initiate at higher densities over a shorter period of time than current old-growth forests did (Tappeiner et al. 1997, Poage and Tappeiner 2002), and consequently often have less complex canopy, vegetation, and habitat structure than old-growth forests. The relatively simple habitat in young, managed forests has been found to be less suitable for some species than that found in more complex old-growth forests (e.g., Hagar et al. 2004, Carey and Harrington 2001). In some cases, the dominant disturbance regime has also been altered (e.g., a shift from low-severity to high-severity wind disturbance). Such findings have prompted many to wonder, if these young forests are left alone, will they ever develop into forests that function similar to the current old-growth forests? Even if they do, will the process take so long that species may be extirpated in the interim? Is there a way to restore these young forests to set them on a 'more natural' developmental trajectory or even hasten the development of late-seral (or other desirable) structure and composition? If so, how?

Density management, or thinning, has become an obvious first approach in the restoration of young, managed forests. Thinning has been used for decades to reduce tree densities in plantation forests and naturally regenerated forests in order to increase growth and, therefore, timber value of residual trees. However, it could also be used to decrease the density of young, managed stands to a density more similar to that under which old-growth stands developed, thereby setting them on a similar developmental trajectory. The rationale for using thinning as a restoration tool is described in more detail in Hunter (2001). Figure 1 illustrates the density difference between a thinned and unthinned stand.

Figure 1. Example of unthinned stand (left) and thinned stand (right).

In the mid 1990s, several large-scale silvicultural experiments (LSSEs) were initiated to test if thinning or other silvicultural tools could accelerate development of late-seral features in young, managed forests. Early findings from these and similar studies indicate that thinned young forests are generally more similar to old-growth forests in structure and composition than unthinned young forests (e.g., Bailey and Tappeiner 1998, Muir et al. 2002). However, there are exceptions and results are often limited to short-term observations and/or relevant only to particular sites, forest types, and species. Also, much of this research has focused on forest stands, prompting questions about the impacts of thinning at larger spatial scales. It is not the intent of this paper to synthesize these findings, but a thorough synthesis of the LSSEs can be found in Poage and Anderson (2007) and Appendix B provides a bibliography of several restoration thinning-related publications. This list is not comprehensive, but includes many key papers.

Though this research has provided many answers and has generated a lot of excitement over the potential benefits of thinning young, managed stands, it has also generated many more questions. Some of the key questions include:

- Should all stands be thinned?
- If a stand is thinned, at what age is it best to thin it?
- How can we introduce species and/or structural diversity into a stand?
- How can thinning prescriptions be designed to be operationally, economically, and ecologically viable?
- Considering that much of the previous research has focused on Douglas-fir forests, how might responses differ if thinning is applied in forest types other than Douglas-fir?
- What is the appropriate size for a treatment (e.g., sub-stand, stand, multiple stands)?
- What happens when we want to manage across stands to larger landscapes?
- How do we prioritize the spatial placement of thinning treatments across a landscape?

The Co-op meeting addressed many of the above questions because they are implicit to using thinning as a restoration tool. However, the meeting also attempted to focus on questions specific to pre-commercial stands. In pre-commercial stands, trees are too small to have market value, thus restoration costs cannot be off-set from the sale of the thinned trees. Some key questions specific to thinning in pre-commercial stands include:

- Is it necessary to thin very young stands?
- What are the trade-offs of waiting to thin a stand until it is of commercial size?
- Does slash need to be treated and, if so, how?
- Is a complex PCT prescription necessary to achieve more complexity in a stand or can this be achieved at a later point in time?
- Are there simple thinning prescriptions that will increase ecological complexity cost effectively ?

Figure 2 presents a conceptual model of how PCT is often expected to achieve ecological objectives and the key uncertainties in those assumptions. The remainder of the paper synthesizes the discussion that ensued regarding the use of PCT as a restoration tool.

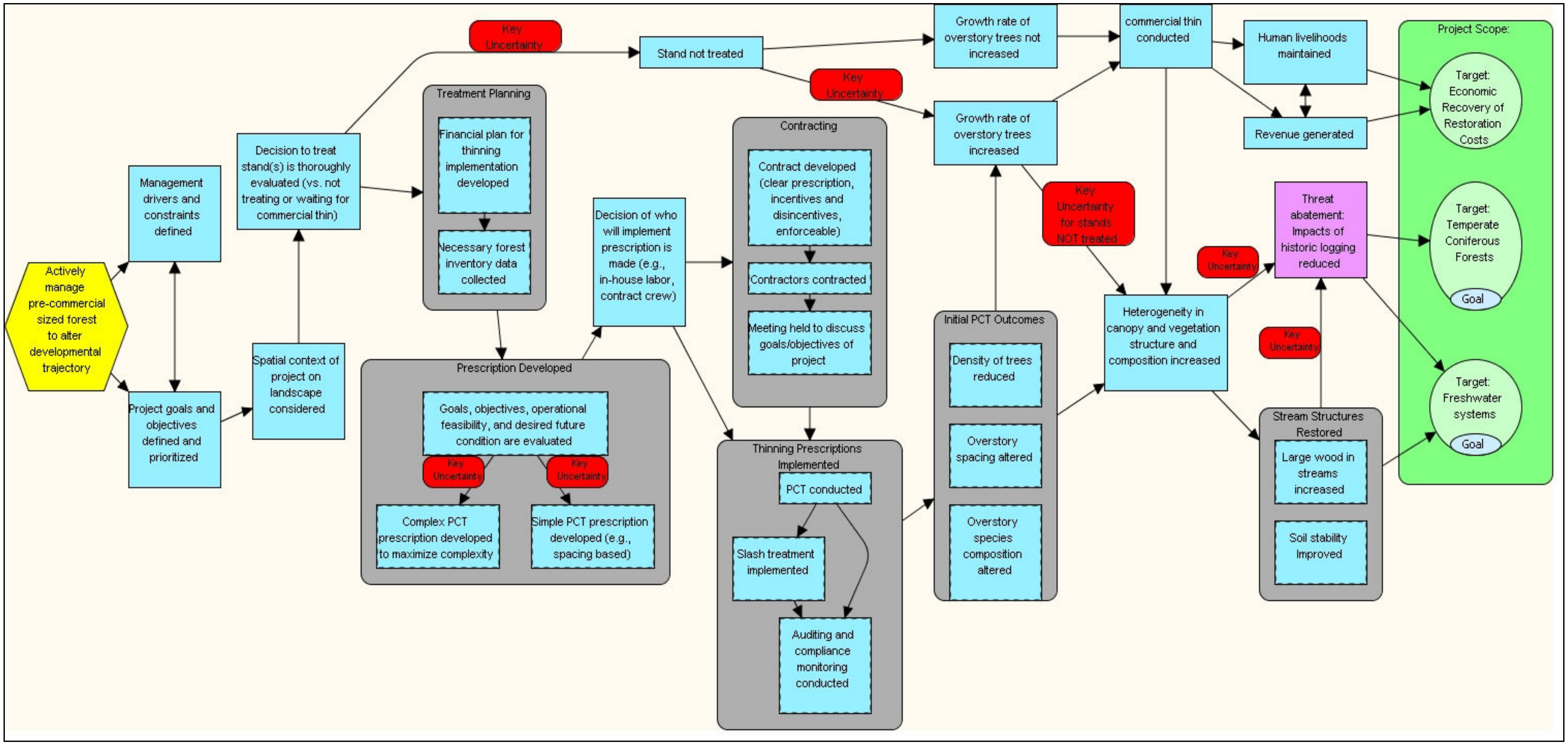


Figure 2. Conceptual model of the use of pre-commercial thinning for restoration purposes.

GOALS AND OBJECTIVES

Key Points:

- ♦ **Projects need clear goals and objectives.**
- ♦ **Goals should include temporal, spatial, and functional elements.**
- ♦ **Objectives should be measurable.**
- ♦ **Goals and objectives need to be prioritized.**
- ♦ **Management drivers and constraints must be recognized from start.**

With forest restoration efforts occurring across such a diversity of landscapes and ownerships, there also arises a diverse set of goals, policy objectives, and economic considerations. **For any forest restoration project to be successful, it must start with clear goals.** Goals should include temporal, spatial, and functional dimensions. Key questions that should be answered include:

- What is the timeframe for the project? (e.g., Is the goal to increase diameter growth in 10 years or is it to increase the number of large snags over the next 50-100 years?)
- What is its spatial context? (e.g., Is it one land-owner with 5 acres surrounded by housing developments trying to improve woodpecker habitat or is it a state park trying to promote development of late-seral structures in a young forest due to a lack of late-seral forest in the surrounding land?)
- What function is the project trying to serve? This is related to forest structure and process. For a particular ecological function, there may be several structures that can achieve that function.

Goals can also include ecological, economic, and social components. The amount of weight that each of these components holds will depend on the specific project. Having a clear understanding of them, though, will facilitate project development. It is important to know if there are conflicting goals and, if so, how goals will be prioritized. A project that does not recognize conflicting goals and plan accordingly can falter once such a roadblock is encountered.

A successful forest restoration project also needs to have clear objectives. Objectives differ from goals in that they need to be measurable, while goals are often value driven. Objectives help people to know if they are achieving the goals of the project. People are often wary of clearly defining objectives because the desired future condition or outcome (e.g., old-growth forest conditions) may not be well defined or understood and good information to quantify objectives may be lacking. However, such sideboards are necessary to provide focus and direction. Objectives can start with simple measures (e.g., increasing basal area of stand) and become more complex as new information permits. They can, and probably should, change over time as new knowledge is acquired or values change.

Goals and objectives should also be prioritized. Projects should clearly list and identify all rationale for prioritization, including ecological justifications (e.g., species habitat) as well as logistical and operational constraints (e.g., staff, budgets, road access). It is important to recognize that a goal or objective that is not operationally feasible may not be achieved, despite ecological need.

SPATIAL CONTEXT

Key Points:

- **Projects should generally be considered within context of overall landscape.**
  - **This consideration should answer the question: "Where should treatments be placed on the landscape and how should their placement be prioritized?"**
- **The scale of the desired outcome can drive the spatial arrangement of the treatments.**
- **Consideration of within-stand spatial variability may also lend insight into the type and placement of treatments necessary to achieve objectives.**
- **The temporal component of changing landscapes will also influence scheduling and placement of treatments.**

As a result of ongoing natural disturbance, forests have historically existed in a complex pattern across the landscape, forming a mosaic of age classes and species mixes. Therefore, **successful forest restoration projects usually need to consider the project within the context of the overall landscape.** Multiple scales and ownerships should be examined. If a small parcel of land is surrounded by old-growth forest, it may not be worthwhile to spend resources attempting to restore late-seral conditions in that parcel and focus on other landscapes where late-seral forest may be lacking. On the other hand, it may be beneficial to add connectivity to the landscape by promoting development of late-seral conditions in that parcel. Considerations such as these can help managers to more clearly define project goals.

In addition, **the scale of the desired outcome can drive the spatial arrangement of the treatments**. If it is desirable to have an entire area of late-seral forest, then fewer types of treatments may be necessary. However, if a range of successional stages is desired, then treatments may need to be varied not only in their prescription, but also in the way they are spatially arranged.

Consideration of within-stand spatial variability may also lend some insight into the type and placement of treatments necessary to achieve objectives. For example, more basic treatments may be sufficient in areas of high within-stand variability while areas of low within-stand variability may necessitate more complex or numerous types of treatments.

It is also important to remember that landscapes will change over time. **The temporal component of changing landscapes will impact the scheduling of management activities**. Management models for timber optimization can lend some insights into this matter. Though they were developed for objectives different from restoration, these models force a formalization of decision criteria that consider both temporal and spatial components on a landscape.

PRE-COMMERCIAL THINNING PRESCRIPTIONS

PCT considerations

Key Points:

- **The first step to developing a PCT prescription is to determine if the stand should be treated at all; consideration should be given to benefits, drawbacks, and tradeoffs associated with the decision to treat or not treat a stand now or to delay treatment until it is of commercial size.**
- **Information on stand structure, composition, and variability is generally needed to decide to treat/not treat a stand and to develop a prescription.**
- **A "one-size fits all" prescription rarely exists; prescriptions must often be tailored for specific goals and objectives.**
- **Not all areas should be treated the same when possible.**
- **Prescriptions should be as simple as possible to meet objectives and goals.**
- **Treatments do not necessarily have to be confined to stand boundaries; stands are often artifacts of past management and using them for future management may be undesirable.**
- **Multiple entries may often be needed to obtain desired results.**
- **If a contractor is used, prescriptions must be able to be audited.**
- **Some areas should be left untreated at different spatial scales when possible.**

The first decision that needs to be made when developing a PCT prescription is if the stand should be treated at all. There are advantages and disadvantages to treating stands when they are very young (generally under 25 years old). Generally, PCT is expensive and costs increase with increasing complexity of prescriptions. By waiting until a stand is of commercial size, costs can often be off-set by selling some of the thinned trees. However, there is evidence that very young stands are quite dynamic and changes can occur quickly, indicating that species composition or other structural features (e.g., tree spacing, density, crown height) may become increasingly difficult to manipulate as stands age (e.g., Puettmann and Berger 2006). Furthermore, some taxa (e.g., mosses and lichens) take a long time to disperse and waiting may preclude their existence in the stand (Sillett et al. 2000). This suggests that, especially in areas of high productivity, postponing management until age 25 or older may reduce the options available to influence forest structure and/or composition. Operational feasibility should also be considered; if access is limited, a stand may be unable to be treated regardless of ecological need. One advantage of PCT, though, is that road access is not always vital since material can usually be left on-site. If multiple stands need treatment and resources are limited then stands may need to be prioritized for ecological reasons (O'Hara and Oliver 1999) or other variables such as changes in access (e.g., road removal), proximity to sensitive areas, or importance at the landscape scale (e.g., connectivity; see LaBarge presentation, Appendix A).

If a stand is to be treated, a minimum amount of information about the stand is required to understand how to get from the current condition to the desired future condition. **This includes: (1) structure, (2) composition, and (3) spatial variability.** Standard forest inventory data can usually provide a sufficient snapshot view of this information. Personal knowledge of the site can also be very helpful, especially in the absence of hard data. This information can inform decisions, such as what should be removed, what should be left, and how these areas should be spaced. It also can permit the inclusion of natural variability (e.g., disease pockets, natural openings, hardwood patches) into the prescription. The more complex the prescription, the more information (e.g., topography, species distribution, location of sensitive ecological features) will likely be needed to effectively develop and implement it.

When developing a specific PCT prescription**, a 'one-size-fits-all' solution rarely exists.** Given the high degree of variability on the landscape, **it is probably a very good idea to not treat all areas the same**. In general, **PCT prescriptions should be as simple as possible to meet the objectives**. The simpler they are, the more easily they can be understood and implemented correctly. Several 'templates' of PCT prescriptions exist, (e.g., standard 12'x12' spacing), but most will require modification based on conditions relevant to the particular stand(s). In addition, many cases may require a mix of treatments to achieve specific goals, such as hastening development of late-seral conditions. Variations in treatments often depend upon several factors, but usually include:

- Goals, objectives, and priorities (including ecological, economic, and social)
- Starting conditions of the stand (e.g., basal area, species composition)
- Landscape conditions
- Forest type(s)

One key component of all thinning prescriptions, however, is that **they must be able to be audited**. Without auditing there is no way of knowing if the prescription has been implemented correctly and, therefore, no way of knowing how the treatment influences development of the desired conditions. It is also a critical component of adaptive management.

It is also important to recognize that **more than one entry will often be needed to obtain certain objectives**. For example, if maximizing future financial return or offsetting restoration costs are objectives, a stand could be thinned to a simple, even spacing to permit growth and then a more complex spatial treatment could be used once trees had reached a size of commercial value to make the thinning more economically feasible. Planning for future entries can also permit more flexibility in the initial treatment. However, repeated entries can cause repeated disturbance to plant and wildlife communities. How quickly these communities recover and how their successional trajectory may be altered is unknown. Decisions about multiple entries will also often depend on starting forest conditions and anticipated future access to stands. Removal of access roads may limit future entries, possibly necessitating a more aggressive first-entry approach.

In addition, **treatments do not have to be confined to a stand**. It is important to remember that a stand is often an artifact of past management and that maintaining current stand boundaries may or may not be appropriate for meeting future management objectives. For different objectives, stands may need to be re-delineated to facilitate management and monitoring. If the future desired condition is a landscape that is not bound by stand boundaries, then treatment delineation should try to soften those current boundaries to the extent possible. A clear goal will help to inform future management.

Finally, if possible, **some areas should also be left untreated at different spatial scales** – from within individual stands to portions of larger landscapes. These areas can be used to protect areas with unstable slopes or where species sensitive to disturbance are present. This also adds some protection in the event that there are unforeseen negative outcomes of thinning and provides something for later comparison to treated areas.

Prescription options

Key Points:

- **No single PCT prescription is considered a best management practice; due to high diversity of ecological conditions on landscape, a mix of prescriptions is probably best.**
- **PCT prescriptions currently in use include:**
  - **Variations on traditional spacing-based thinning**
    - **Including rules to retain species/areas or designate leave trees**
    - **Mix spacing requirements for different species**
    - **Target densities and density ranges**
  - **Neighbor tree concept**
  - **Slot thinning**
  - **Inclusion of skips and gaps**
    - **“Chip” method**
    - **“Monte Carlo” approach**
    - **Assigned skip and/or gap areas (usually includes randomization procedure)**
  - **Visualized circle method**
  - **“DxD” method**
  - **Cell-based thinning**

An objective of many forest restoration-based PCT prescriptions is to enhance spatial complexity and species composition. **There is not one prescription that is considered a**

best management practice for meeting these objectives. With such a diversity of ecological conditions on the landscape and stakeholder goals, probably no single prescription would or should work everywhere. In many cases, a mix of several types of prescriptions may be beneficial. Below are some general types of prescriptions that managers have tried or are trying, including their benefits and drawbacks. Long-term ecological results of many of these remain largely unknown.

Traditional spacing-based PCT prescriptions (e.g., thin to a 10'x10' spacing) **can often be adjusted to obtain restoration objectives.** One way of doing this is to simply incorporate natural variability (e.g., disease pockets, hardwood patches) into a basic PCT prescription (e.g., thin to a 10'x10' spacing but leave hardwoods or other minor species). Another option is to use a traditional spacing criteria (e.g., 10'x10' or 12'x12') or a more aggressive spacing criteria (e.g., 16'x16', 20'x20', 24'x24', and 27'x27' are some spacings currently being implemented), but allow flexibility in the spacing (e.g., ± 4 feet or 25%-50% variability) to help maintain pockets of higher and lower densities. However, contractors accustomed to thinning at even (i.e., exact) spacings are likely to continue to thin at an even spacing if this is permissible even if flexibility is allowed. It is important to work with the contractor to encourage them to add variability into the spacing. **Rather than spacing criteria, a target density may be appropriate in some cases** (e.g., 225 tpa with a range of 200 tpa – 250 tpa). This can coincide with a recommended spacing to obtain that density (e.g., 14'x14'). Knowledge of initial stocking density is necessary when designing such prescriptions. To increase variability in spacing, some managers have experimented with assigning different spacing to different members of the thinning crew (e.g., by attaching a number to them or flagging their saws with different color flagging); this can randomize the spacing, but may be difficult for the foreman to manage or to audit.

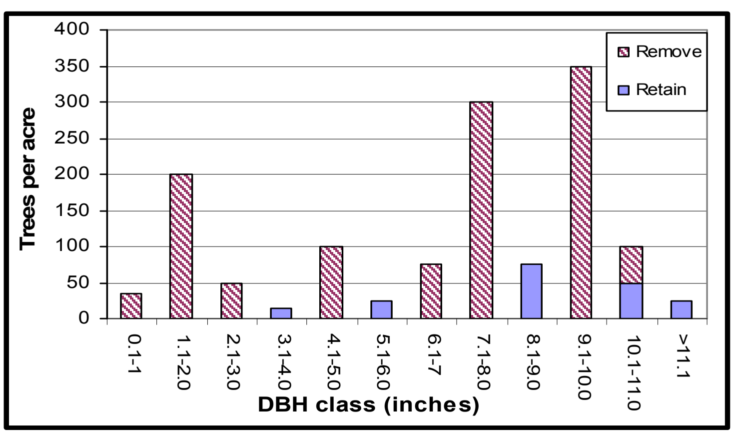
Traditional density management used for maximizing stand yield (e.g., a timber thinning spacing of 10'x10') is not likely to increase tree growth for extended periods of time as canopies in young stands generally close quickly. More aggressive, wider spaced thinning may increase growth of trees more rapidly and sustain higher growth for longer periods of time than some lighter thinnings, but there likely exists a threshold where stand densities may be too low to account for additional loss of residual trees from disease, animal damage, and/or windthrow. In addition, vigorous shrub regeneration or invasion by exotic species (e.g., Himalayan blackberry or scotch broom) in some areas may be problematic if stands are opened up too much and may limit understory tree release and regeneration. Another potential disadvantage to more aggressive treatments is an increase in fuel loading. Slash created by thinning may be slow to decompose due to the drier conditions resulting from the more open canopy. At a certain point, the prolonged short term fire risk associated with lower residual densities may become unacceptably high. The threshold that determines what is "too aggressive" will likely vary with differing environmental conditions (e.g., latitude, elevation, aspect, climate), but less aggressive spacings should be considered if such factors are of concern. Trial plots of different spacings may be helpful to determine an appropriate spacing for particular sites.

Managers are also trying a **combination of specific 'rules'** along with spacing-based thinning to increase spatial heterogeneity and improve species composition in stands. For example, some rules require crews to leave shrubs uncut or retain all trees of a certain species (e.g., western red cedar) or type (e.g., hardwoods). Other rules designate which trees should be chosen as leave trees (e.g., trees greater than 10") or require crews to leave a certain number of trees with growth abnormalities to increase structural complexity. Another option is to **mix spacing requirements for different species** (e.g., thin Douglas-fir to a 20'x20' spacing and western hemlock to a 12'x12' spacing). This can be effective if species are mixed throughout the stand but can have unintended consequences (e.g., wider spacing of residual trees) if species are clumped.

In addition to spacing, **a 'neighbor tree' concept** can also be employed by maintaining one or more 'neighbor' trees (trees occupying adjacent space in the canopy) near some trees. This can add greater spatial variability to areas than using only basic diameter, height, or spacing limits. In areas where trees are prone to sprouting (e.g., hardwood patches or redwoods), thinning of clumps may also add spatial variation to the stand. However, in areas of intense animal damage or windthrow, all clumps may be maintained to ensure retention of these species in the stand.

Yet another option is **slot thinning**. This method is more typically used for commercial thinning because older stands tend to have more size differentiation, but may be appropriate for PCT in some cases. A "slot" can be thought of as a diameter class, but could also be a cover class or other class for which information exists and is useful in determining the condition of the stand (see example in Figure 3). Good stand exam data or vegetation inventory is essential for slot thinning. Based on objectives and stand exam data, decisions are then made regarding what the 'slots' are (e.g., diameter class increments), which 'slots' should be removed, and if they should be completely or partially removed (e.g., remove every tree in the 3"-4" diameter class, regardless of species or remove 2/3 of all trees in the 5"-6" diameter class, excluding hardwoods). One objective of slot thinning is to minimize the number of decisions that a thinning crew has to make. Thus, if possible, the most efficient approach is to use narrow diameter class increments and eliminate all trees in particular increments (Figure 3). The prescription can be adjusted according to the specific starting conditions of the stand in order to obtain the desired species mix, size mix, spacing, or other structural objectives.

Figure 3. Example of diameter distribution 'slots' for use in a slot thinning prescription (Remove = trees removed; Retain = trees retained. These numbers can be adjusted according to goals/objectives.)

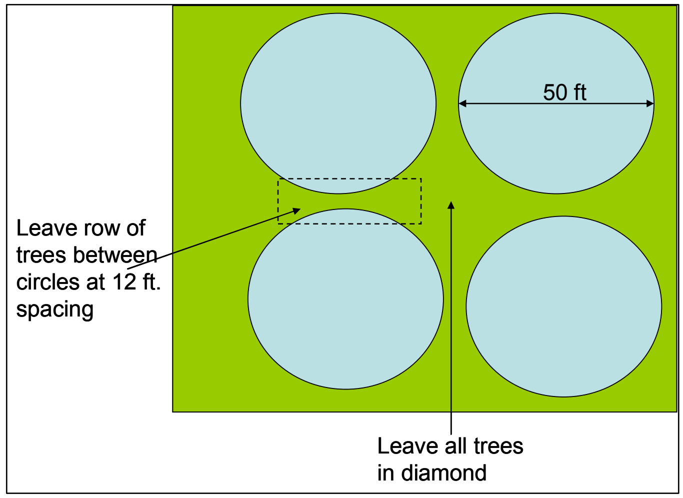


“Skips” and “gaps” can also be included in any prescription to protect areas (“skips”) of biodiversity ‘hotspots’ (e.g., hardwood trees and shrubs) or establish or augment open areas (“gaps”). Gaps can also be used to facilitate tree growth of uncut ‘gap’ trees or diversify crown structure in the surrounding edge (see Harrington and Carey (1997) for additional information on skips and gaps from the Olympic Habitat and Development Study).The optimal size of skips and gaps is dependent upon objectives, though a mix of smaller and larger areas is commonly used. In PCT prescriptions, the use of skips is often more common than gaps because the stand is so young/small that differences in the initial cohort and the new ‘gap’ cohort can often disappear quickly as the stand develops. However, gaps may act as centers of inoculation for understory species or have lasting influences on edge trees (e.g., greater growth rates, lower branching patterns); such phenomena are not currently well understood.

Usually when skips and/or gaps are included, it is desirable to have them randomly placed throughout the stand. Often simple variations in spacing and specifications to retain certain species are sufficient for incorporating skips and/or gaps. One method designed to specifically include gaps in stands is the **“chip” method** (this could also be used for skips). For this method, a number of chips of different colors representing different gap sizes are placed in a pocket and pulled to select the gap size while walking through the stand. Different color flagging is used to mark the gap centers, with different colors representing different sizes of gaps. Another option is the **“Monte Carlo”** approach. This method basically requires three decisions to be made: (1) what ratio of skips to gaps is desired in the stand? (2) how many trees will be left in each skip? and (3) how many trees will be left in each gap? Once these decisions are made, the stand is then walked and a random selection system is used to distribute the leave patches and gaps. Auditing this method can be done using a probability distribution. In practice, however, this method has generally been difficult and expensive to implement, leading managers to favor other methods (e.g., variations in traditional spacing) over this approach. **Yet another way of incorporating skips is to assign an area to be skipped or cut.** For example, for each thinner could skip a designated area once per day at an assigned hour. By assigning each thinner a different time, randomness in skips is promoted. Thinners can also be instructed to leave a specified area unthinned within a certain number of acres (e.g., skip a 50’x50’ area every 5-10 acres).

Another option being explored to include openings and leave areas throughout the stand is the use of **visualized circles** to guide crews (see Figure 4). Thinning crews visualize a 50’ diameter circle, select a center tree, and cut everything within a 25’ radius of the tree with the exception of 3 leave trees. Leave trees are selected for species and size. A row of trees at 12’x12’ spacing is left between circles and the ‘diamond’ area that forms between four circles is also left uncut. Since contractors visualize the size of the circle and terrain and stand boundaries vary, the treatment inevitably gets messy, adding variation to gap and skip sizes and shapes. Though this makes the treated stand more variable, it also can make it difficult to audit the prescription.

Figure 4. 'Visualized circle method' for incorporating 'skip' areas and 'gap' areas into stand. Areas inside circles are cut with exception of three leave trees while areas outside circles are retained.



The **'DxD' prescription** is another example of attempts to incorporate variation in PCT. For this prescription, a leave tree is chosen (generally based on species and size) and a radius is cleared around that tree. For example, a prescription may call for doubling a tree's diameter in inches to determine the radius in feet to clear (e.g., if a 5" dbh tree is selected, everything within a 10' radius is cut). Specific rules can be applied to retain trees of a certain species and/or size within that circle (e.g., do not cut any trees > 12" dbh or leave all Douglas-fir > 10" dbh). An adaptation to this method is to cut all trees touching the crown of the leave tree unless trees fall under specified exceptions.

A '**cell-based'** prescription has also been tried in a few circumstances (see Carey et al. (1999)). This method has the contractor visually identify cells (e.g., 30'x30' area) and randomly assign a different treatment inside each cell. Treatments (e.g., skip, 75 tpa, 150 tpa, gap) are assigned a number and a randomly chosen number inside each cell designates the treatment. While this can work well in a small, experimental area, it has been found to be impractical on a large area. It is generally too complicated for most crews, is difficult for a foreman to control, is difficult to audit, and can be extremely expensive.

Slash treatment

Key Points:

- **Slash can increase fire risk, interfere with understory vegetation, and impede wildlife movement.**
- **Slash is usually left on-site, often due to high removal costs.**
- **"Lopping and piling" of slash can reduce fire risks and create open space for vegetation and wildlife, but can be expensive.**
- **Slash may be removed under certain circumstances, but effects of slash removal on site productivity are largely unknown.**
- **Girdling or 'hack-and-squirt' methods result in standing dead trees and can be used to reduce high initial pulse of biomass onto the forest floor.**

One additional consideration in PCT prescription development is treatment of slash (woody debris left on the ground after thinning). Leaving **slash on the ground can create problems** related to short-term (generally less than 10 year) increases in fire risk, interference with understory vegetation growth and tree regeneration, and disruptions to wildlife movement. Slash may, however, reduce seedling browse by ungulates, leaving room for some creativity in silvicultural treatments. There is **often a disincentive to remove slash from the site due the high cost to remove it and low economic value of the material**. Increasing interest in the use of small diameter cellulosic material for biomass energy production may eventually spur economic incentives to remove such material, potentially making PCT less cost prohibitive. However, **it is uncertain at this time what the effects of removing such material may have on long-term site productivity**. Evidence from one study indicates that in highly productive areas there may be little impact, but impacts on less productive sites are unknown (see Harrington presentation summary, Appendix A). In addition, some amount of slash may benefit wildlife by providing shelter and food.

To reduce problems associated with slash, **some prescriptions require slash to be cut into smaller pieces ("lopping") and occasionally piled in discrete areas** ("lopping and piling"). This treatment opens space for vegetation growth and wildlife movement while maintaining nutrient inputs. However, it can be expensive and some research has indicated that, in some areas, smaller pieces may actually decay slower than larger pieces because they lose moisture more readily during dry summer months, thus delaying decomposition (Johnson et al., 2007). Incorporating **girdling (killing a tree slowly over time by severing or damaging the cambium layer) or a 'hack and squirt' (cutting into a tree and injecting it with herbicide) method into prescriptions are other ways of reducing the high initial pulse of slash onto the forest floor** by creating snags (standing dead trees) that fall periodically to the floor over a longer period of time. Using the 'hack and squirt' method in a very dense stand, however, could result in 'flashback' (herbicide spreading through the roots and infecting other trees). In some cases this may be problematic, but in others it may be beneficial by adding gaps and/or random complexity to the stand. The use of herbicides has drawbacks in that they are often socially unacceptable, restricted by law in some areas, and their impact on non-target organisms (e.g., aquatic insects) is often unknown.

Learning and documentation

Key Points:

- **Regardless of prescription(s) used, the development process should be well documented. This should include starting conditions, rationale for treatment, prescription applied, description of area treated, and auditing/monitoring efforts.**
- **When possible, treatments should be implemented so as to increase learning.**

Regardless of what type of prescription(s) is used, **the prescription development process should be thoroughly documented.** This should include pre-treatment inventories and/or description of initial conditions, rationale for decisions and treatment, prescription(s) applied, description and map of treated area (even a coarse sketch can be useful), and auditing/monitoring efforts as well as photos and other pertinent information. If possible, this information should be stored in both hard copy and electronic files. If different treatments are used throughout the stand, these should be well documented (e.g., what these are, approximately how big they are, and how they are spaced). Finally, when possible, **treatments should be set up to increase learning**; not all treatments need to be a well replicated experiment, but well documented observations can be very valuable for future management. Learning is an essential facet of adaptive management.

ACCOMPLISHING THE WORK

Key Points:

- **In general, contract thinning crews are more proficient, efficient, and cost-effective than in-house crews unless the in-house crew is experienced, there is enough work for year-round employment, and turnover can be minimized.**
- **Contracts need to translate prescriptions into easily obtainable and measurable criteria for the contractor.**
- **Contract specifications must be rigorous enough that they are enforceable and audits can be performed.**
- **The inclusion of incentives and disincentives in contracts can help encourage compliance.**
- **Successful implementation of a prescription is often facilitated by a reliable foreman that can understand the goals of the prescription, how to implement it, and how to communicate it to the thinning crew.**
- **A rigorous pre-treatment meeting should be held to communicate goals and objectives with contractor.**
- **Field audits must be conducted.**
- **Compliance monitoring must be done and is often most easily done as the contractor is working.**

Determining who is going to implement a thinning prescription can be a difficult decision. General contract crews are often used due to anticipated lower institutional costs. Contractors have advantages in that they can work for discontinuous and short periods of time, they often require little in-house time and oversight, and they often have expertise and previous experience that in-house employees do not possess which can make them very efficient. In many cases, though, contractors were trained to thin stands to meet timber management objectives (e.g., create an even spacing; remove all trees of non-timber value). Forest restoration often has different objectives (e.g., create a varied spacing; retain trees of non-commercial value). In addition, many contract crews do not speak English as a first language and translating prescriptions to a second language can often prove challenging. Below are some ideas that can assist managers in evaluating contractor options and facilitate communication of restoration prescriptions to contractors.

Contract crews that specialize in research, monitoring, or other environmental projects ("research crews") are one option that may offer advantages over general contract crews, especially for small, specialized projects or when monitoring data is desired. They generally are reliable, flexible, and are often able to do complex prescriptions with little training. Their disadvantage is that they can be more expensive than general contract crews and may not be as readily available in some areas. Inmate crews can also be effective in some situations. Inmates often see it as an 'honor' to be performing the work, so they typically try to do a good job at a low cost. These crews usually require a significant amount of upfront training, though, in order to obtain high quality work. However, since turnover problems are virtually non-existent, training is generally not a long-term commitment. Inmate crews may not always be readily available, though, and even with extensive training, they will likely work much more slowly than a professional crew initially and will require considerable time to become efficient. There is also often a desire to use local contractors to help build ties to local communities. If these crews have the experience to do the work or time spent training is deemed a sensible long-term investment, this can be a good option; however, if a project requires specialized equipment or specific skills which may not be present in the local contractor pool, a more experienced or specialized contractor that works in a larger geographic area may be better suited.

As an alternative to contract crews, some organizations have considered hiring their own thinning crew. This crew could be trained to specifically implement complex restoration thinning prescriptions, thereby eliminating many problems associated with contract crews. Ideally, once crews were trained, they would only require minimal time and oversight. However, **in-house crews would likely require a great deal of upfront training and supervision to obtain the same efficiency as contract crews**. To reduce turnover, they **would also need continuous work** (i.e., work to do when there was no thinning to be done), which may result in a higher cost to the organization. Despite such efforts, **turnover is still likely**, and the additional time spent training and supervising may diminish the expected advantages. For a small job, though, an in-house crew that understands what needs to be done can be more efficient than using a contractor due to the time commitment necessary to develop a good contract and monitor contractor performance.

If a contract crew is used, there are several factors that should be considered during contract development to improve their performance. First, **the contract needs to translate prescriptions into easily obtainable and measurable criteria for the contractor**. In addition, if the work is to be done by a non-English speaking crew, the use of metric rather than English units should be considered. Diagrams and/or pictures can also be used to address key points; these are often more effective than wordy explanations. **Contract specifications must also be rigorous enough that they are enforceable and audits can be performed**. Also, **the inclusion of incentives and disincentives in contracts can be a useful way to encourage compliance** (e.g., 5% more if contractor meets all specs; 5% off if any hardwoods are cut). Finally, if planting will be done following thinning, the contract may want to specify that trees should be felled away form designated spots or require some spot lopping to improve access for planters.

Regardless of what type of crew is used, **most crews should have a reliable foreman that can fully understand the goals of the prescription**, **how to implement it, and how to effectively communicate it to other crew members** (this may not be necessary on a very small project). This person should be on the ground at all times, overseeing the work. **A rigorous pre-treatment training should also be held to communicate goals and objectives**. This meeting should: (1) clearly communicate desired outcomes, (2) specify environmental considerations (e.g., preventing introduction or spread of invasive species), (3), specify clean-up requirements (e.g., slash treatment), and (4) specify health and safety requirements. If possible, the meeting should also include a pre-work "trial run" to make certain that the contractor is clear on the prescription and to address potential questions. Finally, regular (e.g., daily, weekly) **field audits must be conducted**. Compliance monitoring is absolutely necessary to ensure that contractors are implementing prescriptions correctly and to allow for adjustments if problems or changes arise. It is often easiest from a logistical standpoint to **do compliance monitoring as the contractor is working**. This makes walking through the stand easier and problems can be addressed as they arise.

QUESTIONS

As this paper demonstrates, much has been learned in the field of forest restoration, especially regarding the application of pre-commercial thinning, over the past decade. Despite such tremendous advances in knowledge, many questions remain unanswered. The questions presented below represent a small handful of uncertainties that warrant further attention in order to carry forest restoration forward.

- *To what extent are responses driven by existing conditions versus treatments?*
  It seems reasonable to question, "If you build it, can they come?" In some cases, the desired response may not be achieved despite accomplishing the desired structural and/or functional conditions. A more clear understanding of the linkage between particular structures, functions, and responses is needed.

- *How will stands develop if they are left unthinned?*
  We are not certain how stands will develop if they are left unthinned. Because so much of the landscape remains in a younger condition (under 80 years), we still have little empirical data on the development of unthinned stands. Often, the decision to thin a stand or not thin a stand is a decision based on operational logistics, economics, and expectations of improving ecological conditions of the system.

- *How do treatments interact with the natural processes of the forest system?*
  It is not clear how restoration treatments may interact with or change disturbance regimes or alter hydrologic regimes. For example, it is possible that thinned trees

may become wind-firm and reduce the amount of windthrow patches in the future stand. Alternatively, thinning could encourage increases in forest pathogens (e.g., Annossus root rot in western hemlock) that may prevent the stand from reaching a late-seral state. In addition, thinning can alter wildlife behavior (e.g., increase bear damage, alter ungulate browse). These may have unanticipated impacts on stand development and should be considered from the outset.

- *What are the developmental pathways that lead to particular functions?*
  A better understanding of forest developmental pathways is needed in order to understand the linkage between the creation of particular structures and development of the desired function.

- *What role will climate change play in shaping forest development and future forest conditions?*
  Currently, it is thought that the best way to protect against irreversible ecosystem state shifts due to climate change is to have a diverse mix of species to offer resiliency should the future climate favor particular species. Some have suggested planting species in areas that are currently outside of their native range in anticipation of climate-related range shifts, but this idea is very controversial. At present, the best way to deal with past shifts in species composition and how climate change may affect other facets of forest ecology is unknown.

- *Should the understory be managed?*
  The developmental pathways of understory vegetation are extremely variable, often dependent upon soils, moisture, light, seed source availability, fungal associations, and other factors. There is a tendency in recent thinning prescriptions to add gaps or wide-spacing as a way of facilitating understory development. However, species often found in gaps are early-seral species. It is not clear how such gaps may hinder or facilitate future development of late-seral plant communities. Furthermore, large ungulates (e.g., elk) may dictate understory species abundance and composition more than treatments.

- *If a young stand is treated, what type of treatment should be used?*
  Knowledge on the impacts of variable density thinning and the inclusion of skips and gaps, including size and spatial arrangement, is still unknown. Results from most studies that have investigated these are still in early stages of development, so long-term trends remain clouded. The tradeoffs of one entry versus multiple entries are also unclear. Many believe that multiple entries may be necessary to achieve late-successional habitat, especially where western hemlock is prevalent. However, the repeated disturbance from tree felling and harvesting equipment on other elements of stand structure and composition are not known.

- *What is the most operationally efficient method of conducting variable density thinning?*
  The most operationally efficient method of conducting variable density thinning or other variations of restoration thinning is still very unclear to managers. People

are trying several ways of introducing variability into thinning prescriptions, but often communicating these to contractors can be difficult.

- *What are the impacts of slash removal?*
  With increasing interest in biofuel generation, markets may develop for small diameter material that may provide economic incentive for removing slash after pre-commercial thinning. The impact that slash removal has on site productivity is not well understood. In highly productive coastal forests, slash removal may have little impact, at least in the short-term (see Harrington in Appendix A). However, this may differ after repeated removals or on sites with different site productivity. Furthermore, leaving slash on site or removing it may have implications for plant communities and wildlife that are also currently unknown.

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APPENDIX A

PRESENTATION SUMMARIES

The Nature Conservancy (TNC) – Ellsworth Creek

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Ellsworth Creek is a 5,000 acre watershed owned by TNC in southwestern Washington. It is a coastal temperate forest in the Sitka Spruce forest zone. Thinning is being used as a restoration tool and money generated from commercial thinning will be used to offset restoration costs. However, nearly 50% of the forest is under 30 years of age and pre-commercial thinning (PCT) does not generate money.

Primary goals of 2 preliminary PCT prescriptions implemented in 2006 were: (1) create spatial complexity, (2) establish targeted stem density, (3) test contractor efficiency, and (4) test effectiveness of alternative prescriptions. There were two types of prescription scenarios: (1) may never re-enter stand, so need to get spatial complexity with PCT; (2) may re-enter stand, so can obtain more general spacing and leave development of further complexity for a later re-entry.

Initial PCT prescriptions were not tailored for wildlife goals. They incorporated natural gaps, added gaps in places, avoided wet areas, permitted thinning along non-fish-bearing streams (but no gaps were left near streams), and left slash on the ground. In stands where re-entry was planned, gaps were dropped due to: (1) increased cost of treatment, (2) assumption that blow-down would create natural gaps, and (3) the belief that the understory would be maintained until commercial thinning.

Specifically, two variations of a spacing-based prescription were tested. These included:

- Thin dominant conifer species to a 20'x20' spacing; thin secondary conifer species (>10%) to 12'x12' spacing; retain all western red cedar and other non-dominant tree species (Estimated Cost: $100/acre)
    - One 50'x 50' "gap" shall be created within every acre of the stand. All trees shall be cut within the designated gap. Gaps may be placed at the contractor's discretion, but shall not be located within 100 feet of another gap (natural or created) or placed within 50 feet of water.
- Thin dominant conifer species to a 15'x15' spacing; thin western red cedar to 12' x 12' spacing when grouped, otherwise it remains uncut; retain all other non-dominant tree species (Estimated Cost: $170/acre)

- Both prescriptions contained the following elements:

- One 50’ x50’ “clump” created within every acre of the stand (no trees cut). Clumps may be placed at the contractor’s discretion and may be located near water, but shall not be located within 100 feet of another clump. Clumps may be adjacent to gaps.
- Leave trees were selected using a series of rules based on diameter, height-to diameter ration, and condition (health)
- Specific instructions to retain Pacific yew, understory (< 4’ height) conifer trees, and shrubs.
- Specific instructions to remove invasive species.

A second“Cell-based” prescription was also tried. It contained the following criteria:

- Following this prescription should result in approximately 20% of the stand remaining as gaps (no trees), 20% at a density of 50 trees per acre (tpa), 20% at 100 tpa, 20% at 150 tpa, and 20% skipped or untreated.
- The contractor will work within areas or “cells” of approximately 30 x 30 feet or 1/50th of an acre (visually estimated). There are five possible thinning prescriptions that could be applied to a cell (see below). A randomly chosen number between 0 and 4 determines the prescription that will be carried out within the cell.
- Each morning the crew foreman will supply each crew member with a random number table. This table defines the order that prescriptions will be applied to the cells completed that day.
- Thinning Prescriptions: (0) Gap; (1) 50 tpa; (2) 100 tpa; (3) 150 tpa (4) Skip

Lessons learned from thinning trials:

- Cell-based method did not work!! Too complicated, too expensive! (dropped method immediately, so no official cost estimate available)
- Good stand information is critical; prescriptions were developed using average stand statistics, but species were not evenly mixed throughout stand: ended up with wider spacing between trees of the dominant species than anticipated
    - Mixed-species spacing guideline can produce more heterogeneity in mixed stands but not in single-species stands
- Spacing prescription was successful in reducing densities, improving species composition, and retaining skips and hardwoods.
- There can be a higher upfront cost with heavier thinning
- Heavier thinning may preclude near-term commercial entry; if plan is to re-enter, a lighter PCT may be a better option

New PCT drop and leave prescriptions being applied at Ellsworth Creek and Willapa National Wildlife Refuge include the following elements:

- Leave trees are to be dominant or co-dominant trees of good form, with the largest diameters, and vigor.
- All conifer trees and red alder are acceptable leave trees; red alder trees that do not overtop dominant and/or co-dominant conifer leave trees shall be considered acceptable leave trees.
- Hardwood species, other than red alder, are not required to be cut.
- All conifers 11” or more in diameter are to be leave trees.

- All single red cedar and Sitka spruce of good form will be reserved from cutting, unless such a tree is within 8’ of another red cedar or Sitka spruce.
- Understory red cedar and Sitka spruce leave trees shall be thinned to an 8’ spacing regardless of the overstory leave tree per acre requirement.
- Leave tree preference shall be in accordance with the following descending priority order: (1) red cedar; (2) Sitka spruce; (3) Douglas-fir; (4) true fir; (5) hemlock; (6) red alder
- Areas with pure hardwood stands shall be thinned the same as conifer stands.
- Thinning skips:
- *Option 1*- within thinning units, for every 5 or 10 acres, leave a specified area unthinned or a skip area twice the diameter of the required leave tree spacing requirement. Preference should be give to random locations along streams, around springs, in sparsely stocked areas, and around natural openings.
- *Option 2*- each thinner shall be assigned to skip 15’, once per day, at an assigned hour of the day. Thinners will be assigned a different hour of the day to initiate their skip, to promote randomness.
- Required road brushing- for the designated existing roads within the thinning units, cut all conifer and hardwood trees and snags within 15’ of the road centerline and cut within 1 inch of the round level. All severed trees and slash shall be placed more than 15’ from the centerline of the road.
- Roadside clearing- pull back all slash created during the operations to a minimum of 15’ from the centerline of an existing road, and 15’ from the inlets and outlets of all culverts.
- Spacing requirements are expressed in “target” trees per acre with an acceptable minimum and maximum range, and by an associated spacing goal. Stocking target prescriptions vary depending on wind susceptibility, ownership, stand composition, beginning stocking level, place on the landscape, and future thinning opportunities. Density objectives range, as follows:
    - 14’x14’ leave spacing 211 TPA min 222 TPA target 233 TPA max
    - 16’x16’ leave spacing 169 TPA min 178 TPA target 187 TPA max
    - 18’x18’ leave spacing 127 TPA min 134 TPA target 141 TPA max
- Slash is not treated in any of the prescriptions. It is anticipated that the slash will break down in about 5 years from thinning. To reduce fire hazard, units with hazardous slash accumulations will have vehicular access gated during months of high fire danger.
- Approximate costs for Drop & Leave (PCT) Thinning:
    - Light initial stocking $90/acre
    - Medium initial stocking $125/acre
    - Heavy initial stocking $170/acre
    - Variable initial stocking $210/thinner day
        - Productivity ranges from 1.25 acres to 3.00 acres per day
        - Units will then range from $70 to $168 per acre

Lessons from new prescriptions (on-going):

- One thinning crew has been trained so far; They have done a good job, follow directions well, and engage in productive dialogue with forester to improve methods and meet goals
- Auditing is reasonable and straight-forward
- Method is reasonable to implement and meets goals/objectives to achieve variable density stocking at early ages in stand development, maintains various levels of heterogeneity/diversity within stands and across landscapes, and appears to be putting stands on trajectory to meet future desired conditions.

Save the Redwoods League (STRL) – Mill Creek

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STRL is focused on science and conservation planning and works only in redwood watersheds. The Mill Creek watershed in northern California is owned by California state parks. The primary goal at Mill Creek is to restore late-seral forest characteristics. STRL created an advisory committee to assist the state parks with restoration. It is a very diverse area, spanning 15 different plant community types, and protects anadromous streams.

Past forests of Mill Creek were heavily redwood dominated with a high component of Douglas-fir. Historically, tree densities were approximately 30-50 trees per acre (tpa), with species composition dominated by redwood (approximately 80%) with lesser amounts of Douglas-fir (approximately 20%). Mill Creek now consists mostly of very dense, young, managed forests with a high road density. Stand tree densities can be as high as 1500 tpa and Douglas-fir now dominates stands (approximately 80%) with only a small amount of redwood (approximately 20%). Most stands (approximately 70%) are not yet of commercial value.

Not much research exists in the redwood forest type, so they must ‘borrow’ a lot of research from Douglas-fir forest type. Redwoods are more shade tolerant and wind-firm than Douglas-fir, so they are uncertain how well this information applies to the redwood forest type. Fire risk is also a huge concern due to the high tree densities. To deal with this, thinning must be distributed to discourage fuel connectivity. In addition, slash must be addressed because it can create ladder fuels for about 4-5 years.

STRL is currently working with foresters and forest ecologists from the state and national parks to develop management objectives for the young forests. Due to the high amount of young forest on the landscape, they must prioritize their management. In general, if there are greater than 600 tpa, they are using PCT. If there are less than 600 tpa, they are waiting until stands mature to do a commercial thin.

A variety of PCT prescriptions are being tried at Mill Creek. Due to extensive road decommissioning efforts, future re-entries are uncertain, so most stands are treated as a single entry. Accordingly, they are thinning to low densities and trying to incorporate variation into the spacing.

PCT prescriptions currently being tried include:

- 16'x 16' ± 4' spacing (approximately179 tpa)
- 20'x 20' ± 4' spacing (approximately 109 tpa).
- Combination of 16'x16' and 20'x20' spacing by assigning different spacing to crew members by tying different colored flagging to their saws (flagging color indicates spacing assignment)
- Visualized 50' "cut" circles and 12' leave areas between circles (circles each contain approximately 3 leave trees)
- Slash is not treated in any of the prescriptions; exception is slash within 50' of road which is lopped and pulled 50' from road to create a 'fuel break'
- Thinning redwood clumps is not included in any PCT prescription because of concern that many will be lost anyway to bear damage; may thin clumps during commercial thinning

Lessons from PCT prescription trials so far:

- The flexibility in spacing is intended to increase variation, but contractors are reluctant to do it if they can thin evenly and not get in trouble (have to work with contractors).
- There is heavy bear damage in area; 20'x20' spacing may be too wide with bear damage
- The 20'x20' spacing may pose a greater fire risk due to the increased amount of slash generated
- Both 16'x16' and 20'x 20' spacing prescriptions average approximately $200-$250/acre (more expensive the first year)
- Prescription that mixed spacings using color assignments made it difficult to monitor crew, was hard to audit, and was more expensive (estimate of $270/acre) than single spacing prescriptions.
- Visualized circle technique was very expensive initially (estimate of $400/acre); once contractor understood method (second year), cost dropped significantly (estimate of $195/acre).
- Visualized circle method gives desirable 'messy' appearance, but can be difficult to monitor; works best with consistent thinning crew that can easily understand objectives.
- No problems with regeneration through slash; biggest problem with slash is that it creates difficulty for compliance monitoring (best to do it as crew is working)
- Unsure what effects wider spacing and/or slash may have on bear damage
- Working with one contractor has made it easier to communicate objectives and prescriptions.

- English speaking foreman on crew is very helpful

They are planning to monitor treatments over time. Most of the PCT prescriptions have been set up to compare the treatments to each other. In addition, LiDAR has been flown over entire area and they intend to use it for management and monitoring. Long-term plots are also being used to monitor tree growth, canopy cover, and wildlife habitat.

U.S. Forest Service (USFS) – Mt. Hood National Forest
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Currently on the Mt. Hood National Forest, there is a backlog of approximately 15,000 acres of young stand thinning (PCT). However, very little money exists to do the work. Recently some funding has been secured through the use of stewardship contracts and community projects. Stewardship contracting has the benefit of increasing collaboration with local groups, leading to fewer lawsuits.

The USFS definition of young stand thinning generally includes trees less than 4 inches diameter and 20 feet in height, though some trees up to 6 inches in diameter may be thinned. USFS goals for young stand thinning include: (1) maintain and enhance species diversity, (2) encourage understory vegetation and wildlife forage, (3) maintain and improve growth of conifer species, and (4) restore Riparian Reserves and Late Successional Reserves by thinning to accelerate the development of mature and late-successional characteristics. Mt. Hood Forest PCT prescriptions typically thin stand to approximately 200-250 tpa. In order to maintain flexibility for a later commercial thin, PCT is usually kept basic with the intention of introducing complexity later with a commercial thin.

PCT prescriptions generally adhere to the following guidelines:

- Maintain species representative of stand – this takes into account uniqueness of stand (allows retention of major and minor species)
- Maintain hardwood shrubs as much as possible
- Cut trees left on ground (reduce height of slash)
- No thinning within 20’ of streams, but use girdling near some streams
- Thin at 15’ spacing with 25-50% variability in spacing
- Maintain a residual density goal, but permit flexibility in spacing
- If disease is present in stand (e.g., white pine blister rust), incorporate it into prescription (e.g., if anticipating future mortality, may leave areas unthinned or lightly thinned)
- Do not purposefully incorporate ‘skips’ into PCT, but with 25-50% variability in spacing, some of this is obtained

The Nature Conservancy – TNC & USFS Tongass National Forest collaboration
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TNC is partnering with the USFS in southeastern Alaska to develop a restoration strategy for Prince of Wales Island. This area is highly productive forest, consisting mostly of mixed Sitka spruce and western hemlock. Approximately 200,000 acres are 20-40 years of age, with very little over 50 years old. There is also a high road density (~3000 miles of roads).

Restoration on Prince of Wales is very focused on wildlife goals. Their primary goal is to maintain an intact population of top predators (e.g., wolves) on the island and there is interest in developing watershed restoration priorities that target salmon and deer habitat. Currently, they are struggling with what to do and how to do it. Young stand thinning can be problematic due slash accumulation and the negative impacts this can have on deer survival.

City of Seattle – Cedar River Watershed
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The Cedar River Watershed is a 90,000 acre watershed owned by the City of Seattle that provides the majority of the region's water supply. A habitat conservation plan designated the entire watershed as an ecological reserve with a management emphasis on restoration and no commercial forest management. Approximately 15,000 acres of forest are less than 40 years old and approximately 56,000 acres are over 40 years old. They are prohibited from designing treatments to generate revenue (i.e., 'commercial' thinning is not permitted; thinning conducted in watershed is instead called 'restoration' thinning). The watershed spans the western hemlock, Pacific silver fir, and mountain hemlock forest types, in some of which little scientific information exists to guide restoration activities; thus, they must 'borrow' science mostly from Douglas-fir forest type. It is unclear how well this information applies, for example, to the Pacific silver fir forest type.

In such a large watershed, priorities for restoration thinning must be set. A candidate pool of stands to be thinned was developed using a landscape synthesis which sought to create synergy across the watershed and helped define areas to target and how to best coordinate resources among upland, riparian, and aquatic restoration programs. Stands less than 30 feet in height were first selected using LiDAR data. Selected stands were then evaluated and ranked based on proximity to three priority habitat types: (1) fish habitat, (2) old-growth forest habitat, and (3) special habitat areas (e.g., rock outcrops or wet areas). Once a candidate pool of restoration thinning stands was developed, it was overlaid with road decommissioning areas to determine areas that were operationally feasible or prioritized for road decomissioning.

Currently, a variety of restoration thinning prescriptions are being implemented at Cedar River. Prescriptions are based on landscape objectives, including large-scale seral-stage diversity, protection/promotion of unique habitats, and wildlife corridors. For example, in meadows they are incorporating gaps to open the meadow, but also retaining a few clumps of trees to provide shade for amphibians.

Practices currently incorporated into PCT prescriptions include:

- Stands are often thinned to a certain density (e.g., 200-300 tpa) in a 'matrix' area.
- Spacing criteria varies, but is generally between 10' to 20'.
- Some prescriptions provide a general spacing (e.g., 14'), with guidelines to thin certain species further apart (e.g., 18').
- Some prescriptions are based on diameter limits (e.g., under 8", thin to a 14' spacing but do not thin anything over 10"). This can create high density patches and also create growing space for larger diameter trees.
- A proportion of the area is often designated for skips and gaps
- When skips are used, they are often located around certain topographic features such as swells, streams, and wildlife corridors
- Gaps are often used in areas where trees do not respond as well to widely spaced thinning or where fewer trees are desirable (e.g., meadows). In such cases, trees are thinned to a higher density spacing (e.g., 200-250 tpa) and several small gaps are created. Generally, 2-5% of an area is designated as gaps. One to two gaps/acre may be used, but can be limited to fewer gaps per unit if gap area is increased. Gaps can vary in size, but average approximately 30'-60' in diameter. In some cases, 1-2 trees are left in the gaps.
- A 'neighbor tree' concept is also occasionally used. A general spacing is employed, but near some trees, a few 'neighbor' trees are maintained (e.g., all trees within 4'-6' of a designated leave tree are maintained). The goal of this concept is to obtain more structural complexity than with a basic spacing and/or diameter limit.
- When done, slash treatment includes at least one of the following components: slash lopping, lopping and piling (creating slash-free space), and cable-yarding of slash out to facilitate wildlife movement.

Financial lessons learned:

- In general, more complex prescription are more costly to implement
- Heavier thinning can often increase costs
- On average, most of their prescriptions can be implemented for approximately $150-$270/acre, but can vary widely

- Slash treatment often averages $500/acre
- Slash treatment is generally limited to 10% of treatment area due to high cost of implementation

Ecological lessons are still being learned. Effectiveness of treatments is being monitored with long-term plots. Some key questions that they still struggle with include: What level of complexity is important? How do we obtain a more diverse species composition when species composition is currently species poor? What is the appropriate scale for introducing structural complexity? Do we need to impose structural complexity at an early age?

Washington Department of Natural Resources (DNR) – Riparian restoration on DNR lands

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Restoration efforts on DNR lands are mostly on stands over 20 years old, of which approximately one-third are in riparian areas. Most are in the Sitka spruce/western hemlock zone. Some stands were planted 2-4 times with Douglas-fir, but now have 1500 tpa of western hemlock. In many of these areas, the goal is restoration. The DNR primarily uses variable density thinning in riparian areas.

The DNR is conducting a study in 14-20 year old stands where they have reduced tree densities and created a systematic grid of gaps (gaps are approximately 100 feet apart). The goal of including gaps in the prescription is to restore the understory while keeping the overstory growing for later flexibility.

Oregon State University (OSU) – Synthesis and OSU & Oregon State Dept. of Forestry Young Stand Management Study

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Many people question the need to manage very young stands (typically less than 20 years old). However, some taxa (e.g., mosses and lichens) take a long time to disperse and waiting may preclude their existence in the stand. The Oregon Department of Forestry (ODF), which employs a structure-based management of young stands, collaborated with researchers from OSU to examine what, if anything, is lost if young stands are not managed until after they are approximately 20 years old.

In this study, a crown recession and density affect was evident in trees by age 13 and was more pronounced by age 20. After age 20, the crown radius began declining. This indicates that very young stands are quite dynamic and can change quickly. This suggests that, especially in areas of high productivity such as the Oregon Coast Range, postponing management until age 20 or older may reduce the options available to manipulate forest structure.

Another lesson from this study is that not every acre in the stand has to be managed for same objective. In many cases institutional constraints will define objectives over ecological objectives, so having flexibility in prescriptions will add options. In this study, they combined spatial diversity objectives and timber objectives by introducing gaps throughout the stand to increase spatial complexity and managing the remainder of the stand for timber. They also worked with variability already present by incorporating disease pockets and natural openings. By integrating new ideas with the existing standard management practices, 'new practices' can be more readily accepted.

Inclusion of gaps in thinning prescriptions has raised many questions that deserve attention. These include: Is management necessary to maintain gap functionality (i.e., what happens to gaps as stand closes)? What are the edge effects and how far do they persist? Does the impact of gaps scale up to the stand level (e.g., if 6% of stand is in gaps, does that matter to wildlife)? Will gaps act as inoculation centers for future understory plant communities or will they simply fill in with conifers and act as a second cohort?

USFS Olympia PNW Lab – Synthesis and Clearwater Study
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Young stands are often treated to change current or future conditions. There can be many reasons for this, including the creation of late-successional habitat, creating flexibility in the face of climate change, or other habitat goals. Stands are often treated while young to gain control over species composition or other structural features (e.g., tree spacing, density, crown height) that may become increasingly difficult to manipulate as stands age. However, it is likely unwise to treat all stands. Decisions regarding which stands to treat will likely involve the following criteria: (1) stand and/or landscape objectives, (2) access to the stand, and (3) resource availability (i.e., other competing priorities).

If obtaining late-seral conditions is a goal, a mix of treatments may be necessary. It is unlikely that one type of treatment will be best for meeting all objectives, even in one stand. However, the actual design of the treatment(s) will depend heavily on the starting conditions of the stand, the condition of surrounding landscape, forest type, and management objectives. It is also unlikely that treating a stand one time will achieve all objectives, though this too will depend on the factors listed previously. Planning for future entries will permit greater flexibility in management and prescription development. The ideal age that a stand should be treated will again depend on objectives and often on site productivity. For example, treatments may need to be done as early as 6-10 years of age on highly productive sites to obtain certain crown structural objectives.

An example of research that has investigated pre-commercial thinning in young stands (10-20 year old) is the Clearwater / Blue River Study. This study was conducted in young plantations and included a control, uniform thinning, and thinning with gaps. Gap size was randomly assigned by using a “chip” method. For this method, a number of chips of different colors representing different gap sizes were placed in a pocket and pulled to select the gap size while walking through the stand (sampling without replacement). Different color flagging was used to mark the gap centers, with the different colors representing different sizes of gaps. Different patterns of flagging (e.g., solid, stripes, and dots) indicated different species or species mixes to be planted in the gaps.

Eleven year results from the study showed that thinning increased average tree diameter and altered diameter distributions. Crown length (measured as height to live crown (HLC)) in uniformly thinned areas approached values in control plots rapidly, but remained much longer in treatments that included gaps. This illustrates that stands can change very quickly, but it depends on initial objectives if the change is good or bad. Once crowns have receded (i.e., lower branches on the bole have died) it is rarely possible to reverse the trend. It also indicates that if management concerns include crown attributes (e.g., HLC), stands must be treated early.

The Fall River Long Term Site Productivity Study investigates the impacts of removing biomass on site productivity. This study was conducted on a very productive coastal site in western Washington and included a wide range of woody organic removal treatments as well as treatments with vegetation control, compaction, and tillage. Biomass removal had little impact on nutrient pools at this site, likely because this site already had high pools of nitrogen and carbon in the soil and the above-ground biomass amounted to only a small percentage of the total nutrient pool (Ares et al. 2007b). Removing it, therefore, had little impact on growth of planted Douglas-fir trees (Ares et al. 2007a). The study also found no negative effects of compaction (Ares et al. 2005). This indicates that, on some sites, biomass removal may have little or no impact and soil compaction may not always be problematic.

The Olympic Habitat Development Study investigates thinning in slightly older stands (40-70 years) on the Olympic Peninsula. The study uses variable density thinning and manipulations of coarse woody debris to try to accelerate the development of stand structures and plant and animal communities associated with late successional forests. Information is available on study implementation (Harrington et al. 2005), windthrow and logging damage (Roberts et al. 2007), and on differences in tree growth associated with thinning and with the edges around skips and gaps (Roberts and Harrington 2008).

USFS Portland PNW Lab – Synthesis and LOGS Study

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When developing current restoration treatments, it is important to look at past work to better understand potential treatment impacts. The Levels of Growing Stock Study (LOGS; Marshall and Curtis 2001) is a very controlled experiment testing different thinning intensities on tree growth. The study was not intended to examine thinning as a restoration tool, but it still provides extremely valuable information regarding tree response to thinning. The study has demonstrated that the thinning can affect the Height:Diameter (H:D) ratio, which can be a very good indicator of stability. The control (unthinned) has a lot of unstable trees while all trees are stable in the heavy thin. It has also demonstrated the trade-offs of short-term loss versus long-term benefits that must be considered. For example, a heavy thin at age 15 may not benefit certain wildlife species, whereas 30 years later, that heavy thin may provide substantial benefit to those species.

Two types of thinning prescriptions that may be useful when trying to keep PCT basic are slot thinning and the Monte Carlo approach. Both prescriptions require good pre-treatment stand information. Slot thinning requires good stand data in order to generate diameter distributions. An understanding of the spatial variability of the stand is also useful to avoid over/under thinning areas where the diameter distributions are unbalanced. For slot thinning, a "slot" can be thought of as a diameter class. Based on objectives and pre-treatment data, decisions are then made based on which 'slots' should be removed and if they should be completely or partially removed (e.g., remove every tree in the 12"-15" diameter class, regardless of species). This prescription is fairly straight-forward to audit. The Monte Carlo approach basically requires three decisions to be made: (1) what ratio of leave patches to gaps is desired in the stand? (2) how many trees will be left in each patch? and (3) how many trees will be left in each gap? The stand is then walked and a random selection system is used to distribute the leave patches and gaps. Auditing this prescription can be slightly more difficult, but can be done using a probability distribution.

Perhaps the most primary threat that is going to affect all forest restoration actions in coming decades is climate change. It will impact everything. This raises many questions that should be considered while making current management decisions. Future climatic conditions may be unfavorable for many of the present understory species, potentially voiding any current efforts on managing the understory. In addition, one should consider what the long-term targets are. In this context, the trees or understory species that are there may no longer be a factor under future conditions. Another matter is if managers should consider the introduction of species that are not present currently but whose ranges are expected to expand or shift under different climatic regimes.

APPENDIX B

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