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Guide to Variable-Density Thinning Using Skips and Gaps

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Cover: A stand in Nisqually State Park near Eatonville, Washington, immediately after the implementation of a variable-density thinning treatment using skips and gaps. Photo by Leslie Brodie.

Abstract

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In recent years, many forest managers have become interested in managing forests for a wider range of objectives than previously. As an initial or intermediate treatment, variable-density thinning (VDT) can help meet objectives such as improving wildlife and plant habitats, increasing structural and compositional diversity, and enhancing aesthetic values in stands that are currently lacking spatial variability. The "skips and gaps" method of VDT is flexible, allowing for the preservation of existing desirable features. Areas that are not thinned ("skips") will protect existing features that are best preserved by being within an area where logging equipment is excluded. "Gaps" can be created to closely approximate natural disturbance regimes through harvest of small groups or patches of trees. Gaps can increase growth and crown lengths of neighboring trees. Furthermore, gaps can be created that favor underrepresented tree species that are either already present or are planted after treatment. Areas that are not within skips or gaps (the "matrix"), are thinned to encourage growth of the overstory trees and the development of understory plants. This publication demonstrates the steps necessary to implement this type of VDT based on lessons learned from eight sites on the Olympic Habitat Development Study and two western Washington state parks.

Keywords: Variable-density thinning, stand management, Douglas-fir, gaps.

Contents

Introduction

In the Pacific Northwest, many forest management objectives have focused on creating and maintaining stand homogeneity to improve the efficiency of timber production. Even-aged stands with uniform spacing make the logistics of stand management relatively simple. Greater diversity in spacing, species distribution, and tree age classes, however, provides a variety of microconditions favorable to different understory plant and wildlife species (Beese et al. 2019a, Frey et al. 2016, Wilson and Puettmann 2007, Zobrist and Hinckley 2005).

Thinning is an intermediate or mid-rotation stand treatment designed to reduce stand density. Traditional uniform thinning generally increases stand uniformity by leaving trees spaced to increase individual tree growth and maintain consistent volumes across a stand. The primary goal is typically wood production; however, other objectives, such as reducing resource competition or promoting understory production, may be important outcomes. Variable-density thinning (VDT), on the other hand, is designed and implemented to deliberately increase the variability in the stand. Although trees are harvested during VDT—either to produce raw materials or provide funds to support other activities—the primary purpose of most VDTs is to enhance wildlife habitat and biodiversity while improving forest health and aesthetic values (Wilson and Puettmann 2007, Zobrist and Hinckley 2005).

VDT is one possible component of a comprehensive management plan. It is intended to move the stand's development toward greater compositional and structural complexity. VDT can increase the spatial and structural variability in a stand by creating conditions that retain or increase crown lengths, promote residual overstory tree growth, and encourage growth in the under- and mid-stories (Comfort et al. 2010, Willis et al. 2018). VDT, however, as a single, intermediate stand treatment, is not likely to result in significant long-term tree regeneration—such as in an uneven-age management system—unless further stand entries (and possible plantings) are made.

The increase in complexity of forest structure implies an increase in operational complexity. Marking an even-aged stand for a uniform thinning is a relatively simple process. Marking or cutting crews can select "leave trees" based on systematic spacing and desirable crop trees that will result in the target number of stems per unit area. By contrast, marking a VDT may require a higher skill, depending on the method used.

Several approaches have been proposed and used to start the process of converting structurally simple stands (those with few canopy layers, even spacing, or those that lack species diversity) to stands with greater complexity (fig. 1). These include using a grid or within-stand stratification to identify "cells" thinned to

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Figure 1—(A) Even-aged stands may have some degree of stem size differentiation and understory development but generally have much less structural variation than (B) late-successional stands or those managed specifically for variation in stem size and number of species.

multiple density levels (Carey et al. 1999, Knapp et al. 2012, O'Hara et al. 2010), or thinning based on tree characteristics such as diameter rather than spacing (Keyes et al. 2010), which relies on the natural variability of individual trees in a stand to determine spacing. Other approaches can be complex without providing the flexibility to adjust to specific sites. For example, one approach systematically places circular clearings containing a few released individuals of underrepresented species within a matrix of thinned and reserve areas (O'Hara and Oliver 1999). Although all these approaches can be successful at increasing stand complexity, they vary in difficulty of implementation. Generally, those that are easiest to implement are least effective at creating stand heterogeneity (O'Hara et al. 2012). VDT systems that are implemented by marking and cutting trees at the same time require a greater skill level on the part of the fellers because either randomized cell thinning levels are designated in the field or varying plot sizes based on tree characteristics require field personnel to visualize varying plot sizes on the ground. Although thinning using skips (untreated areas) and gaps (small patch cuts) requires some additional layout work, the majority of the stand (the matrix) can be marked and thinned using uniform thinning practices that are easier to implement.

This guide demonstrates the steps necessary to implement a VDT operation using the skips and gaps method. Although this method requires two or more site visits to lay out the thinning operation, it is relatively easy to implement. It also has the benefit of prioritizing placement of small gaps and no-entry areas to promote or maintain stand elements that already exist—an important factor for maximizing the effect of the treatment (Brokaw and Busing 2000, Kern et al. 2017, Puettmann et al. 2016). The first visit identifies the features that are desirable to preserve or enhance (e.g., release a desirable tree or species, or protect large coarse woody debris) and the second is used to mark treatments around the selected areas that have been identified. Although the preliminary stages require the ability to identify desirable features, this is a relatively short phase of the process. Once the skip and gap areas have been identified and marked, the majority of the stand (the remaining matrix area) can be marked or thinned using more traditional systematic thinning protocols.

Prescription Overview

Both traditional uniform thinning and VDT have multiple beneficial effects. Thinning helps to maintain high crown ratios and low height-diameter ratios that generally exist before the stem exclusion stage (Tappeiner et al. 2015). Thinning also allows development of understory tree, shrub, and herbaceous species and promotes the early, rapid diameter growth that has been thought to be a common characteristic in many old-growth stands (Tappeiner et al. 1997).

Timber production strives to maintain a balance between providing enough space for tree growth and maximizing the number of trees per acre. Managing stands for wildlife habitat, biodiversity, or forest health, however, generally requires more open stand conditions than those associated with timber production (Hanley et al. 2005) because larger crowns provide more area for some species to nest and forage (Hayes et al. 1997). The goals of VDT are to promote variation in vertical structure and a greater number of tree and understory species by introducing horizontal variation across a stand. This generally will involve the development of multiple tree size classes through thinning and gap creation (O’Hara 2014), releasing individuals of lesser represented tree species, and creating a wide range of microsites for development of understory species. Also of importance is the increased growth and crown development of the trees on the edge of gaps and in the more uniformly thinned areas. Depending on initial stand conditions, achieving these goals may involve several stand entries or include additional treatments such as planting or snag creation. Thinning with the skips and gaps method uses three levels of thinning intensity: skips, gaps, and matrix (table 1; figs. 2 and 3). The three levels of thinning intensity provide a wide range of microsites favorable to multiple management objectives.

Table 1—Attributes of uniform and variable-density thinnings

Attribute	Uniform thinning	Variable-density thinnings
General purpose	Produce wood, increase tree growth.	Allocate areas for wildlife habitat or biodiversity; will also produce wood.
Specifications	Percentage of trees (basal area or volume) to be removed; relatively uniform spacing of remaining trees; basal area or volume of residual stand; marketable species with few defects favored.	Number and size of gaps; species to remain in gaps; number and size of skips (equipment permitted?); thinning specification in matrix could be similar to those in uniform thinning or implemented in more complex fashion based on stand conditions and objectives; less common tree species or individual trees with high wildlife value can be favored.
Reserve areas	As part of landscape (e.g., riparian reserves) or if within stand, based on nest tree or similar restrictions.	Typically incorporated within stand to protect snags, coarse woody debris, understory plants or other special features. Provide areas with greater cover (shading) and more moderate temperature extremes.
Gaps	Not usually included.	Included to increase tree growth and crown retention in trees in and around gaps and to increase light to promote understory development.

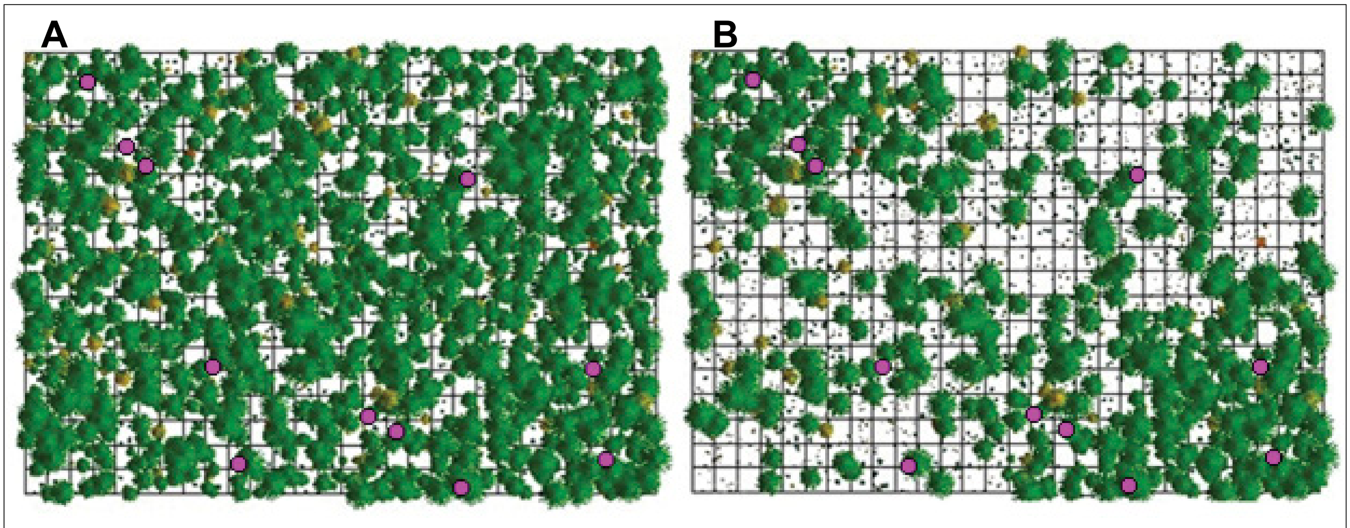

Figure 2—Aerial view of thinning using skips and gaps; (A) prior to thinning—snags are marked in bright pink and (B) post thinning—skip areas (no treatment) can be seen in the upper left and lower right corners. Small gaps are created to promote the development of less abundant species and enhance or retain tree crowns adjacent to the gap. Secondarily, gaps provide a microsite for less shade-tolerant species. The remaining matrix is moderately thinned, thus maintaining the healthy development of dominant and co-dominant trees in this portion of the thinning.

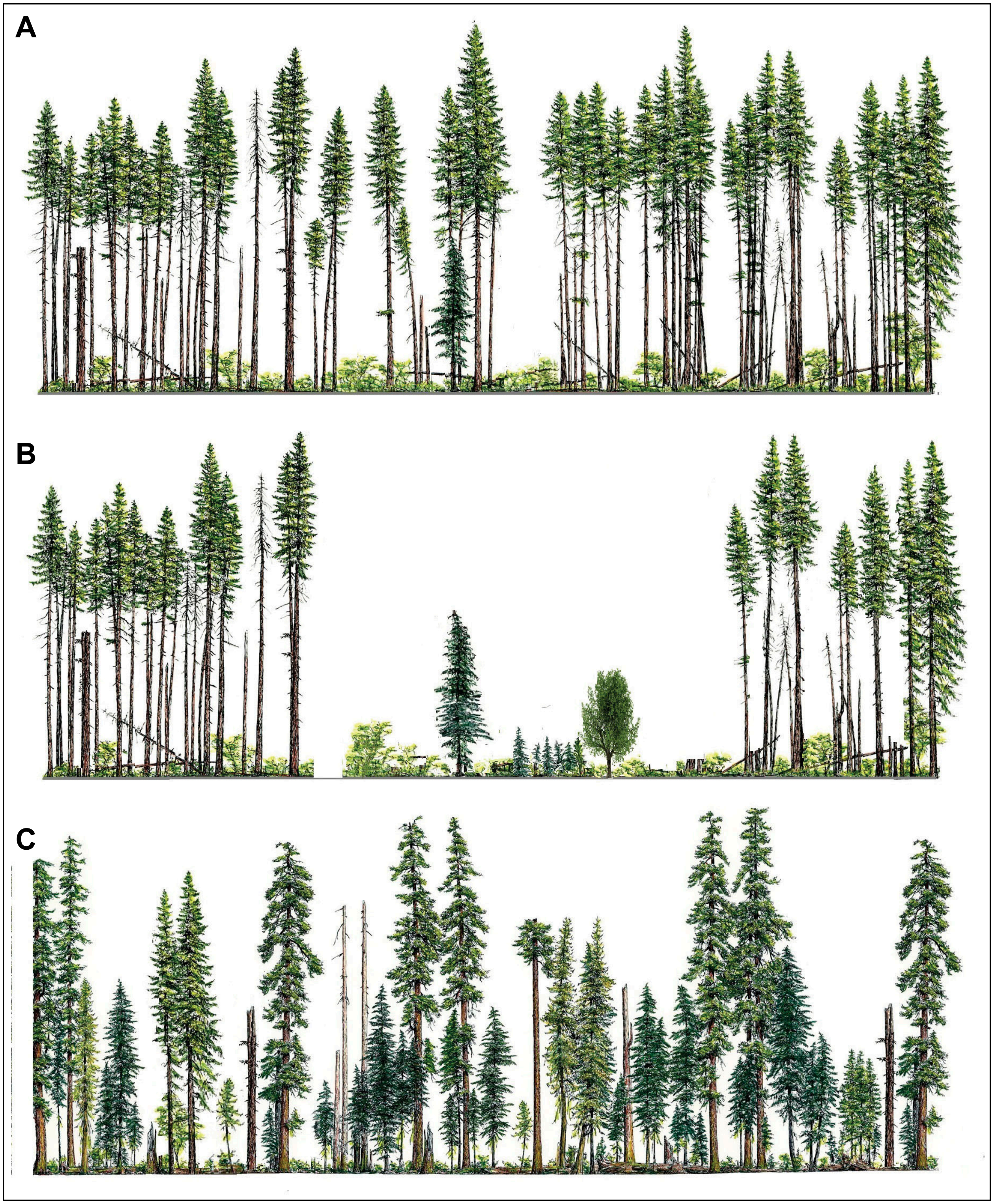

Figure 3—(A) Depiction of an even-aged stand with little variance in age classes or species composition. (B) Depiction of how the even-aged stand might be thinned using skips and gaps to accelerate the development of structurally complex features, some of which may develop to be functionally similar to (C) a late-successional forest. The area on the left of the thinned stand (B) has been designated as a skip where no equipment will enter. The gap in the center will allow for the development of existing shrubs and under- or mid-story trees. Gaps can also be planted with additional species. The area to the right has been thinned to promote the development of larger diameter trees and to provide an intermediate level of canopy cover favorable to some species (diagram modified from Van Pelt 2007).

Skips

Skips are reserve areas that are not thinned These will help protect existing features of interest that are best preserved by being within an area where logging equipment is excluded. For example, large-diameter coarse woody debris and standing dead trees provide wildlife habitat and favorable plant microsites, but are likely to be considered obstacles or hazards during a logging operation (fig. 4). Skips also serve as small refugia for shade-tolerant plant species and wildlife sensitive to thinning activities (Hayes et al. 2003). They also provide habitat for species that favor the dampened temperature extremes and reduced snow depths that a dense overstory cover provides (Frey et al. 2016).

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Figure 4—Features that can be protected within a skip area include tall, large-diameter snags, large-diameter coarse woody debris, and areas that show indications of high wildlife use, such as woodpecker holes, dens, or burrows.

If there are not many features that warrant protection, the skips serve as untreated areas that allow portions of the stand to reach the stem exclusion stage of stand development and will produce small-diameter snags in the future. The snags produced may not be of the diameter needed to provide habitat for many wildlife species, but will eventually produce coarse woody debris material. Trees with slow growth rates can provide good substrates for epiphytes, and the cooler moister conditions created by the dense overstory may also benefit amphibians and other species.

Features that might indicate a potential skip location would include:

- Large-diameter standing dead trees or stumps
- Large-diameter, or a concentration of small-diameter, coarse woody debris
- Indications of wildlife usage (such as tree cavities, travel ways, dens, etc.)
- Concentrations of shade-tolerant or uncommon understory vegetation
- Any desirable features that are relatively uncommon and would be negatively affected by logging activity, such as seeps, sites of archeological importance, or old-growth individuals
- A location close to a road or adjacent property where buffering is necessary
- A location where added visual heterogeneity would be beneficial, such as close to a trail

In addition to the existing features that might be protected or maintained by skips, the location and shape of the skips need to accommodate the logging system that will be used. For example, cable logging systems might make it difficult to access an area directly downhill from a skip; thus, skips in these stands may need to be located at the edges of the harvest unit. For ground-based harvesting, location and dimension of skips should be considered in relation to skid trails—right-angle turns around the corners of skips can increase rutting and ground disturbance.

Gaps

Small-scale, low- to moderate-intensity disturbances (such as windthrow or disease pockets) are the most common factors that lead to horizontal structural diversification in natural stands and are an important factor in forest dynamics (Spies et al. 1990). Artificial gaps can be created to closely approximate natural disturbance regimes through harvest of small groups or patches of trees (Franklin et al. 2002). Furthermore, gaps can be created that favor existing underrepresented tree species; this will release these trees from competition and favor their advancement into a mid-story or overstory position (Muir et al. 2002). The gaps will also provide sites where species that are resistant or immune to existing pathogens such as *Phellinus* root rot can be planted. Such species might include bigleaf maple (*Acer macrophyllum* Pursh), western redcedar (*Thuja plicata* Donn ex D. Don), and western white pine (*Pinus monticola* Douglas ex D. Don). The incidence of invasive plant and shrub species may initially increase within created gaps but is expected to decrease after 3 to 5 years when the crowns of overstory trees expand and provide additional shade in the openings, and the preexisting advance regeneration and shrub species develop (Tappeiner et al. 2015). Invasive species with some shade tolerance, such as Robert geranium (*Geranium robertianum* L.) or English holly (*Ilex aquifolium* L.), may require additional treatment to reduce their cover or future spread within

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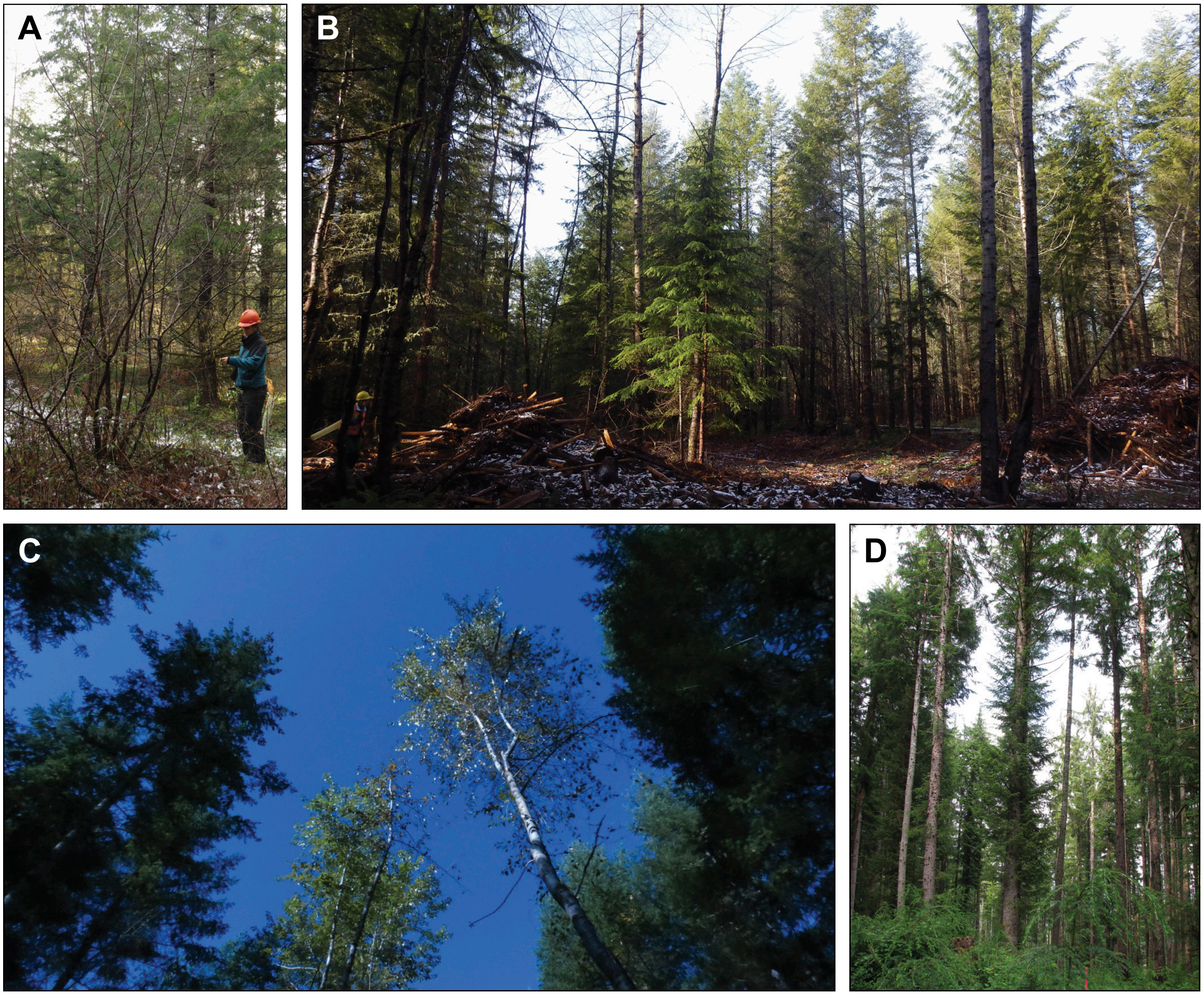

Figure 5—Gaps can be placed to encourage the development of (A) understory shrubs, (B) mid-story trees of desirable species, (C) crowns of specific overstory trees, and (D) vertical differentiation of crowns along gap edges.

the stand. Gap features (fig. 5) will be subjected to hazards caused by felling and skidding activities. For logistical reasons, gaps often become landings and staging areas. It is therefore important that gap features that are desirable to retain are clearly marked with flagging or some other indicator. Potential gap locations are indicated by the following:

- Existing gaps that are suitable for planting and that can be enlarged on the leeward side (to prevent wind damage)
- The presence of underrepresented tree species or large shrubs that could benefit from overstory release

- Areas where patches of advanced regeneration could rapidly advance to the mid-story if released
- Trees with large crowns or trees of desired species that could be favored on the edge of a gap

Matrix

The matrix area is the portion of the stand between the skips and the gaps (fig. 6). Thinning in the matrix can be accomplished much as thinning has been completed under more traditional silvicultural regimes, or, could be more variable in terms of spacing and species retained. Although the trees removed from the gaps may provide much of the volume for the project, determining the method and level of thinning within the matrix will also have a significant role in determining the financial viability of the project. Maintaining a higher retention level in the matrix of the stand will reduce the spread of exotic species within the stand and the risk of windthrow. Thinning at heavier levels will produce more harvested volume, sustain or increase diameter growth of residual trees for a longer period of time, and allow understory shrubs and regeneration to develop. The reduced canopy cover, however, may also encourage the growth of invasive species already present on the site (most notably, species such as Scotch broom (*Cytisus scoparius* (L.) Link), Himalayan blackberry (*Rubus armeniacus* Focke), and evergreen blackberry (*Rubus laciniatus* Willd.). Additionally, thinning to widen spacings may increase the risk of subsequent wind damage, especially in stands with a high height-diameter ratio (Roberts et al. 2007).

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Figure 6—The three components of variable-density thinning: the gap is in the foreground (note the hardwood tree that has been released on left edge), the dense skip can be seen in the background to the left, and the thinned matrix is in between.

Assessment of Current Stand Conditions

The primary objective of the initial stand assessment is to determine if thinning would help to achieve objectives more completely or more quickly. A pretreatment inventory will also determine the potential to augment variation within the stand that was not apparent from previously collected information and to assess the financial feasibility of the undertaking. Volumes can be estimated after skips and gaps are established by attributing the pretreatment inventory estimations to the relevant portions of the stand. Gaps will be considered as very small clearcuts, matrix areas can be considered as a more traditional thinning operation, and the area within the skips will be subtracted from the total area.

First, consider if the area to be thinned should be broken into separate subunits. It is important to consider not only the mean of stand attribute values, but also the range of attribute values present. The same differences that may prompt stratification of the inventory protocol—differences in stand origins, histories, or factors affecting growth and development—are likely to trigger differences in thinning prescriptions. For example, previous treatments may have resulted in one portion of the potential VDT area having larger and more widely spaced trees. In another area, topographical positioning may have resulted in extensive blowdown. Differences such as these might require different sampling intensities for the preharvest inventory and might also require different gap sizes or thinning intensity in the treatment design. Other areas that may need to be identified as subunits include buffers for adjacent land ownership and riparian or other sensitive areas that should not be crossed by equipment. Sources of information for determining if stratification is necessary might include historical records, aerial photographs, LiDAR data, topographic maps, on-the-ground observations, and administrative boundaries.

The survey for "features" can be completed either separately or concurrently with the stand inventory or as part of other required surveys (such as for threatened and endangered species). Existing gaps should be mapped if possible. If recent aerial photos for the area are available, this is relatively straightforward using a geographic information system to delineate openings. It is not necessary to document the presence of every small gap within the canopy; however, the locations of larger gaps (those wider than average overstory tree height) will give some indication of existing spatial variability within the stand. Also, it is often within or adjacent to existing gaps that increased light availability has encouraged the development of understory tree and shrub species. If these larger specimens are to be protected during the logging operation, the larger gaps need to be identified and included in the initial survey. If aerial photos or LiDAR data indicate that an area has greater variability in crown sizes or spacing, it may be advisable to increase the intensity at which features are searched for. It is reasonable to assume that relatively homogenous areas need less sampling than those that are more variable.

Mapping features on the ground can be easily accomplished through the use of handheld global positioning system (GPS) units with good accuracy under forest canopy. Waypoints are established using a naming convention, and further detailed information and photos can be recorded separately (see app.).

Transecting the treatment area for the purposes of finding and recording features that indicate areas of potential skips and gaps also presents an opportunity to document other important habitat features. Such features might include the following:

- Invasive species that might be considered for treatment before or after logging; the presence of these species might also make a specific location less desirable for the creation of a gap
- Skid trails from previous logging that could be of use for the current operation
- Pathogens such as root rot, mistletoe, bark beetle, etc.
- Administrative boundaries
- Signs of public use (horse trails, garbage dumping, etc.)
- Riparian areas, seeps, and steep slopes

Layout of Skips and Gaps

The percentage of area to be designated as skips, gaps, and matrix depends largely on the current stand conditions and the management objectives. The edges of skips will receive additional sunlight from adjacent thinned areas; therefore, if maintaining areas with a dense overstory within the stand is desired, skips need to be of adequate size to have a "core'" to fully provide that end of the stand density spectrum in the VDT. However, minimum skip size needs to be balanced by the fact that areas designated as skips are essentially removed from the land base from which to generate revenue for the current harvest. Also, if they are specified as "no entry" areas for equipment, they may also present an obstacle for the removal of timber in other parts of the stand. The perimeters of skips need to be clearly marked so that the no entry policy can be easily followed (fig. 7).

Gap size and frequency are also dependent on management objectives. More numerous small gaps might seem less disruptive visually but may lead to increased damage to the retained trees. In addition, small gaps could result in the development of more shade-tolerant species than would occur in large gaps. Fewer large gaps would provide more opportunities for the development of less shade-tolerant species (including those that are planted), but might also encourage the spread of nonnative species that are present on the site. Implementing a range of gap sizes may make it

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Figure 7—Skip boundaries at the Nisqually State Park site (described in “Examples” on page 21) were clearly marked with either pink flagging or pink flashers (seen on the left of both photos). For treatment purposes, it is not necessary to distinguish between skip boundaries and exterior treatment unit boundaries as long as the sale contract indicates that no equipment enters areas delineated in this manner.

possible to meet several objectives. For example, in some cases, the removal of only a few trees can adequately release a tree of a favored species. In other areas, large gaps could be created (or enlarged) to facilitate the planting of less shade-tolerant species. These larger gaps can be especially valuable if root rot or other pathogens exist—they provide an opportunity to plant root-rot-resistant species. In areas where wind damage is a concern due to topography or high height:diameter ratios, it may be more prudent to enlarge existing gaps on the leeward side rather than creating new gaps. Enlargement on only one side should also help retain individual edge trees that are desirable because of their increased crown size. Placement of gaps away from skips will likely reduce the edge effect within skips and will allow some flexibility for possible expansion of gaps or skips in the future.

Gaps may be marked for cutting in several ways. If an area is to be cut-tree marked, each stem within the gap will be marked for cutting (fig. 8A). Alternatively, perimeter trees are marked and all trees within the gap are stipulated in the contract as trees to be cut (fig. 8B). This second method, however, can produce a gap that is difficult to visualize on the ground. In both cases, trees and large shrubs to be retained within the gap—those of underrepresented species to be released—should be flagged or otherwise marked so that they are clearly visible. A third method is to mark a tree as the center tree and stipulate that all trees within a given radius will be cut (figs. 8C and 9). The center tree itself can be either a cut tree or one that is desirable to retain and be released by the creation of the opening. This method is simple for both the marking and cutting crews. If gap sizes are variable within the stand, gap radius can be painted directly on the center tree. A series of marked center trees can be used to create elongated openings (fig. 8C).

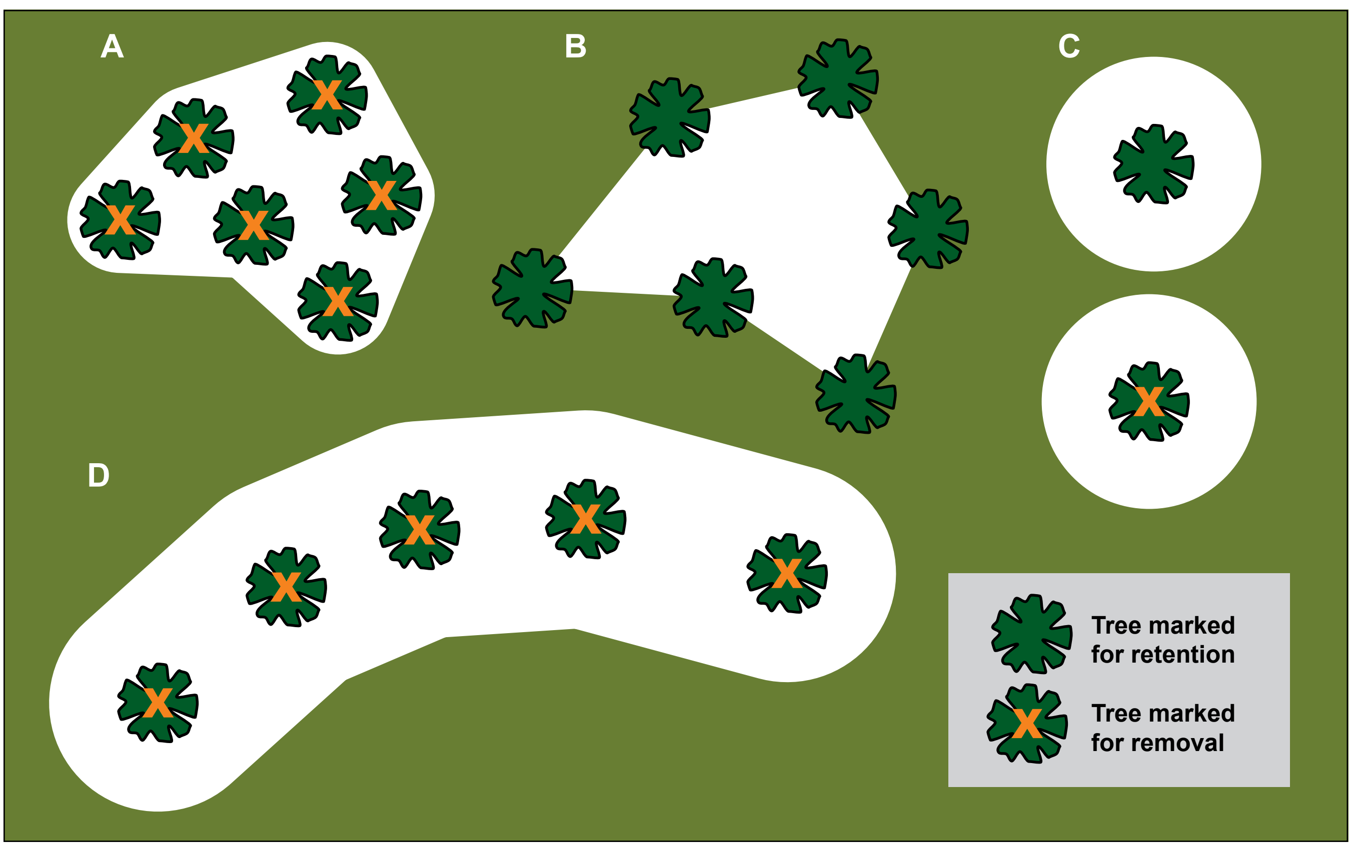

Figure 8—Gap marking examples: (A) cut trees are marked; (B) the perimeter is marked, (C) the center tree is marked, and the radius is stipulated (the marked tree can be a cut tree or a leave tree of a desirable species); (D) to create elongated gaps, a series of center trees are marked with a stipulated radius or distance to an uncut boundary.

Cut- or leave-tree marking is generally done with tree-marking paint and includes marking the stump so that appropriate harvesting can be verified post-treatment. Alternatively, marking the perimeters of skips and gaps can also be done with flagging, signs, or flashers; however, these can be easily moved or removed by others, which can complicate inspection for contract compliance. In either case, we have found it useful to apply GPS tags to perimeters (or centers in the case of small round gaps) to ensure good distribution throughout the stand and as a useful tool to document location.

Thinning the Matrix

In VDT, one of the goals within the thinned matrix area may be to promote the development of large-diameter trees. Although the objective and rotation length may differ from traditional silvicultural treatments that prioritize timber production, the short-term goals are similar. Diameter growth rates are inversely related to stand density, therefore, a reduction in density will increase the rate at which trees will grow. Although this is a simple concept, there are many means of achieving the same goal. Thinning from below (removing smaller trees) or crown thinning (reducing the density of the overstory canopy to release those that are most vigorous) may be the quickest path to large-diameter trees, but which trees are selected to favor will obviously change the outcome. Thinning operations aimed at maximizing the production of quality timber will favor uniform spacing of crop trees and fewer diameter classes, while thinning aimed at promoting species diversity and wildlife habitat may favor less represented species in both the understory and overstory. Additionally, those trees that may provide habitat for wildlife (those with broken tops, cavities, large branches, longer crowns, etc. [McComb 2015]) could also be selected as leave trees, and cut trees can be selected to release established mid- or understory trees.

Within the matrix, the choice to select one marking methodology over another is partially dependent on the resources and logging contractors available in the region. Some of the more common methods include individual tree marking with paint, Designation by Description, or Designation by Prescription (Dickinson and Cadry 2017). The different methods offer varying levels of control for the land manager and require different skill levels for both the contractor and the sale administrator.

- **Individual Tree Marking (ITM)**—Using tree-marking paint allows the land manager the most control over which trees are to be cut. Marking can easily be fine-tuned to individually release specific trees or to leave trees with high value to wildlife. Cut-tree marking (as opposed to leave-tree marking) would be the preferred ITM method in high-visibility areas. Tree marking, however, can be time consuming and costly in terms of personnel and paint, especially in dense stands.

- **Designation by Description (D × D)**—This method does not require that trees be pre-marked. The prescription to be used is described by the landowner or land manager and implemented by the logger. Because trees are selected and cut by the contractor, the sale preparation stage is greatly reduced. This method provides a balance between consistent spacing and some flexibility to select dominant or desirable tree species for retention. As an example, to achieve a 15-ft (4.6-m) spacing in a predominantly Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stand, a D × D spacing of 10 ft (3.0 m) is used. A tree to be retained is selected, and all Douglas-fir within 10 ft (3.0 m) are marked for cutting. The next tree outside of the cutting radius in the direction of travel is examined and considered the center tree for determining the next leave tree. All trees within 10 ft of this center tree are examined and the tree with the largest diameter (or all tree(s) of favored species) is selected for retention. Final spacing will have some variation, but will range from 10 to 20 ft (3.0 to 6.1 m) with an average of 15 ft (4.6 m). Use of "ghost trees" (trees of a specific species not considered part of the spacing) will also increase spacing variability. Monitoring compliance requires more time and skill than the ITM method and can only be achieved if selection is based solely on size and species. Other factors such as crown ratio or wildlife value cannot be determined from the stump. This method results in relatively uniform spacing of the predominant species.
- **Designation by Prescription (D × P)**—This method is also known as "operator's choice" and offers the land manager the least amount of control but is an option when the skill and experience of both the sale administrator and the contractor are known. As with D × D, trees are selected and cut at the same time. The D × P method designates trees for removal by describing the desired end result of the treatment. Within the prescriptions, very clear descriptions on desired spacing, basal area, species, and form preferences must be stipulated. D × P prescriptions can be complex and usually involve a certain amount of subjectivity on the part of the contractor. In situations where skilled contactors and sale administrators are available, this method can save time and expense in sale preparation; however, if the treatment goal is quite complex, it may be difficult to write a D × P contract with specific enough guidance to achieve the desired objectives.

Several tree selection methods can be used or even mixed. For example, in a stand with D × D or D × P used as the primary selection method, it might be desirable to use the ITM method in a highly visible strip along a trail or in a small area where multiple high-value wildlife trees exist. It would also be possible to premark a few critical trees for either retention or cutting prior to a DxP thinning operation.

The thinning intensity level within the matrix could depend on the same factors that a traditional systematic thinning would use as criteria. These include current relative density, height:diameter ratio, species composition, age, and factors that increase the likelihood of wind damage such as topography, soil type, and the presence of root rot. Non-uniform thinnings, however, can also vary spacing based on distance to a gap, presence of snags, or other factors. The "Individuals, Clumps, and Openings" method, for example, was designed to restore the clumpy, mosaic pattern common in pine and mixed-conifer forests east of the Cascade Range (Churchill et al. 2014). It is important to keep in mind, however, that the majority of priority stand features that need to be protected or enhanced have already been addressed by the designation of the skips and gaps. One of the advantages of using skips and gaps is that the majority of the stand—the matrix—can be treated using standard thinning procedures if desired.

The addition of the gaps within the matrix increases the risks of wind damage over a traditional systematic thinning (Beese 2019b). It would therefore be prudent to thin on the lighter end of the range that would be recommended for uniform thinnings if the stand has a high height:diameter ratio. Blowdown, however, may not necessarily be considered a problem if the recruitment of additional coarse woody debris is an objective. The number and frequency of potential future entries is also a consideration. In some cases, old roads or skid trails have acted as linear gaps within the stand, resulting in increased size or species diversity along the edges. In these cases, it may be beneficial to slightly increase thinning in these areas to release individual trees.

Additional and Future Treatments

In addition to thinning, other treatments can be used to promote habitat complexity. Underplanting (fig. 9A), coarse woody debris augmentation (fig. 10), and snag and cavity creation all add to stand complexity and provide a wide range of microsites.

Underplanting should be accomplished relatively soon after logging operations are completed to minimize the effects of competing vegetation. Species selection would be site as well as microsite specific because gap sizes (and therefore light availability) will vary. Species that are preferred for browsing, such as western redcedar, may need protection when planted because the increased shrub and forb production in the gaps are likely to attract foraging animals (Forbes et al. 2016).

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Figure 9—Using a center tree to mark a gap location makes it simple for the marking crew. (A) In this case, the maple to be released was used as a center tree. During the assessment stage, it was marked with flagging as both a feature to be retained and a possible gap location. Later, it was painted with "G30" to identify it as a center tree in a gap with a radius of 30 ft (9.1 m), similar to (B) a Douglas-fir in another gap. Note the redcedar seedlings in plant protectors planted after logging (A).

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Figure 10— (A) year 1 (2001), (B) year 6 (2007), (C) year 8 (2009). Coarse woody debris can be augmented by creating small log piles. These serve as nurse logs for small trees and substrate for mosses and lichens. In addition, they provide protection and foraging grounds for terrestrial amphibians, small mammals, and birds. These structures, located on the Olympic Peninsula, were created with postharvest blowdown and additional trees, which were piled with a chainsaw-powered winch.

Retention of coarse woody debris is beneficial for small mammal habitat (Carey and Johnson 1995). Creation of coarse woody debris structures may be desirable because logs supported aboveground may have slower decay rates and greater longevity than those in contact with the ground. Interstitial spaces will provide additional habitat for amphibians and small mammals. Coarse woody debris structures can be completed either when equipment is present during harvest or 2 to 3 years after thinning. It is logistically easiest to create coarse woody debris structures while the logging equipment is still onsite, and it also eliminates the need to disturb understory vegetation a second time. Contracting restrictions for some agencies, however, may not permit combining timber sales with other activities. Creating coarse woody debris structures 2 to 3 years after logging also allows post-logging windthrow to be incorporated into the new structures. Alternatively, creation of coarse woody debris structures, snags, and cavities by nonmechanized means can be completed at a later date when resources allow. If current tree size is relatively small, postponing snag or cavity creation may be desirable. Trees within the thinned matrix will grow more rapidly after thinning and should reach the larger size classes that can accommodate higher quality habitat as snags or cavities.

Thinning with skips and gaps can be considered part of a process, especially if tree stability is a concern (O'Hara 2014) or if the stand is relatively young and the gaps cover a small percentage of the treatment area (Curtis et al. 2017). Multiple entries could improve wind firmness, produce multiple canopy layers, and encourage sustained diameter growth; however, these are probably not economically advantageous until accretion and periodic annual increment start to decline after the first treatment. If an additional entry is undertaken, new skips should encompass most of the current skips to provide continued protection for snags, coarse woody debris, and the understory previously identified for protection. Future enlargement of existing gaps should attempt to retain the majority of the edge trees that have developed elongated crowns. This can be accomplished by placing the gap extension to one side of the existing gap, rather than extending it in all directions. Topography and prevailing wind directions are also factors; it may be desirable to extend openings on the leeward side to minimize risk of windthrow.

Although small-scale disturbance can be beneficial in creating stand heterogeneity, it can also have unintended effects such as favoring invasive species; such consequences can be reduced with initial planning. Control of invasive species (fig. 11) might be desirable, especially in gaps near roads or where they existed prior to harvest. It may be advantageous to consider control activities for invasive species both before and after the logging operation. Monitoring sites for 2 to 3 years following thinning can indicate if control activities have been effective or if invasive species have expanded.

Although vertical differentiation is one of the goals of VDT, shade-tolerant species, such as western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), may be released by the creation of gaps or thinning treatment and grow into dense thickets (fig. 12). In such cases, it may be advantageous to reduce stocking by thinning and creating gaps in the understory to encourage the development of other understory tree and plant species.

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Figure 11—Invasive species such as English holly (*Ilex aquifolium*) should be monitored and considered for treatment both before and after thinning.

USDA Forest Service

Figure 12—Preexisting understory regeneration is likely to develop into mid-canopy levels at a much faster rate in the gaps and matrix once released. However, dense patches of western hemlock can preclude establishment or development of other species. Small gaps are unlikely to result in the recruitment of future overstory trees without further treatments.

Predicting Growth Using the Forest Vegetation Simulator

The Forest Vegetation Simulator (FVS) is a forest growth model developed by the U.S. Forest Service to aid in management decisions (https://www.fs.fed.us/fvs/). It projects growth of stands into the future based on inventory data and management regimes input by the user. As with many aspects of VDT implementation, using FVS to project stand development into the future is less straightforward than with traditional uniform thinning operations. There are, however, a few suggested methods to accommodate the variability implicit in VDT while using FVS.[1] All involve modeling the three different treatments (skip, gap, and thin) separately and do not take into account the growth differences that occur along the edges of treatments, which can be significant (Roberts et al. 2007, Willis et al. 2018). Errors associated with these edge effects would vary from overpredicting to underpredicting growth depending on the number and size of the skips and gaps used in the prescription. Further details of the methods outlined below can be found in the FVS training guides (USDA FS 2018).

The first method separates the individual plots that make up the inventory data into the various components of the future VDT. For example, the unit has 12 inventory plots and the planned VDT includes 25 percent skips and 25 percent gaps. In this case, after the inventory data are loaded into FVS, the user applies no treatment on three plots (to represent the skips), a clearcut on three plots (the gaps), and the remaining six plots are thinned. This method is an effective option for FVS variants that use plot density in the growth equations.

The second method also involves separating the plots in the inventory data. In this case, prior to loading the data into the simulation, the preferences are set to run by plot within FVS' graphical user interface (Suppose). This runs each plot as a separate stand with a sample size of one plot. Again, plots are selected in proportion to the area in skips, gaps, and thin and the corresponding treatments applied. After the model is run, the resultant data will need to be post-processed to average the separate stands into a summary for a single stand.

The third option maintains the sampling integrity of the inventory data by keeping it intact. Using all of the plots, the model is run multiple times, altering the treatments a proportional number of times. Using the same example—25 percent skips and 25 percent gaps—the model is run four times: once as no treatment, once as a clearcut, and twice as a thin. After the model is run, the resultant data will need to be post-processed to scale the results to the appropriate area. Alternatively, the model could be run three times to represent the three treatments (skip, gap,

[1] Smith-Mateja, E. 2016. RE: FVS, erin.smith-mateja@usda.gov.

and thin) and then the averages weighted appropriately to match the proportions within the stand. This method is a good choice for those variants that only use stand density (rather than plot density) as independent variables in their growth equations. Weighting the runs representing the three treatments might be a good alternative if the cover percentage of each treatment is in awkward proportions.

Examples

Three examples of VDT in western Washington are presented here. Although one was a study and the other two had slightly different management objectives, all three were planned in a similar manner. Among the three examples, the percentage area in skips ranged from 4 to 15 percent and the area in gaps ranged from 5 to 10 percent (table 2) (0.10 to 0.15 ac, or 0.04 to 0.06 ha). The Olympic Habitat Development Study (OHDS) was implemented in eight different locations. As part of a replicated study, the proportion of skips and gaps was kept consistent across all sites. The Nisqually and Seaquest VDTs are part of an effort to promote diversity on sites in the Washington State Parks system that were originally fairly uniform; they are not part of a research study and were implemented in a more operational manner.

The Olympic Habitat Development Study

At the time of treatment, the OHDS study sites were 45- to 70-year-old, mixed-conifer stands on the Olympic Peninsula in Washington state. Most plots were predominantly Douglas-fir, but some were dominated by western hemlock and Sitka spruce. Western redcedar and red alder were also significant components. The OHDS stands were 16 to 22 ac (6 to 9 ha) each and monumented by placing upright sections of tagged PVC pipe at 66-ft (20-m) intervals in a grid. Most OHDS stands had large-diameter stumps, logs, and snags remaining from the previous stand (fig. 13). These features, as well as any existing gaps or sizable individuals of favored species were mapped using the grid markers for reference. Skips were approximately 0.6 ac (0.25 ha) in size and were placed to protect the greatest number of snags and other coarse woody debris structures as possible. They were also dispersed throughout the stand, with no more than one skip placed in each quarter of the plot. In the stands where cable logging systems were used, consideration was also given to the obstruction caused by the skips; skips were usually placed at the ends of the cable corridors. Gaps (0.1 ac, or 0.04 ha) were also dispersed and, when feasible, were placed to release favored species. In some cases, existing gaps were enlarged on the leeward side to reduce the risk of future blowdown or top breakage from wind (fig. 14; table 2). At both 6 and 14 years after treatment, the VDT treatments have been shown to have increased the

Table 2—Characteristics of example skip and gap treatments

Study/site	Area size	Description of stand(s)	Skips	Gaps	Matrix
Olympic Habitat Development Study	8–10 ha (20–25 ac)	40- to 70-year-old stands of primarily Douglas-fir or western hemlock with western redcedar and Sitka spruce as well as other conifers and hardwoods. All previously logged, some previously thinned. As part of a replicated study, all eight stands were thinned and treated similarly without subdivision into smaller areas.	15 percent of area, approx. 0.24 ha (0.6 ac) each	10 percent of area, 0.4 ha (0.1 ac) each	Individual cut-tree marking. Thinned from below to remove approximately 33 percent of existing basal area. Only Douglas-fir and western hemlock removed. Favored species included bigleaf maple, western redcedar, western hemlock, red alder, and Sitka spruce.
Nisqually State Park	49 ha (120 ac)	Young, dense, Douglas-fir plantation with a depauperate understory. Includes scattered western redcedar, bigleaf maple, red alder, black cottonwood, and western hemlock. Area 1: QMD 24.4 cm (9.6 in), RD = 43, mean height of Douglas-fir = 18.9 m (62 ft) with mean crown ratio 48 percent. Shown as stands 21, 25, and 26 in figure 19. Area 2: QMD 23.4 cm (9.2 in), RD = 60, mean height of Douglas-fir = 23.2 (76 ft) with mean crown ratio 62 percent. Shown as stand 27 in figure 19.	4 to 7 percent of area, mean 0.15 ha (0.36 ac) with plans to expand in future	6 to 8 percent of area, mean of 0.02 ha (0.06 ac) each; 9 m (30 ft) radius	Subdivided into two areas based primarily on differences in density, both thinned from below to retain dominant and codominant trees with high crown ratios. Only Douglas-fir removed. Non-Douglas-fir individuals >22.9 cm (9 in) DBH given double spacing as a localized release. Area 1: thinned to 400 PSME/ha (160/ac), 425 t/ha (172 tpa)—40 percent of stems harvested. Mean PSME spacing 5 m (16 ft) posttreatment. Area 2: thinned to 494 PSME/ha (200/ac), 546 t/ha (221 tpa)—50 percent of stems harvested. Mean PSME spacing 4.6 m (15 ft) posttreatment.
Seaquest State Park	36 ha (90 ac)	Area 1 primarily Douglas-fir with high height/diameter ratio (91–92), QMD 31.2–36.1 cm (12.3–14.2 in), RD 56-67, mean height 33–35 m (107–114 ft). Area: Contained dispersed large-diameter Douglas-fir and hardwoods, QMD 31.2–40.9 cm (12.3–16.1 in), RD 56-67, mean height 33–37 m (107–122 ft). Shown as “individual tree marking” areas in figure 15.	7 to 10 percent of area, mean 0.21 ha (0.52 ac)	5 to 9 percent of area, mean 0.04 ha (0.09 ac); 10.7 m (35 ft) radius	Area 1: previous systematic thinning prescription recommended retaining 296 t/ha (120 tpa). Variable-density thinning prescription thinned matrix area to 371 t/ha (150 tpa), but when gaps included, average is 296 t/ha. Thinned from below and marked using Designation by Description method Area 2**:** consisted of three sub-areas, a boundary adjacent to a clearcut with substantial windthrow, an area with many red alder on the edge of a riparian area, and an area with bigleaf maples and large-diameter Douglas-fir with a clumped distribution and heavily used by the public. These areas were individual cut-tree marked to release favored species.

d.b.h. = diameter at breast height; QMD = quadratic mean diameter; RD = relative density; PSMA = Douglas-fir.

Figure 13—Fresca is one of the sites in the Olympic Habitat Development Study shown here (A) before treatment and (B) 12 years after treatment. Although it originally contained large-diameter trees, stumps, snags, and coarse woody debris, it had very little understory or mid-story development prior to the implementation of variable-density thinning.

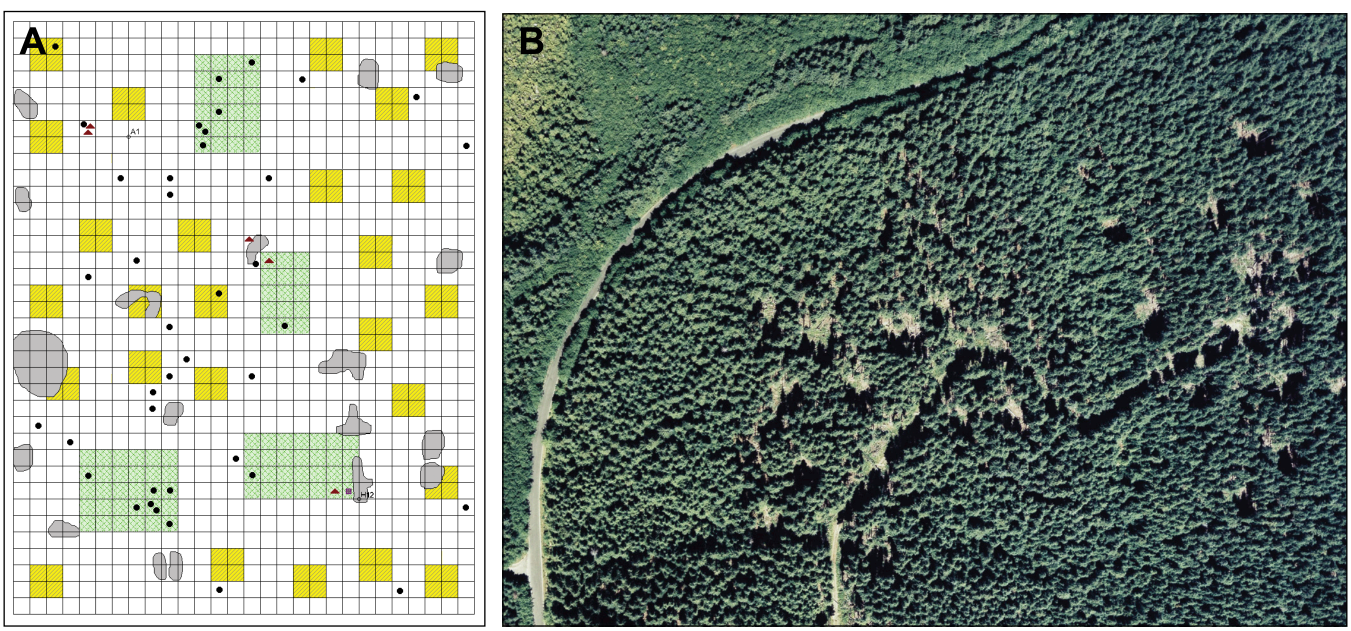

Figure 14—Example of a stand within the Olympic Habitat Development Study (OHDS). Corners of 66- by 66-ft (20- by 20-m) squares were marked on the ground (squares in diagram are 33 by 33 ft [10 by 10 m]). (A) This preexisting grid framework was used to map snags—black circles represent snags from previous stand, red triangles represent snags from current stand) and existing openings (gray). Subsequently, the grid was used to layout the skips (green) and gaps (yellow). (B) Aerial photo shows two OHDS plots at a different site shortly after treatment.

number of shade-tolerant mid-story trees, and promoted mid-story diameter growth and crown depth for smaller trees (Comfort et al. 2010, Willis et al. 2018). Note that these stands were part of a study in which many stand characteristics were being monitored. The installation and use of the grid system for mapping and reference allowed different types of research data to be easily related to one another; however, this level of documentation is not necessary for non-research VDT applications.

Seaquest State Park

Seaquest State Park is a 475-ac (192-ha) property in the Washington State Parks system containing a visitors' center for Mount St. Helens National Volcanic Monument, a campground, and an established trail system. Unlike the OHDS, the implementation of a VDT at this site was not part of a replicated research study; instead, the treatment application was tailored to the individual site goals and conditions. Goals for the forested portion of the park include improving forest health through reduction in stocking, diversifying species composition, and accelerating the development of old-growth characteristics. As a popular state park, other goals important to Seaquest include increasing aesthetics, habitat values, and opportunities for environmental education. Previous reconnaissance and evaluations of stand conditions (Ettl and Emmonds 2008, Fischer et al. 2011, Smith and Morrison 2006) indicated that thinning four stands, covering an area of approximately 54.8 ac (22.2 ha) (fig. 15), would be the first step in creating future stand conditions that are aligned to the park's management goals.

As a non-research site, the Seaquest site lacked the gridded framework and some of the baseline data from which to work. Traditional forest inventory measurements, however, had been completed relatively recently. To complement the earlier sampling efforts, an assessment of the area was done to determine the prevalence of habitat features that would maximize the impact of the skip and gap placements. This was not a 100 percent survey, but it covered a large portion of the four stands (fig. 16). We traversed each stand in corridors wide enough to see approximately to the edge the of proceeding corridor, but frequency of traverse routes varied widely depending on site distance, stand species, and structural diversity. Salient features were mapped using handheld GPS units and notes on the feature characteristics were recorded on a field sheet (see app.). In addition, many of the existing openings were mapped digitally from aerial photos.

Using the mapped features, the location of skips and gaps were determined. The majority of the matrix area was thinned from below using the D × D method for cutting, which resulted in an average tree spacing of 18 ft (5.5 m). Several areas, however, required a lighter cutting prescription. Individual tree marking was used

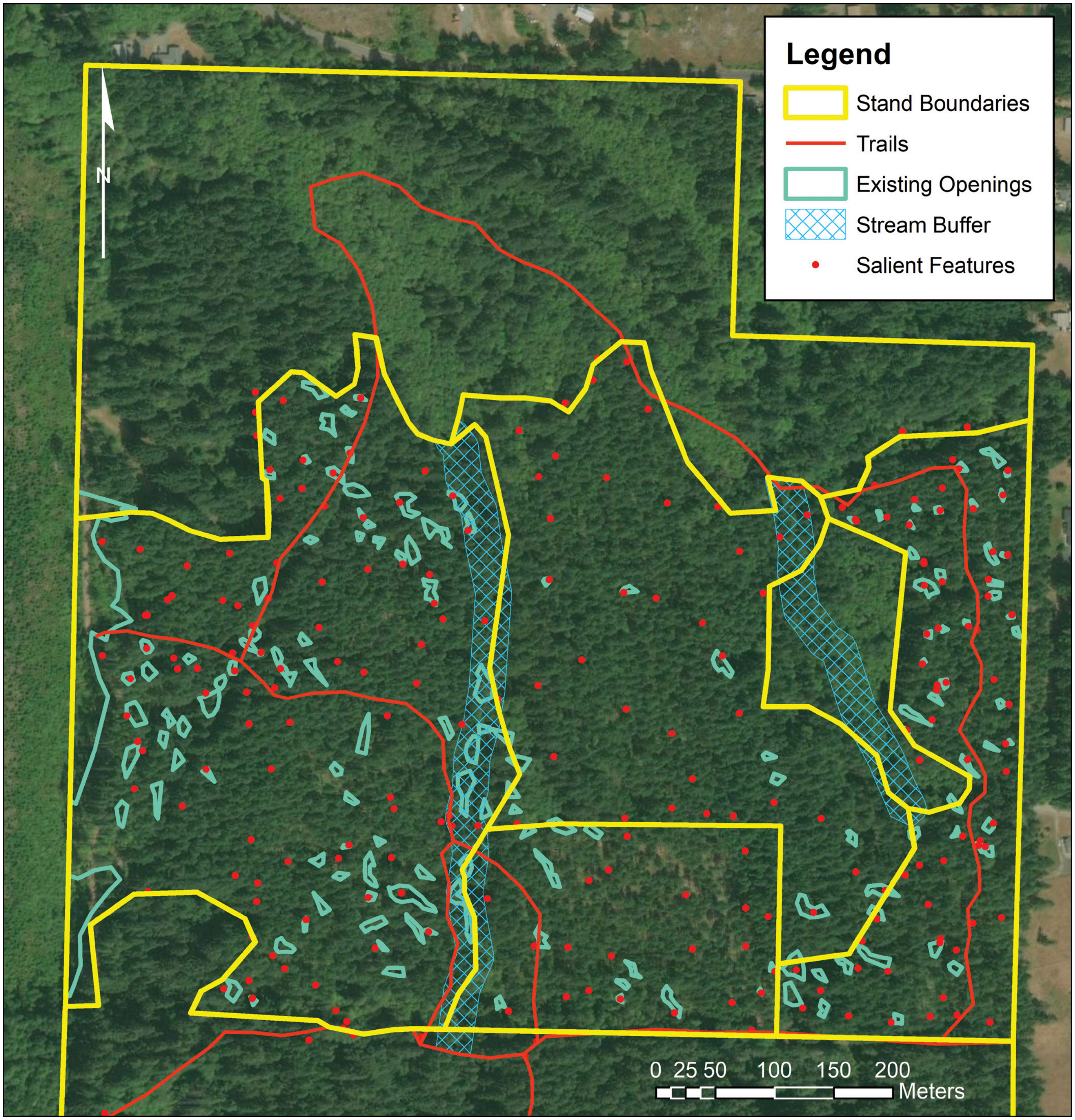

Figure 15—Prior to field efforts at Seaquest State Park, stand boundaries, stream buffers, and existing openings were mapped using a geographic information system. Trails and features indicating possible skip and gap locations were then mapped in the field using handheld global positioning system units.

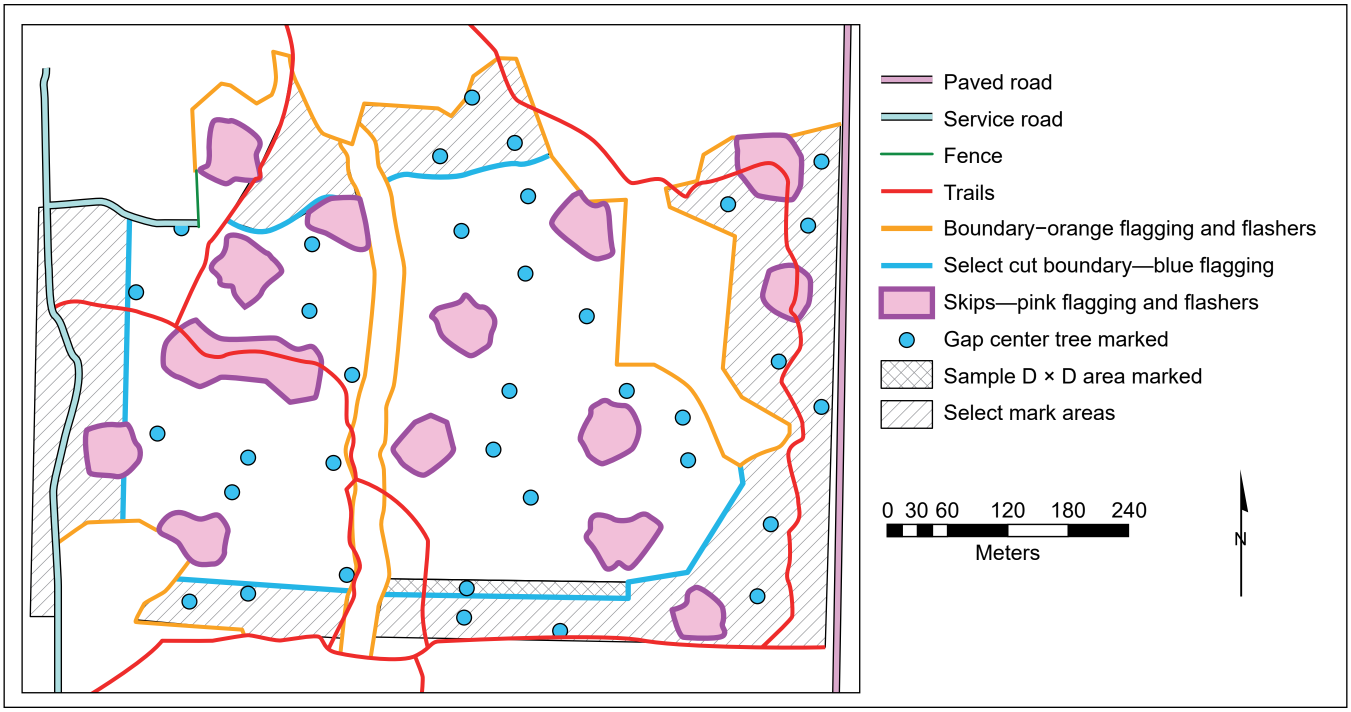

Figure 16—After mapping features at Nisqually State Park, skip and gap locations were selected and marked on the ground. One gap along the trail was enlarged to a length of 500 ft (160 m) as part of a possible future interpretive project.

in these areas, which included (1) a border with extensive previous wind damage, (2) a riparian area, and (3) an area adjacent to a heavily used public trail (fig. 17; table 2). Fewer trees per acre were cut in the "selection cut" buffer areas where small gaps were widened or created, often to release trees >9 inches (22.9 cm) in diameter at breast height (d.b.h.) of species other than Douglas-fir. A large gap was located along one of the trails to provide an opportunity for an interpretive trail stop in the future.

Nisqually State Park

Nisqually State Park is a recently developed property in the Washington State Parks system. Although management goals for this park were similar to those of Seaquest State Park, the initial stand conditions were quite different (fig. 18). The proposed treatment area (Nawbary et al. 2011) was characterized in a previous vegetation survey (Luginbuhl and Darrach 2006) as a Douglas-fir forest type with a depauperate understory. As a young, dense, forest plantation in the stem-exclusion stage, the lack of diversity could have persisted for many years if left undisturbed. A forest inventory had been completed 2 years prior to the project, but because younger trees can grow rapidly, additional inventory plots were completed so up-to-date figures could be used to determine the volume available for harvest. As with Seaquest State Park, a survey for salient features was completed using hand-held GPS units (fig. 19; table 2).

Leslie Brodie

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Figure 17—The matrix area at the Seaquest State Park site was marked using two methods. (A) Areas with relatively even spacing and tree diameter were marked using the Designation by Description method. (B) Other areas were marked using individual tree marking.

Leslie Brodie

Figure 18—Most of the Nisqually site could be characterized as a young, dense Douglas-fir stand with a depauparate understory and pockets of *Phellinus* root rot.

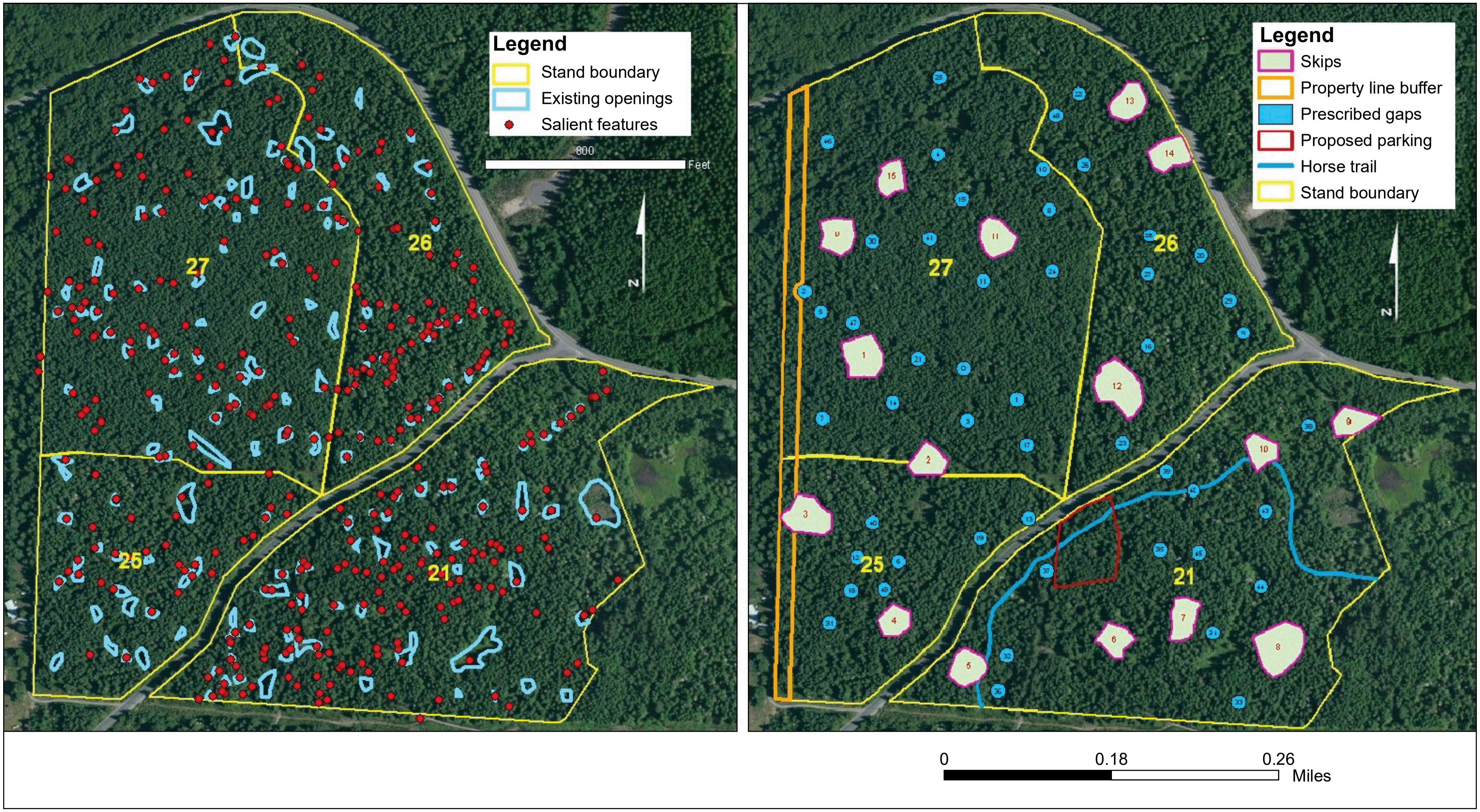

Figure 19—Implementation of variable-density thinning using skips and gaps at Nisqually State Park. Skip perimeters marked with pink flagging and pink flashers. Small protected features (large stumps and alternative tree species) were also individually flagged in pink. Gaps were marked by painting the center cut tree with the radius of the gap in blue tracer paint (i.e., "G 30" denotes a gap radius of 30 ft). Western edge was given a buffer of approximately 50 ft due to the presence of an administrative boundary and marked with orange flagging and orange flashers.

Phellinus root rot *(Phellinus sulphurascens)* was present and widely dispersed throughout the site. Although future mortality associated with *Phellinus* infection is likely to occur, the spread of *Phellinus* does not appear to be affected by thinning (Tappeiner 20015), so the presence of infection does not rule out thinning as a desirable activity in these stands. A study looking at the presence of *Phellinus* in southern Washington showed that many more trees were infected than were obviously symptomatic—66 percent of trees not exhibiting crown symptoms were actually infected by the disease (Filip 1986). Thies and Sturrock (1995) recommended cutting all trees within 50 ft (15.2 m) of visibly infected individuals to provide a buffer to reduce spread of the disease. In the stands at Nisqually State Park, this could have resulted in numerous openings of 120 ft (36.6 m) in diameter or greater and would still not rid the stand of nonsymptomatic trees. Thinning or clearing trees specifically to control root diseases, therefore, did not seem practical (Roth et al. 2000). Because gaps from *P. sulphurascens*-induced mortality are widespread throughout the stands and more are expected to develop in the future, the planned percentage of area in prescribed gaps was reduced from 15 percent used in other projects (Harrington et al. 2005) to 6 to 7 percent. Existing gaps and those that develop in the future should be planted with species that are immune or resistant to the disease, such as bigleaf maple, western redcedar, and western white pine (Thies and Sturrock 1995) and are intermediate or tolerant to shade. It is possible that larger gaps could be planted with lodgepole pine (*Pinus contorta* Douglas ex Loudon) or western white pine. Because some gaps already existed, the amount of additional gaps created differs per stand.

The mean gap size was 0.06 ac (0.024 ha) and 30 ft (9.1 m) in radius, but ranged from 10 to 50 ft (3.0 to 15.2 m) in radius. A few gaps, either because of their proximity to roads or to preexisting seed banks, may develop patches of Scotch broom and invasive *Rubus* species that will inhibit the growth of planted trees, existing native shrubs, and understory herbaceous species. Project plans included monitoring the larger gaps and spot-treating with herbicides to suppress nonnative species for at least 3 years. Treatment of invasive nonnative species in the few years immediately after treatment should allow desirable species to establish and should reduce the need for further treatment in the future.

Post-thinning gaps covered approximately 6 to 8 percent of the total area; this value included the gaps that already existed prior to the VDT and the gaps that were created. Smaller gaps, created by cutting 1 to 12 Douglas-fir trees per gap, were located primarily to release one or more trees of alternate species, such as bigleaf maple, western redcedar, western hemlock, bitter cherry (*Prunus emarginata*

(Douglas ex Hook.) D. Dietr.), black cottonwood (*Populus balsamifera* ssp. *trichocarpa* (Torr. & A. Gray ex Hook.) Brayshaw), and grand fir (*Abies grandis* (Douglas ex D. Don) Lindl.). In some cases, existing root rot pockets (*P. sulphurascens)* were widened. Close to roads, where risk of invasive species and illegal vehicle entry is greater, gap sizes were kept small. The total number of gaps was kept small overall because additional gaps created by *Phellinus* root rot can be anticipated in the future. These future gaps should have much the same effects on the forest structure as the created gaps (Holah et al. 1993). The western edge was given a buffer of approximately 50 ft (15.2 m) because of the presence of an administrative boundary, and additional buffers were later added along the public roadways to deter unauthorized entry and dumping.

Left unthinned, and barring any other disturbances, these second-growth stands will pass through a competitive-exclusion stage. Although the skip areas may not represent desired final stand conditions, excluding small areas from thinning during this initial entry does aid in the recruitment of coarse woody debris and allows portions of the stand to remain undisturbed during the harvest operation. These areas will be excluded from any equipment entry. The skips were positioned to protect features such as existing coarse woody debris and snags, and appeared to have relatively little or no incidence of *Phellinus*. They were kept small (0.3 ac, or 0.12 ha) with the expectation that they will be expanded to include larger diameter trees during subsequent entries. With that in mind, gaps were not placed in areas directly adjacent to skips. In addition to skips, a few protected features were flagged (primarily large stumps and significant piles of coarse woody debris) to ensure they did not get destroyed during the logging process. Although the area would benefit from an increased number of snags, snag recruitment at this early stage was not recommended. It would be more beneficial to wait until the matrix trees have attained a greater diameter before selecting snag recruits.

Final Thoughts

Forest managers in the Pacific Northwest inherit stands of varying ages, species, structures, and densities. In the past, most regeneration harvests in the region were clearcuts and millions of acres were replanted in single-species plantations. These even-aged stands developed with generally simpler stand structures and species compositions compared to preharvest forests and areas that were cut and left to regenerate naturally. In recent decades, some forest managers have wanted to increase the structural and spatial variability in even-aged stands because the simpler stand structures supported fewer species of wildlife and plants and were less aesthetically pleasing to many people. In these situations, VDT is a management practice that is being considered. As an initial or intermediate entry into a stand, it will increase variability and, if the stand is dense, begin increasing wind firmness. They are usually implemented in ways that result in more attractive stands because they increase the light reaching the forest floor and provide more visual interest. Finally, these entries generally do not remove much volume, and, typically, one entry will be insufficient to result in multi-aged stands.

Multi-aged (or uneven-aged) stands are defined as stands with two or more age classes. Implementation depends on the starting conditions (species composition, age-class distribution, etc.) and objectives. Either removing individual trees (single-tree selection) or patches of trees (group selection) can be appropriate. Uneven-age management can be quite complex depending on the scale on which the stands are managed and tracked. It may, however, be the appropriate regeneration method to employ depending on the starting and desired future conditions and the time scale under consideration. By contrast, VDT may increase tree regeneration (Willis et al. 2020), but as an initial or intermediate stand treatment, it is not, by itself, designed to result in uneven-aged stands. The increase in regeneration resulting from a VDT does not necessarily develop into the mid- or upper canopy, or if it does, its occurrence is spatially irregular and on only a small percentage of the stand area (Kuehne and Puettmann 2008). Impacts are likely to be relatively short lived (two to three decades), unless additional future treatments are implemented. For some objectives, however, a VDT can achieve immediate results by increasing spatial and structural diversity in ways that uniform thinning cannot. Alternatively, VDT might best be viewed as the first step in a longer process designed to convert an even-aged stand to a multi-aged forest.

Acknowledgments

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Appendix: Sample Field Sheet

Species and gap size codes can be modified to reflect species and gap sizes prevelant in the area. The numbers recorded under the tree species codes were the estimated number of individuals in close proximity. The numbers were then used to prioritize the placement of skips and gaps. If a large range of tree diameters exist, it may be desirable to include a column for tree size.

		Gap size code (approximate diameter) 1 = small <10 m, 2 = medium 10–25 m, 3 = large >25 m												
Wypt no.	**Wypt type**	**Gap size**	**ACMA**	**THPL**	**TSHE**	**POBAT**	**PREM**	**Shrub**	**Stump**	**Down CWD**	**Photo #**	**Other Spp**	**Invasive**	**Commments**
1	Gap	2			5			HODI			1		CYSC	TSHE avg ht 4 m
2	Snag										2	Lots BLSP		THPL snag 50 cm d.b.h. woodpecker use
3	Log									>10				Multpl sm stems
4	Gap	3						COCO					RUBUS CYSC	could plant seedlings
5	Trees			2										15 cm d.b.h. TSHEs in mid-story

ACMA = Big Leaf Maple; BT = broken top; BLSP = deer fern; COCO = Chinese house; CWD = course woody debris; CYSC = Scotch broom; FT = forked top; HODI = oceanspray; LIBO = twinflower; MS = multiple stem; OG = oldgrowth; POBAT = black cottonwd; PREM = bitter cherry; RUBUS = non-native blackberry: THPL = western redcedar; TSHE = western hemlock; Wypt = waypoint.

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